International Olympic Committee consensus statement on youth athletic development

Michael F Bergeron,[1,2] Margo Mountjoy,[3,4] Neil Armstrong,[5] Michael Chia,[6] Jean Côté,[7] Carolyn A Emery,[8] Avery Faigenbaum,[9] Gary Hall Jr,[10] Susi Kriemler,[11] Michel Léglise,[12] Robert M Malina,[13,14] Anne Marte Pensgaard,[15] Alex Sanchez,[16] Torbjørn Soligard,[17] Jorunn Sundgot-Borgen,[18] Willem van Mechelen,[19,20,21] Juanita R Weissensteiner,[22] Lars Engebretsen[17,23]

For numbered affiliations see end of article.

Correspondence to
Dr Michael F Bergeron, Youth Sports of the Americas; Lemak Sports Medicine, 500 Office Park Drive, Suite 200, Birmingham, AL 35223 USA; mbergeron.phd01@gmail.com

Accepted 18 May 2015

To cite: Bergeron MF, Mountjoy M, Armstrong N, *et al. Br J Sports Med* 2015;**49**:843–851.

ABSTRACT

The health, fitness and other advantages of youth sports participation are well recognised. However, there are considerable challenges for all stakeholders involved—especially youth athletes—in trying to maintain inclusive, sustainable and enjoyable participation and success for all levels of individual athletic achievement. In an effort to advance a more unified, evidence-informed approach to youth athlete development, the IOC critically evaluated the current state of science and practice of youth athlete development and presented recommendations for developing healthy, resilient and capable youth athletes, while providing opportunities for all levels of sport participation and success. The IOC further challenges all youth and other sport governing bodies to embrace and implement these recommended guiding principles.

INTRODUCTION

The goal is clear: Develop healthy, capable and resilient young athletes, while attaining widespread, inclusive, sustainable and enjoyable participation and success for all levels of individual athletic achievement. Yet, this is a considerable challenge for all stakeholders in youth sports—parents, coaches, administrators, sport governing bodies *and*, especially, youth athletes.

The process begins with a subjective assessment of potential talent, followed by a structured programme of training in a specific sport. However, the limited success of talent identification and athlete development programmes is not surprising, as the model of athlete development is built on an individually unique and constantly changing base, including the demands of normal physical growth, biological maturation and behavioural development, and their interactions.[1 2] Athletic development is also multidimensional and difficult to assess in youth, and the trajectories from the novice to elite levels can vary greatly among athletes. Adding to the complexity, the demands of specific sports are superimposed on this dynamic integrated scheme. Moreover, the development of sport-specific skills, motivation and behaviours in an integrated learning culture is not well characterised; and, given the selectivity and exclusivity of sport, it is the choice athletes who generally receive the most attention in research. Accordingly, less is known about those who are systematically excluded (cut), who drop out (voluntarily withdraw) or are injured, along with contributing factors such as overuse, overtraining and burnout.

There is also an urgent need to extend our views of youth athlete development to include the 'culture' of specific sports and youth sports in general, including the underlying philosophy for developing youth athletes, the systems of specific sports and interactions between athletes, coaching styles and practices, the effects on youth athletes from parental expectations and the view of youth athletes as commodities, which is often intrusive with a fine line between objectivity and sensationalism.

In an effort to advance a more unified, evidence-informed approach to youth athlete development, the IOC convened a consensus meeting of experts in the field in November 2014. The group was charged with two tasks:

1. Highlight key considerations and challenges in competitive youth sport, and critically evaluate the current state of science and practice of youth athlete development;
2. Create guidelines for a sustainable model to develop healthy, resilient and capable youth athletes, while providing opportunities for all levels of sport participation and success.

