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Sixty minutes of what? A developing brain perspective for activating children with an integrative exercise approach

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ABSTRACT

Current recommendations for physical activity in children overlook the critical importance of motor skill acquisition early in life. Instead, they focus on the quantitative aspects of physical activity (eg, accumulate 60 min of daily moderate to vigorous physical activity) and selected health-related components of physical fitness (eg, aerobic fitness, muscular strength, muscular endurance, flexibility and body composition). This focus on exercise quantity in youth may limit considerations of qualitative aspects of programme design which include (1) skill development, (2) socialisation and (3) enjoyment of exercise. The timing of brain development and associated neuroplasticity for motor skill learning makes the preadolescence period a critical time to develop and reinforce fundamental movement skills in boys and girls. Children who do not participate regularly in structured motor skill-enriched activities during physical education classes or diverse youth sports programmes may never reach their genetic potential for motor skill control which underlies sustainable physical fitness later in life. The goals of this review are twofold: (1) challenge current dogma that is currently focused on the quantitative rather than qualitative aspects of physical activity recommendations for youth and (2) synthesise the latest evidence regarding the brain and motor control that will provide the foundation for integrative exercise programming that provide a framework sustainable activity for life.

INTRODUCTION

Although recommendations for school-based physical activity focus on the health-related components of physical activity (eg, aerobic fitness, muscular strength, muscular endurance, flexibility and body composition),[1 2] there has been a measurable decrement in muscular strength and motor skill performance in youth that is concomitant with the increasing trends in overweight and obesity among youth.[3–6] Current trends in daily physical education[7] (eg, less frequent) and healthcare delivery[8] (eg, not enough time to perform recommended exercise screening and physical activity counseling/referral) provide fewer potential opportunities to identify and treat youth who exhibit muscle weakness and poor fundamental motor skills (eg, jumping, throwing, kicking and balancing).

Increased participation in activities purposely designed to enhance health-related and skill-related (eg, agility, balance, coordination, reaction time and power) components of physical fitness during childhood and adolescence may provide youth with a mechanism for a lifetime of physical activity and a reduced risk of musculoskeletal injury.[5 9–12] In the past, children engaged more in spontaneous and unstructured physical play while having regular opportunities to enhance fundamental movement skills, increase muscle strength, make friends and have fun. To support the development of muscular strength and motor skills in school-age youths, physical education classes were more gymnastics based in nature until the late 1950s.[13]

Because of the timing of brain development and the associated neuroplasticity for motor skill learning,[14] preadolescence and early adolescence may provide a unique opportunity to enhance muscular strength and develop fundamental movement skills to prepare youth for a lifetime of health-enhancing physical activity and cognition.[11 15 16] In addition, the bidirectional relationship between motor skill learning and physical activity may reveal a positive feedback loop that could enhance physical fitness and lifelong engagement in physical activity.[17] At present, there is growing interest from parents, clinicians, researchers, youth coaches, physical education teachers and fitness professionals regarding the optimal time to integrate more structured fitness training into youth physical development programmes.[11 18]

This review synthesises the latest research regarding the brain-mediated development of motor control and its implication for planning exercise-based activities for youth. First, we provide a conceptual model for maximising the potential health-related and skill-related benefits for children and adolescents by capitalising on the 'plasticity' of preadolescence for enhancing motor skill development, myelination and brain wiring development which includes managing neuronal pruning (changes in neural structure by reduced overall number of neuron and synapses, allowing more efficient synaptic configurations) during corticomotor maturation in youth.[19 20] We then outline a novel approach for incorporating a variety of feedback driven, strength-building and skill-enhancing movements into a developmentally appropriate intervention purposely designed to enhance health-related and skill-related components of physical fitness. Finally, we propose that a training-age specific, motor skill-based training paradigm that capitalises on corticomotor plasticity during preadolescence is most effective for providing a foundation for school-age youth to maintain a physically active lifestyle.[10 11 21–23]

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NATURE VS NURTURE—ARE WE NEGLECTING OUR CHILDREN'S HEALTH?