MATURATION

Assessment of biological maturity status and timing

Biological maturation is an ongoing process that begins prenatally and continues through approximately the first two decades of postnatal life. Outcomes of the underlying biological processes are observed, assessed and/or measured to provide an indication of *maturity status* (ie, the status of the youngster at the time of observation), commonly specified by skeletal age (SA) and secondary sex characteristics. *Maturity timing* refers to the chronological ages when specific maturational events occur, frequently assessed by age at peak height velocity (PHV) and age at menarche. For accuracy, both require longitudinal data that span adolescence, as recalled age at menarche has error associated with memory and a tendency for reporting in whole years.[2–6]

SA is the most useful estimate of maturity status and can be used from childhood into late adolescence.[2 7] It can also be used with current body height and/or mid-parent height to predict mature height, which is of interest in some sports. Radiation exposure with hand-wrist radiographs is minimal; although, expert interpretation is required. SA and fusion of the distal radius based on MRI are periodically used for chronological age verification, especially in some male youth sport competitions.[7–9] Given the maturity-related gradient in selection favouring early maturing males in many sports, the likelihood of false negatives is increased.[7] Ethnic variation in skeletal maturation is also a related consideration.[2 7] As such, SA and fusion of the distal radius should not be used for age verification purposes in sport.

Secondary sex characteristics (breasts, genitalia, pubic hair) are useful only during the pubertal interval. Assessments indicate stage of puberty at the time of observation, but provide no information on age at entry into and duration of a stage. Moreover, for some, assessment of secondary sex characteristics can be invasive; and accuracy of assessment can be significantly discordant among physicians, and between physicians and youth in self-assessments.[10 11]

Percentage of predicted mature (adult) height at the time of observation provides an estimate of maturity status.[12] The method has moderate concordance with classifications of maturity status, based on SA in youth American football and soccer players.[13 14] Predicted time before PHV (maturity offset) and, in turn, predicted age at PHV provide an estimate of maturity timing.[15] However, validation studies indicate several limitations.[16–18] Predicted offset and age at PHV increase with chronological age at prediction; predicted ages at PHV have a reduced range of variation (SDs ~0.5 year); and predicted age at PHV is affected by actual age at PHV in both sexes, and age at menarche. Also, height prediction equations are available primarily for European ancestry, which limits their global applicability. Maturity offset was suggested as a categorical variable, pre-PHV or post-PHV;[15] as such, it is most useful close to the time of actual age at PHV in average (on time) maturing boys within a narrow age range, 13.00–14.99 years, which limits its utility with elite male athletes who tend to be early maturing.[7] The trend is more variable in girls, as the protocol overestimates age at PHV more than in boys. Ethnic variation in sitting height and estimated leg length is also a confounder in the prediction equations. Moreover, identification of the ethnicity of youth is not permitted in some countries.[19]

Physiological and performance changes across maturation

Muscle metabolism

Muscle biopsy studies indicate that resting muscle ATP concentration is invariant with age; but phosphocreatine (PCr) and glycogen concentrations increase with age, at least in boys aged 11–15 years. Glycogen depletion with exercise is greater in older boys and is reflected by increased muscle lactate accumulation with age. Children and adolescents accumulate less blood lactate than adults during exhaustive exercise, and there is a negative relationship between the percentage of peak VO_2 at the lactate threshold and age. However, sex and/or maturation effects on blood lactate accumulation remain to be proven.[20 21] Sparse data indicate enhanced oxidative enzyme activity in children and adolescents compared with adults and lower glycolytic enzyme activity in pre-pubertal children than in adolescents or adults; though, differences in glycolytic enzyme activity between adolescents and adults are less clear.[21–23]

During submaximal exercise, children's enhanced ability to oxidise lipids, and therefore spare glycogen, means that they are well-equipped for long-term moderate intensity exercise. Young people have higher rates of exogenous carbohydrate oxidation than adults; but, the optimal carbohydrate supplementation to sustain endurance performance during youth is unknown.[24 25]

Muscle strength

The development of muscle strength is dependent on a combination of muscular, neural and biomechanical factors. Strength increases with few sex differences in a relatively linear manner through childhood. During puberty, however, sex differences emerge with boys demonstrating accelerated increases in strength, while girls continue to develop at a similar rate as during pre-puberty. Sex differences in strength are both muscle-group and muscle-action specific; but, on average, by late puberty, there is a sex difference in the expression of strength of ~50%.[26 27]