Children may inherit sensitivity to the certain types of training and exercise during the growing years.[24] There may also be genetically linked nervous system thresholds that differentiate between a child's ability to exploit critical maturational thresholds for the development of complex motor skills (ie, physical acts of the body or implement that must be moved into the right place at the right time in order to accomplish a task).[25 26] The intricate interaction of genetics and environment has been described as follows: contrary to what we have been taught, "genes do not determine complex traits on their own. Rather, genes and the environment interact with each other in a dynamic process."[27] Following that construct, skill-related fitness is not an innate functional limit hardwired at conception or gestation but rather an accumulation of learned skills and reinforced abilities, driven by the interaction between genes and the environment during childhood and adolescence.

In this same light, a child in a non-enriched environment who is deficient in opportunities to regularly engage in physical activities (that enhance muscular strength and fundamental motor skill ability) may not acquire the physical prowess and perceived confidence needed to be physically active. This view is supported by data on 6-year-old children with low and average levels of motor coordination who demonstrated lower levels of physical activity 5 years later when compared with children with high motor coordination.[28] Furthermore, in a 10-year longitudinal study of 630 adolescents, the participants who first became involved in organised youth sports clubs between the ages of 6 and 10 years were more physically active as adults than adolescents who initiated sport involvement at older ages.[29] Today, technological influences and sedentary leisure time activities have reduced moderate to vigorous physical activity (MVPA) during the growing years; replacing time and the needed opportunity that should be spent to practice and reinforce developing motor skills (figure 1).[30 31]

Focused activities that enrich the motor skill-learning environment of preadolescents are needed early in life.[11 21] Environments enriched with this type of multidisciplinary training may not only help children overcome potential genetic deficiencies,[32] but may also help school-age youth achieve a level of motor skill competence and perceived confidence that is equal to or exceeds their expected adult potential.[11 33] The most effective youth development programmes should incorporate multifaceted training modalities that are characterised by a sampling of different games, sports and physical activities implemented early in life. Elements of this approach were suggested in some of the work Seefeldt[34] performed three decades ago. This contention was recently supported by Stodden *et al*[35] who demonstrated that a motor skill competency 'proficiency barrier' related to 'good' and 'poor' health-related fitness may exist because it was unlikely that young adults aged 18–25 years with low motor skill competency exhibited 'good' levels of health-related fitness. Collectively, these observations highlight the importance of teaching children fundamental movement skills early in life in order to gain confidence and competence to engage in a variety of physical activities as they mature into adulthood.

SIXTY MINUTES OF WHAT?

Although there have been several sets of physical activity guidelines published in recent years, these guidelines lack clarity when it comes to the need for resistance training and developing motor skill prowess (table 1). Some guidelines mention the importance of including muscle-strengthening activities, but they are not very specific in terms of sets, repetitions and exercise choice. Most importantly current guidelines do not detail critical aspects of integrating motor skill development in exercise programming for youth.

The 2008 US Physical Activity Guidelines for Americans clearly state the duration, frequency and intensity of aerobic physical activity recommended, with general recommendations for muscle-strengthening activities to be performed three times per week.[36] The World Health Organization (WHO) mirrors these guidelines with similar specificity for aerobic activity, and lack of specificity for resistance exercise.[37] The physical activity guidelines from the National Association for Sport and Physical

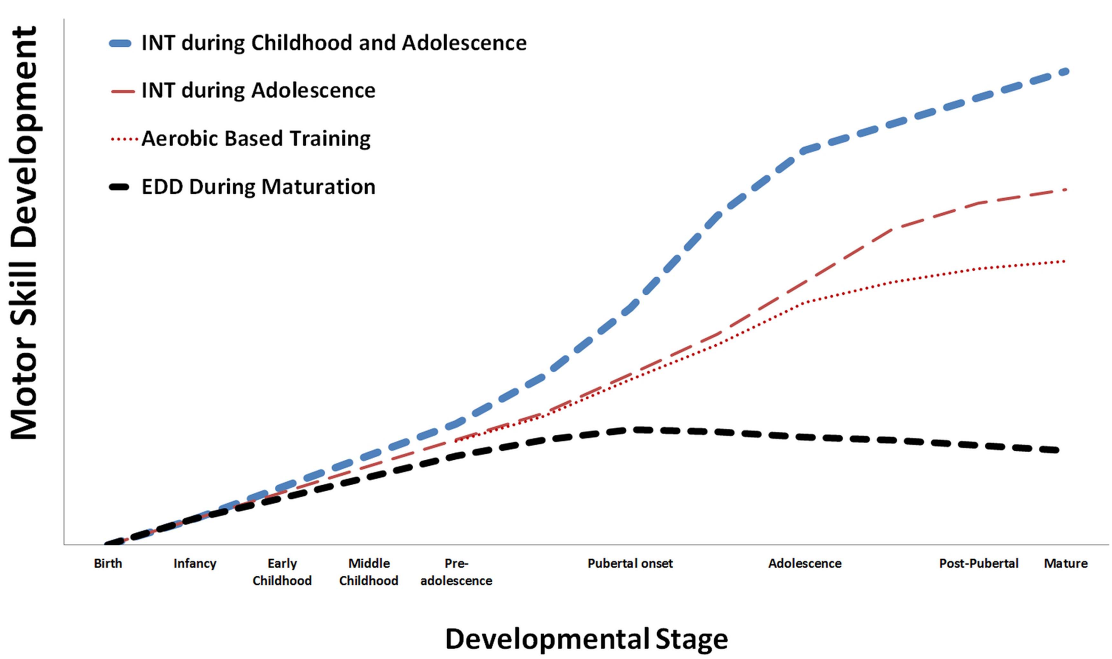

Figure 1 Theoretical plot of the potential for improved motor skill development in generation Y with INT during youth. EDD, exercise deficit disorder; INT, integrative neuromuscular training.

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Table 1 Organisations and their associated physical activity guidelines or recommendations

Organisation	Country	Year released or last update	Age	Primary type	Duration (minutes)	Frequency	Intensity	Strengthening
WHO[37]	International	2010	5–17 years	Unspecified	60	Daily	Moderate or vigorous	2–3 times per week
Department of Health and Human Services (DHHS)[36]	USA	2008	Children and adolescents	Aerobic	60	Most, if not all, days	Most moderate or vigorous	At least 3 days per week
Department of Health[40]	UK	2011	5–18 years	Aerobic implied	60	Daily	Moderate or vigorous	At least 3 days per week
Department of Health[39 98]	Australia	2010	5–18 years	Aerobic implied	60	Daily	Moderate or vigorous	Skill learning mentioned
Centers for Disease Control & Prevention (CDC)[99]	USA	2011	Refers to 2008 Physical Activity Guidelines for Americans, listed above (DHHS)					
National Heart, Lung, and Blood Institute (NHLBI)[100]	USA	2011	Refers to 2008 Physical Activity Guidelines for Americans, listed above (DHHS)					
President's Council on Fitness, Sports & Nutrition[101]	USA	2014	Refers to 2008 Physical Activity Guidelines for Americans, listed above (DHHS)					
Institute of Medicine (IOM), Physical Activity in Schools[7]	USA	2013	School children	Unspecified	60	Daily	Vigorous or moderate	Not mentioned
National Association for Sport and Physical Education (NASPE)[38]	USA	2004	5–12 years	Age-appropriate	60, up to several hours	All or most	Should include moderate and vigorous	Not mentioned
American Cancer Society[102]	USA	2010	Children and adolescents	Unspecified	60	At least 3 days per week	Moderate or vigorous	Not mentioned
National Football League PLAY 60[103]	USA	2007	Youth	Unspecified	60	Daily	Unspecified	Not mentioned
Canadian Society for Exercise Physiology (CSEP)[104]	Canada	2007	5–17 years	Unspecified	60	Daily	Moderate to vigorous	At least 3 days per week

Education for children aged 5–12 years (which predate the US guidelines by 4 years) recommend at least 60 min of physical activity on most days of the week, but make no mention of muscle-strengthening activities.[38] The Australian guidelines for physical activity in youth include guidelines for MVPA, as well as a noteworthy recommendation for development of fundamental movement skills but do not provide details for resistance exercise.[39] The UK guidelines are similar to the US guidelines, with mention of muscle-strengthening activities made, but no specificity other than frequency (three times per week).[40] Physical activity at schools are similarly non-specific in the area of muscle strengthening, although there is increased recognition of and focus on movement skills in these school-focused guides.[41 42]