Aerobic and anaerobic fitness/performance

There is an almost linear increase in boys' peak VO_2 from 8 to 18 years, with a similar but less consistent trend in girls' values, which tend to plateau in the mid-teens. Peak VO_2 increases by ~80% in girls and by ~150% in boys from 8 to 16 years of age, with the sex difference increasing from ~10% at age 10 to ~35% by age 16 years. Increasing muscle mass is the dominant influence on peak VO_2 during adolescence; but, maturation has a significant positive effect on peak VO_2, independent of age and body size and composition.[28] The time constant of the exponential rise in the pulmonary (p) VO_2 kinetic response to exercise above the lactate threshold increases with age from childhood through adolescence. The pVO_2 slow component also increases with age. Pulmonary VO_2 kinetics studies provide compelling evidence that, at the onset of exercise above the lactate threshold, children and adolescents have an enhanced potential for oxidative metabolism compared with adults.[29]

In the absence of intra-muscular data, research on anaerobic performance has focused on the assessment of external cycling peak power output (CPP), using variants of the Wingate anaerobic test. There is an almost linear increase in CPP in both sexes from ~7 to 12 years and then a more marked increase in boys' CPP through to young adulthood. Girls often outscore boys until ~12 years of age, due to their more advanced maturation; but, by age 17 years, the sex difference in CPP is ~50%.[30] There is an asynchronous increase in anaerobic and aerobic performance with age and maturation. From ages 12 to 17 years, girls increase their CPP by ~65% compared with boys, who experience a ~120% increase in CPP. Both sexes experience a more marked improvement in CPP than in peak VO_2 during maturation, with peak VO_2 increasing by ~70% and ~25%, respectively, in boys and girls aged from 12 to 17 years.[31 32]

Fatigue resistance and recovery

Resistance to fatigue and recovery from high-intensity intermittent exercise undergo a gradual decline from childhood to adulthood in males. In females, the adult profile appears to be established by mid-puberty. The distinction has been attributed to children having more rapid cardiorespiratory recovery kinetics, enhanced oxidative activity, faster PCr re-synthesis, different motor unit recruitment, better acid–base regulation and lower production and/or more efficient removal of metabolic by-products, than adults.[33 34]

Responses to exercise training

Evidence-based IOC recommendations for muscle strength, and aerobic and anaerobic training programmes are documented.[35] Pre-pubertal children benefit from resistance training; but, the trainability of muscle strength increases with age. There is a minor sex-effect during pre-puberty, which increases with age and maturation. It is, however, unclear which maturational changes account for the enhanced strength trainability of boys.

There is no compelling evidence to suggest that, after adjusting for initial fitness, aerobic or anaerobic responses to training are related to sex, age or maturation during youth.[36–38]

Sleep

Several hormonal and neurological changes occur during puberty, affecting the homoeostatic and circadian regulation of sleep.[39–41] Adolescents have later bedtimes and wake times,[42] with a recommended optimal level of sleep of 8.5–9.5 h.[43] However, international trends indicate a prevalence of insufficient sleep among adolescents,[44] often prompted by early school-start times, academic demands, social activities and events, caffeine consumption and screen-time at night.[43 45 46] For youth athletes, the training and competition schedule further exacerbates the deficiency of sleep,[47–50] with preliminary evidence indicating an increased likelihood of injury with insufficient sleep.[51] Given the potential consequences of insufficient sleep on health, behaviour, attention, and learning and athletic performance, interventions (eg, tailored training and even perhaps schooling schedules) to support adequate sleep in youth athletes should be implemented.[40 52]

Growth, maturation and performance on the field

Sport performance during youth is underpinned by a range of physical and physiological variables that are governed by the timing and tempo of growth and maturation. Youth sport, however, is highly selective,[53 54] with a maturity-associated selection/exclusion process commonly occurring during the interval of puberty and the adolescent growth spurt, which covers the period between 9 and 15 years of age.[7 55–58] Sport performance progressively improves with growth and maturation, and appropriate aerobic, anaerobic and resistance training further enhance performance; but there is asynchronous development through childhood and adolescence into young adulthood. Thus, initial selection, long-term athletic/sport performance prediction and optimal athlete development remain a challenge. Research has developed a sound scientific foundation to inform decision-making; but those involved in youth athlete development must nurture talented individuals, and appreciate that both positive and negative changes in performance might be more related to biological clocks than to coaching and training.

CHALLENGES TO HEALTH, WELL-BEING AND PERFORMANCE

Specialisation

Children are increasingly specialising in a sport at an early age, beyond the customary early specialisation seen in gymnastics, swimming, diving and figure skating. Various factors account for this contemporary phenomenon, including investment by the myriad stakeholders involved in sports, as well as incentives for Olympic and other athletic success. This has led to the development of talent identification and development schemes, aimed to identify and guide youth athletes towards professional sports, and/or Olympic achievement. The result has been an increase in competitiveness and professionalisation within youth sport itself, intensified and expanded physical training and increased competition volume and frequency with insufficient allocation of time for rest and recovery. One consequence is an ongoing escalation in sport-related injuries and health problems at all levels of youth sports,[59–62] including overuse injury, overtraining and burnout.

In contrast to premature emphasis on a single sport, research suggests that youth should avoid early sport specialisation, as diverse athletic exposure and sport sampling enhance motor development and athletic capacity, reduce injury risk and increase the opportunity for a child to discover the sport(s) that he/she will enjoy and possibly excel at.[61 63–66] Numerous successful elite athletes participated in several sports before specialising.[54 60 61 63 67–69] However, the message would be reinforced with more definitive evidence indicating that children who participate in a variety of sports and specialise only after reaching the age of puberty, for example, tend to be more consistent performers, have fewer injuries and adhere to sports play longer than those who specialise early.[59 66]

Injury and health concerns of systematic training and competition

Musculoskeletal injury

The competitive careers of youth athletes across all sports are too often temporarily halted or permanently derailed by overuse injuries that are the consequence of disproportionate training and repetitive homogenous loads, hastened and exacerbated by insufficient rest and recovery.[70 71] This scenario is notably pervasive with youth athletes transitioning too rapidly to higher levels of training and competition demands during adolescence.[60 70] However, certain aspects of growth (eg, linear rate) and maturation may predispose some youth athletes to specific injuries involving the immature spine (eg, spondylolysis, spondylolisthesis), joint surfaces (osteochondritis dissecans) and traction apophysitis (eg, Osgood-Schlatter disease, Sever's disease).[60 72–75] Because of potential growth disturbances, injuries to epiphyseal growth centres are of particular concern.

Growth and sexual maturation

There has been a long-standing concern that extensive high intensity sports training can alter growth rates; however, results from cross-sectional and longitudinal studies do not support this speculation.[2 56 57 76] The short stature of youth athletes in artistic gymnastics is often cited in the context of potential negative effects of training. Nevertheless, current consensus is that regular gymnastics training does not attenuate pubertal growth and maturation or compromise adult stature.[58] Youth gymnasts of both sexes have the growth and maturity characteristics of short, normal late-maturing children with short parents.[58] It should also be noted that youth figure skaters and divers also, on average, present with shorter statures, though not as short as gymnasts. Likewise, evidence indicates no effects of systematic training and competition during childhood and adolescence on the sexual maturation of either sex. Although menarche occurs, on average, at a later age among participants in some sports,[55 57 77] close scrutiny of the data indicates overlap with the normal range of variability in the general population.[78 79]