General physical activity recommendations for school-age youth (ie, at least 60 min of physical activity daily, mostly of moderate or vigorous intensity)[12 43] are too generic for children and adolescents who require a greater need to develop fundamental motor skills and enhance muscular strength.[10 44–47] Youth with reduced motor skill competence and poor muscle strength may be more likely to be overweight and less likely to participate in sports and recreational activities.[28 48 49] The Specific Adaptation to Imposed Demands (SAID) principle asserts that the human body adapts specifically to imposed demands, and general physical activity advice (eg, walking and cycling) may not enhance muscular strength or motor skill performance to a level that is needed to best prepare youth for a lifetime of physical activity. In addition, sedentary youth often find prolonged periods of continuous aerobic exercise to be boring or discomforting, and hence may demonstrate reduced compliance to traditional aerobic training programmes. Interestingly, self-reported pretreatment participation in weekly strengthening activities was significantly associated with completion of a paediatric weight management programme in which attrition generally hovers around 50%.[50] As current recommendations for physical activity focus on aerobic training and cardiovascular fitness,[12 43] consistent and measurable decrements in muscular fitness and motor skill performance in youth have been reported over the past decade.[4 5]

Despite the well-known health-related benefits of continuous endurance training typically observed in adults,[51] regular participation in motor skill-based and strength-based activities is often associated with enhanced gains in skill-related as well as health-related fitness measures in school-age youth.[28 44 52] Since there are no medications to treat physical inactivity, a preventive strategy of integrating both health-related and skill-related fitness components into a physical education class or youth fitness programmes might be an ideal approach. In addition, efforts to enhance a child's confidence and competence to perform various motor skills early in life might also be an ideal cost-effective strategy to prevent the eventual decline and disinterest in physical activity.[21] We propose that developmental exercise programming that is enjoyable, challenging and stimulating to the child's mind and body may positively influence exercise compliance as well as their attitudes towards play, sports and fitness throughout adolescence.[21 53 54] In addition, the variety of exercises and progressive nature of integrative neuromuscular training (INT) could theoretically influence the 'hard wiring' of motor skills that will carry over into adulthood.

THE IMPORTANCE OF TIMING OF BRAIN DEVELOPMENT—WINDOW OF OPPORTUNITY TO ENHANCE MOTOR SKILLS

In preadolescence, the combination of a high degree of plasticity in neuromuscular development and appropriately timed implementation and progression of INT, may allow for strengthened physical, mental and social development, which may contribute favourably to their physical fitness and athleticism later in life.[11] Every individual has an interconnected dynamical system comprised of critical subsystems that develop differently during childhood (eg, cognitive, sensory, emotional, perceptual, control).[55] Classic motor development theory defines the skill acquisition process and also clearly links the relationships among neural codes and movement patterns.[56] Likewise, a version of this is seen in the developing brain via synaptic pruning.[19 20]

The concept of 'use it or lose it' commonly applied to physical and physiological settings may also be important with neurocognitive development.[57 58] Brain development during childhood corresponds to the time when these subsystems are optimally developing for the formulation of specific skills acquisition.[59] Improved motor competence developed through adolescence facilitates the establishment of desired behaviours and habits that may carry over into adulthood.[11 22 29] On the basis of motor skill learning theory, preadolescence may provide an ideal window to develop and maintain long-lasting fundamental movement skills as well as visual motor skills, reaction time and academic attainment in school-age youth.[23 60 61]

The developing brain chooses to use and reinforce pathways that are utilised and cull or prune those that are underutilised. In the child's brain, as many as 50% of the neurons do not survive to adulthood. Following maturation, an adult's corticomotor plasticity and potential for learning dynamic interceptive actions may be diminished once certain pathways have been established and/or myelination has progressed past a certain point(s) (figure 2).[26 62 63] This diminished learning is generally thought to occur via a combination of neuronal, axonal and synaptic pruning. So, growth-related neurodevelopment likely has a lifelong impact on a person's ability to train and learn new skills.[19 64] Anecdotally, a visual assessment of CT or MR image of a 'young looking' brain is where the gyri gaps are small and the cerebrospinal fluid spaces between the brain and skull are small. Thus, there is a unique opportunity for INT (carefully designed exercise programmes) to influence structural brain development during the growing years in children (figure 2).