Cardiac

Despite the well-documented benefits of regular physical activity in promoting cardiac health,[80 81] unsuspected cardiovascular disease represents the most common cause of sudden death in competitive youth athletes.[82] Accordingly, careful assessment to rule out hypertension, congenital heart disease, dysrhythmia, heart murmur or structural/acquired heart disease, is imperative.[83] However, the utility of pre-participation cardiovascular screening in reducing the (already very low) prevalence of sudden cardiac death (SCD) remains contentious,[84 85] and there is no consensus for screening youth athletes. While there has been some evidence indicating features of the 'athlete's heart' with pre-pubertal children involved in intensive endurance training, these structural changes are mild and may simply represent adaptive responses versus pathological conditions.[86–89]

However, given the nature and grave consequences of potential negative cardiac adaptations and dysfunctions, closer longitudinal study of the cardiac characteristics and health profiles of youth training at elite levels is recommended.

Injury rates and prevention strategies

Injury rates in youth sport

An estimated injury incidence proportion in athletes aged 11–-18 years has been reported as 35 injuries/100 youth annually requiring medical attention.[90 91] Lower extremity injury and concussion accounted for over 60% and 15% of the overall injury burden, respectively.[90 91] The highest sport-specific injury incidence rates for boys are in ice hockey, rugby, basketball, football (soccer) and American football, along with wrestling, running and snowboarding. For girls, the highest injury incidence rates are in basketball, football, ice hockey, gymnastics, field hockey and running.[92 93] The combination of high sport-specific participation rates in those sports with high injury rates leads to the highest burden of injury in youth sport.

Injury prevention in youth sport

It is impossible to eliminate all injury in youth sport; however, injury prevention strategies can reduce the frequency and severity of injuries. Multifaceted neuromuscular training and programmes focused on intrinsic factors such as strength, endurance and proprioception/balance, have been shown to reduce injury incidence in youth football, handball, basketball and multisport by between 28% and 80%,[94–106] with specific efficacy in reducing lower extremity, knee and ankle injuries.[94 96 100 101 104 107 108]

Prevention strategies have also been developed to address extrinsic risk factors via the use of protective equipment (eg, ankle bracing and taping,[109] mouth and wrist guards,[110 111] and helmets[112]), and implementing rules and regulations.[113 114] Unfortunately, without policies to enforce the implementation of prevention strategies, the uptake may not be optimal.[94 97] Rule changes in some sports have often not been rigorously evaluated; however, meta-analysis and cohort evidence demonstrate that policy allowing body checking in youth ice hockey increases the risk of injury and concussion twofold to fourfold,[114 115] which has led to national policy changes in Canada and the USA.

Effective and sustainable implementation of injury prevention research into practice is context-specific (eg, sport, age, level and organisational structure).[116 117] There are also evident deficiencies in coach, athlete and parent knowledge and behaviours regarding injury prevention programmes in youth sport populations, despite the evidence to support their implementation.[118–120] Accordingly, there is a need to focus on effective evidence-informed injury prevention strategies in all youth sports, with special attention to sports with a high risk of injury and a paucity of research (eg, rugby, field hockey, football, volleyball, field hockey, running, lacrosse, gymnastics, martial arts, tennis and wrestling).

Chronic and acute clinical health conditions

While many clinical health conditions (CHCs) are not compatible with high-level sports participation, numerous youth athletes with asthma, attention deficit-hyperactivity disorder, insulin-dependent diabetes, iron deficiency or certain orthopaedic malformations train and compete. However, special considerations for youth athletes with these and other CHCs are essential to ascertain and optimise well-being and minimise the risk of injury.[83] A break in training and competition is often therapeutically essential, and ultimately more beneficial to the athlete, than trying to maintain the usual routine and consequently inhibit recovery of an injury or acute illness. The responsible physician must assure that individual-specific health-related risks from training and competing are minimised, including proper instruction for the athlete, parents and coaches, especially regarding detection and management of potential life-threating conditions, such as seizures in epilepsy,[121] hypoglycaemia in insulin-dependent diabetes,[122 123] or SCD.[124]