Of note, there are nervous system thresholds that contribute to the differentiation between each child's ability to exploit critical maturational phases for development. Specifically, these thresholds are broached when the brain and nervous system choose to emphasise/retain/expand innate neural pathways of dynamic interceptive actions (actions for which the body, or an implement, must be moved into the right place at the right time in order to accomplish a task).[25 26]

Regular participation in physical education, sports and well-designed fitness programmes that integrate both health-related and skill-related fitness components may provide a mechanism to develop dynamic interceptive actions and to increase physical activity levels in youth.[65 66] In sports such as baseball, for example, being able to field an infield ground ball without being distracted by a runner on base can decrease injury risk as well as enhance motor skill performance.[67] As such, mental and cognitive practices that are part of INT have the potential to improve performance and decrease risk for injury. INT that is initiated during preadolescence (before ages 10–12 in girls and 12–14 in boys), could exploit the consolidated (physical and cognitive) factors that contribute to motor skill development during maturation, which can improve dynamic interceptive skill development and also reduce injury risk factors.[11 68]

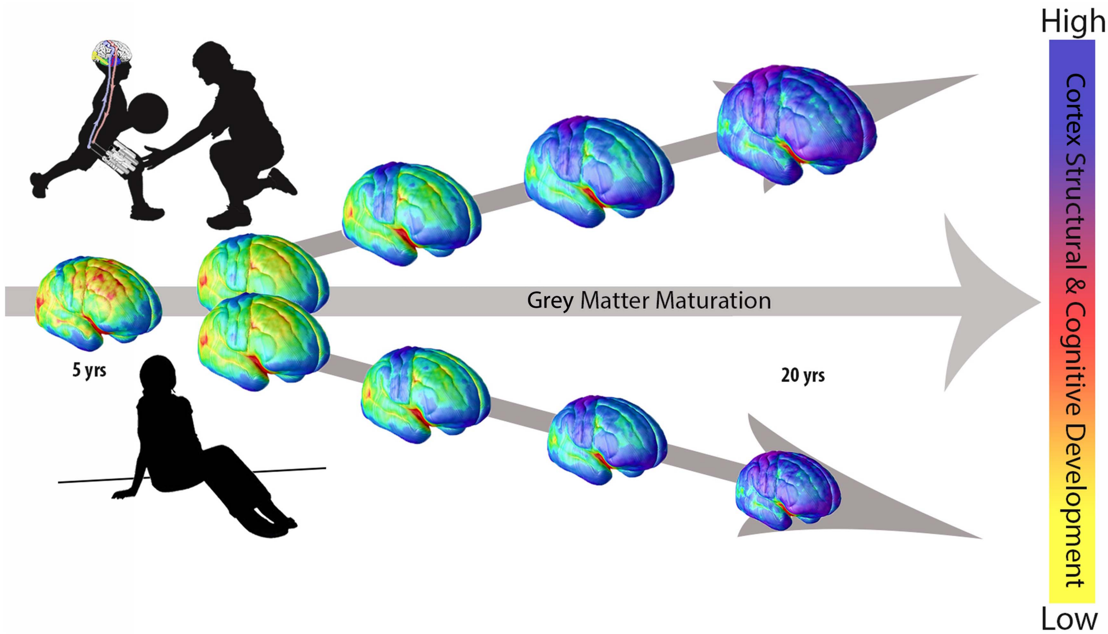

Figure 2 Right lateral views of the dynamic sequence of grey matter maturation over the cortical surface. The provided visual image of grey matter density provides a human cortical development model that can be visualised across the age range in a spatiotemporally detailed time-lapse sequence. Following brain maturation, a young adult's corticomotor plasticity and potential for adapting dynamic interceptive actions may be strongly diminished. Integrative neuromuscular training implemented prior to maturation may facilitate fundamental motor skill development. Conceptual model indicating the potential for integrative neuromuscular training during childhood to influence increased neuromuscular, cortex structural and cognitive development. Likewise, the down arrow indicates the potential for physical inactivity during the important growing years that can influence increased risk of metabolic syndrome and deficits in cortex and structural development. Adapted with permission from Gogtay *et al*[14] (Copyright 2004 National Academy of Sciences, USA).

Developmental training and exercise for youth can and should be specifically focused to improve motor control in children and adolescents,[69–71] and it may be particularly effective for youth whose cognitive and motor capabilities are highly 'plastic' and amenable to age-appropriate interventions.[21 72–74] Furthermore, integrative motor skill-based training may be even more important for youth with a decreased genetic potential for motor development.[11 75] Since corticomotor plasticity and potential for learning dynamic interceptive actions may be diminished or even lost following maturation, activities that influence the combined adaptations in cognitive and physical development arguably should be optimised during childhood to maximise benefits throughout all ages.[26 62 63] Specialised skill-based training during preadolescence may also influence neurocognitive development and motor evolution that may increase spontaneous physical activity.[76 77] The more plasticity the brain has engaged in during all stages of life helps retain plasticity as we age.[19 20]

A multisport approach to physical education (introducing a sampling of varied experiences tied to multiple sports in a coordinated fashion to students, matched to ability and interest) induces a more pronounced improvement in aerobic fitness and kinaesthetic discrimination ability, as well as improvements in task orientation and self-efficacy, when compared with traditional physical education.[78] Collectively, these observations support the contention that motor skill training and the consequent inducement of regular physical activity may enhance corticomotor development as well as academic performance in school-age youth.

INT: A FRAMEWORK TO CAPITALISE ON BRAIN AND MOTOR SKILL DEVELOPMENT

INT is a conceptual exercise training model we define herein as a developmentally appropriate conditioning programme that incorporates general (eg, fundamental movement skills) and specific (eg, exercises targeted to motor control deficits) strength and conditioning activities that include resistance training, dynamic stability, core focused strength development, plyometrics and agility exercises with neurocognitive/visual motor feedback to enhance muscle strength and fundamental motor skill development in youth (figures 3 and 4).

INT is a safe, enjoyable and worthwhile programme designed to help youth to improve proficiency with fundamental motor skills, movement mechanics, increase muscle strength and gain confidence in their physical abilities.[10 11 79] The cornerstone of INT is age-appropriate instruction and advancement by qualified professionals who understand the fundamental principles of paediatric exercise science and appreciate the physical and psychosocial uniqueness of youth (figure 5). Qualified professionals could include persons who spend a substantial proportion of their efforts on youth instruction, have substantial experience and/or training in paediatric exercise science, and have a substantial interest in contributing to youth fitness. As such, a paediatric exercise specialist is someone who maintains the requisite content knowledge in paediatric exercise and developmental physiology, and has the pedagogical skill to teach motor skills and other age-related exercises in a game-play environment that is fun and mentally engaging.[80]

A meta-analysis on youth resistance training found that improved muscular strength is dependent on adequate frequency, volume and intensity to provide sufficient adaptive stimulus.[81] Moreover, additional analyses revealed that appropriate resistance training is an effective method for enhancing motor performance in youth, with the effects being most pronounced in children rather than adolescents.[82] Despite outdated concerns associated with youth resistance training, this mode of