Prior to sport participation, as part of the pre-participation examination, the following should be considered for any athlete with a CHC: (1) evidence-based diagnosis, severity and progression of the CHC; (2) CHC burden to the athlete; (3) potential performance limitations by the CHC or its treatment; (4) health risks for the athlete from the CHC or its treatment and (5) application for a Therapeutic Use Exemption for the treatment of the CHC, if required by WADA. Antidoping rules generally do not pose a major problem for the elite young athlete with a CHC, so long as team physicians are knowledgeable of the Therapeutic Use Exemption programme of the World Anti-Doping Code.[125] Over-reporting or overdiagnosis is sometimes motivated by a medical treatment having a purported potential of performance enhancement, as in asthma or attention-deficit hyperactivity disorder;[126 127] although performance-enhancing effects at therapeutic doses are often unremarkable.[128 129] Moreover, at the elite level, athletes need to meet strict diagnostic criteria, so overdiagnosis is less likely.

Psychological overload from excessive demands and expectations

Psychological stress can have both training and straining effects on the individual.[130] Psychological overload, however, occurs when the level of stress becomes excessive, no longer affecting a positive response. Youth athletes are increasingly being exposed to inappropriate and unrealistic demands and expectations, and consequent psychological overload (self or coach/parent induced).[54 60] How youth athletes perceive and cope with these stressors is neither predictable nor benign,[131] with athlete burnout and subsequent related drop-out from sport being a recognised part of competitive youth sport.[132] Use of performance-based field criteria (eg, resting cortisol levels and Profile of Mood test) may facilitate early detection of youth at risk of burnout.[133] There is also the potential for developing maladaptive perfectionistic tendencies, prompted by elevated parental expectations and criticism.[134]

Widespread (often unrecognised) depressive disorder is especially prevalent in adolescent girls,[135] and the psychosocial stress of an unhealthy youth sports environment or an injury could exacerbate the risk and levels of depression and anxiety.[135 136] Providing youth athletes with specific coping skills through mental training seems promising,[137] and goal setting can have a positive effect in reducing fear of failure among young elite athletes.[138] Coping effectiveness specific to the competitive level and the demands of the sport can also be directly related to athletic achievement.[139 140] Potential interactions between sport-related stressors and those associated with normal adolescence must also be recognised and addressed.

Coaching education should emphasise the importance of creating autonomy-supportive, mastery-oriented sporting climates that result in less stress and more intrinsic motivation,[141 142] which is especially important in elite youth sport where the pressure to perform is often overwhelming and can even increase the risk of injury.[143 144] By focusing on a mastery developmental climate, a positive (sporting) community can evolve.[145] Parent supporting involvement is also important in mitigating dysfunctional and/or destructive responses. Indeed, parents reportedly welcome advice on how to become a better sporting parent;[146 147] although implementation is a challenge.

Safeguarding the youth athlete from abuse in sport

While sexual abuse and harassment in sport is one of the more concerning threats to children,[148] other forms of relational abuse have also been identified involving emotional and physical abuse, including forced physical exertion.[149] The scope of threats to the youth athlete, however, extend beyond relational abuse to include organisational threats, such as systems that promote overtraining,[150] the endorsement of abusive hazing rituals[151] and the utilisation of selection procedures that promote eating disorders or competing with an injury.[152] Medical mismanagement is another organisational threat for the child athlete. In particular, the excessive and often systematic use of analgesic medication by team physicians in elite youth football is reported.[153] As indicated in selected study settings and populations, almost 25% of youth athletes have admitted to misuse of their prescribed medication (pain, stimulant, sleep, antianxiety),[154] and 13–68% have admitted to anabolic androgenic steroid abuse in the sport context.[155] Insufficient medical coverage during training and competition, by relying on insufficiently trained coaches to manage medical issues, is another recognised threat to youth athletes.[156]

The prevalence of various forms of abuse, associated risk factors and consequences for the athlete need to be more closely examined. Moreover, an organisational approach beyond the perpetrator and the victim is essential to reveal how the culture of an organisation can facilitate or prevent abuse. There is also a need for research exploring the efficacy and effectiveness of specific strategies that can protect and promote the well-being of youth athletes.