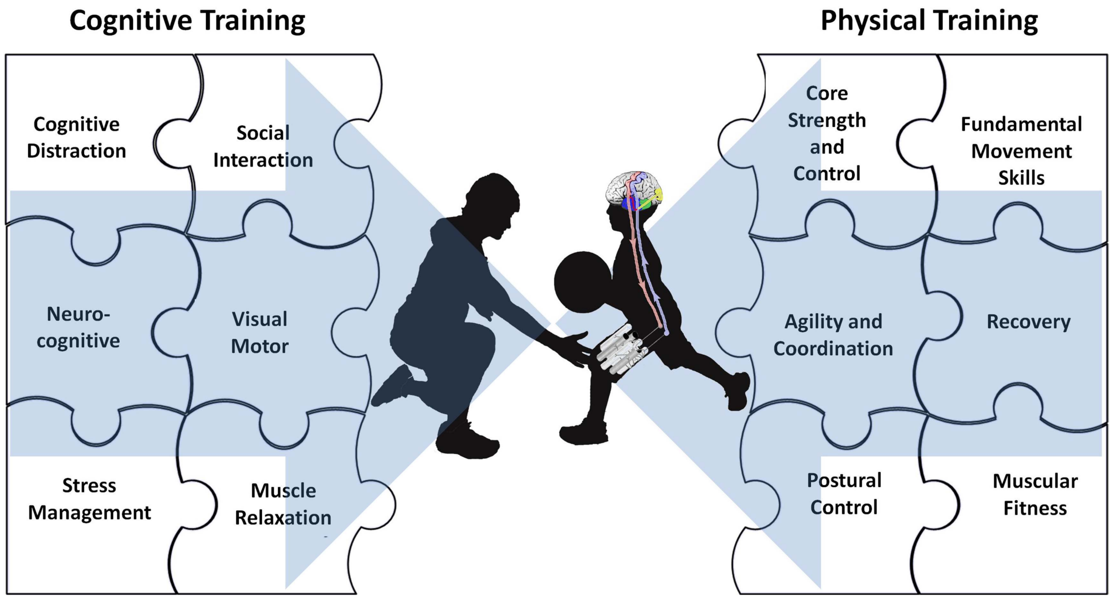

Figure 3 Integrative training model indicating a focus on integration of physical and cognitive training that is consistent with programming for youth.

training is now recognised as a safe, effective and valuable method of conditioning for children and adolescents with different needs, goals and abilities.[83 84]

Recent findings indicate that INT that is taught by trained specialists and incorporates intermittent-type activities into a well-designed plan may offer valuable health and fitness benefits to school-age youth.[10 21 23 71] INT is typically characterised by short bursts of meaningful physical activity purposely designed to enhance motor skill development interspersed with periodic periods of rest.[10 11] The intermittent rather than continuous nature of INT is more consistent with how youth move and play and thus are analogous to free-play.[85] It also includes a variety of training modalities that are strategically prescribed and progressed over time. For example, one INT programme was developed for a second grade physical education class. The routine was performed two times per week for approximately 15 min at the start of gym class. The programme incorporated body weight exercises with punch balloons that focused on enhancing muscular strength, muscular power and fundamental movement skills. This progressive training programme was an effective, time-efficient addition to physical education, as evidenced by improvements in health-related and skill-related fitness measures.[21] High compliance and self-reported positive attitudes towards INT provided evidence of feasibility and value to incorporating this approach into paediatric fitness programmes.[21] Enjoyment and general acceptance of this type of programming is found in other forms of intermittent or interval training in youth.[86]

Objectively measured spontaneous physical activity can be induced in healthy children with a structured resistance training or INT.[76] Meinhardt *et al*[87] followed 102 school children (aged 10–14 years) who participated in a 19-week resistance training

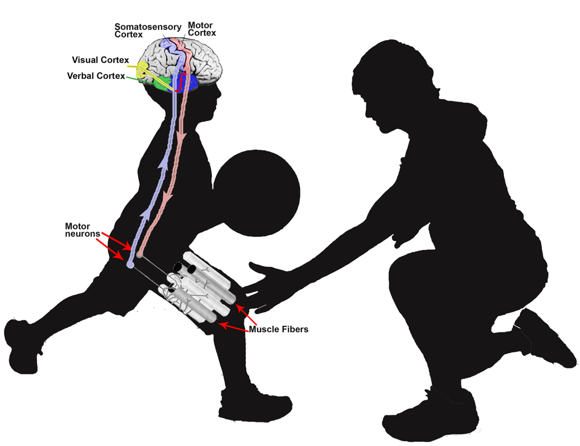

Figure 4 Active feedback and instruction to youth can maximise the integration of motor sensory, visual and verbal inputs that can support muscular motor pathways development with integrative neuromuscular training during youth.

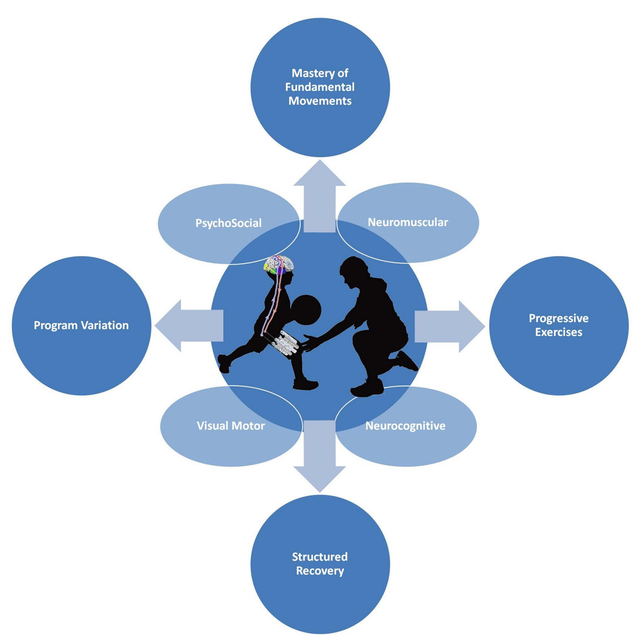

Figure 5 Qualified education and instruction support the complex programming components for effective implementation of integrative neuromuscular training. Reprinted with permission from Myer *et al*.[105]

programme and found significant increases in daily spontaneous physical activity behaviour in boys, and the effect was most pronounced in the less active children. It appears that INT (which includes resistance training) initiated early in life and maintained throughout adolescence will likely maximise one's potential to optimise motor skill abilities and engage regularly in physical activity.[10 11 21 53] And also, 7-year-old females who had incorporated INT into their standard physical education class appeared to be particularly sensitive to this type of training which suggests a potential sex-specific window for optimal implementation.[73] On the basis of these data it may be warranted to consider developmentally specific programmes that are tailored to the needs of growing boys and girls.

The potential impact of physical inactivity during childhood on health service utilisation and costs later in life has created a need for immediate action to manage, if not prevent, risky behaviours during this critical period of development.[53 88 89] It is becoming strikingly more apparent that physical inactivity during childhood may result in a vortex of inactivity and related health consequences in later years.[22 53 89–91] Figure 2 represents a conceptual model indicating the potential for INT during childhood to influence increased neuromuscular, cortex structural and cognitive development. Of greater concern from a public health perspective is the arrow indicating the potential for physical inactivity and reduced motor skill development during the growing years that can influence the risk of developing metabolic diseases and deficits in cortex and structural development.[92]

While the determinants of youth physical activity are complex, and involve the spheres of biological, familial, attitudinal, environmental and social determinants,[93] physical education, youth sport and recreational activities could provide a means for increasing MVPA and enhancing motor skill development through participation in a variety of developmentally appropriate activities. In addition, the recent data provide further support for the notion that preadolescence may be an important time to institute programmes aimed at reducing movement deficits that accelerate during maturation and lead to increased musculoskeletal injury risk and related health concerns.[11] If children grow-up in an environment that is deficient in opportunities to regularly participate in a variety of health-enhancing and skill-building activities early in life, they may be less likely to engage in more challenging activities later in life and more likely to suffer from the adverse consequences of a sedentary lifestyle. Paediatric exercise specialists who are skilled in teaching and communicating with youth who have different needs, goals and abilities should design, supervise and instruct age-appropriate exercise programmes for children and adolescents. These professionals should have practical experience working with youth and a philosophy that is consistent with participation in physical activity as an ongoing lifestyle choice. In addition, efforts to increase public awareness about specific types of physical activity that are most appropriate during the growing years, may help to support the need for daily physical education as a core subject in primary school.

SUMMARY AND CONCLUSIONS

With heavy technological influences on leisure time choices and limited exposure to daily physical education in most schools, many modern-day youth are unlikely to enhance their motor skills and improve their muscular fitness, the building blocks for a lifetime of MVPA. Moreover, youth who are ill-prepared for play and sport will have fewer opportunities for positive social interactions and will be less likely to experience enjoyment of physical activity. Age-related exercise programming for school-age youth should be taught by paediatric exercise specialists, including physical education teachers, who understand the fundamental principles of paediatric exercise science and genuinely appreciate the physical and psychosocial uniqueness of children and adolescents.[94] This goal may be attainable on a widespread basis if professional development is expanded to those already in a position to promote daily physical activity and healthy lifestyle choices (eg, healthcare provider skilled in identifying and treating children with exercise deficit disorder).[53 95–97]

Although the benefits of aerobic training should not be overlooked, INT approaches may offer benefits over general exercise programming to enhance motor competence and improve physical fitness in school-age youth because it capitalises on the corticomotor plasticity during preadolescence. INT that incorporates a variety of strength-building and skill-enhancing movements into a developmentally appropriate intervention may also provide an optimal method for the promotion of injury-free physical activity as a long-term lifestyle choice.

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