Nutrition: energy and nutrient needs and dietary supplements

Owing to metabolic variability within and between individuals,[157] and methodological difficulties in estimating energy intake and expenditure,[158] it is difficult to define the precise energy requirements of youth athletes. Carbohydrate needs and fat intake should be in accordance with established guidelines,[159] and youth athletes do not need protein supplements to meet elevated protein needs, as these can be readily met by appropriate and well-timed eating patterns.[159] As many youth athletes are at risk of low vitamin D status, correction of insufficiency through supplementation may be necessary to ensure optimal bone health and mitigate injury risk.[159 160] Dietary iron intake (particularly for girls) should be consistent with the Reference Daily Intake, with only medically warranted supplementation.[159] Increased calcium intake, especially in adolescent female athletes, is often needed to meet the recommendation of 1300 mg daily. Not surprisingly, poor nutrition knowledge among elite coaches[161] and adolescent athletes[162] has been reported.

Supplement use (including energy drinks) and muscle-enhancing behaviours (eg, excess protein intake) are common, especially among male adolescents.[163 164] Factors influencing supplement use include pressure to perform, physical ideals and availability of dietary supplements targeting youth athletes. However, it is recognisably considered inappropriate and unacceptable to encourage dietary supplements for performance enhancement with youth athletes.[159 165 166] Athletes who take supplements are also at risk of violating antidoping rules.[167]

Eating disorders in adolescent athletes

Weight and body composition are crucial performance variables in some sports. Unfortunately, in an attempt to conform to various self-imposed expectations, demands from others or competition regulations that might be ill-suited to their physique, many youth athletes develop the Female Athlete Triad,[168] recently termed ‘Relative Energy Deficiency in Sport’ (RED-S),[169] with or without disordered eating (DE) or eating disorders (EDs). The prevalence of DE is high in competitive youth sports, with the peak onset of EDs[170] coinciding with sport specialisation and increases in demanding competition. A high prevalence of EDs exists in male (3%) and female (14%) elite adolescent athletes, compared to non-athletic male (0%) and female (5%) controls.[171] DE and an ED can lead to adverse short-term and long-term effects on health and performance.[172]

The pathogenesis of EDs is multifactorial. Cultural, individual, family and genetic/biochemical factors are involved,[173–175] in addition to sport-specific factors, such as dieting to enhance performance, personality factors (such as perfectionism, obsessiveness), pressure to lose weight, frequent weight cycling, premature sport-specific training, overtraining, recurrent and non-healing injuries, inappropriate coaching and parental behaviour, and regulations in some sports.[172] The potentially grave health consequences related to RED-S and EDs underscores the importance of early screening, during the annual Periodic Health Examination.[169 176] The diagnosis of RED-S and an ED, however, is challenging, as symptomatology can be subtle. Athletes in judged, weight category and endurance sports are particularly at risk, so that early detection is crucial to prevent long-term health consequences and to improve performance. Investigation and treatment should be initiated when an athlete presents with unexpected weight loss, lack of normal growth and development, recurrent injuries and/or illnesses, mood changes and/or unexpected decreased performance.[169]

Very few studies have examined EDs prevention in youth athletes. However, a recent randomised controlled trial demonstrated that it is possible to prevent new cases of EDs and associated symptoms in adolescent female elite athletes.[161]

Environmental challenges

All stressful environmental conditions, including heat and humidity, cold and altitude, can pose particular health and performance challenges for youth athletes.[177] With the cold, elevated metabolic heat production from physical exertion, and behavioural and physiological responses acting to minimise exposure and preserve body temperature, are generally sufficient to mitigate cold-related health risk during sport; although, inhalation of cold air during sport can have adverse health effects for asthmatic and healthy athletes. Moreover, cold acclimatisation efforts provide little, if any, practical advantage in terms of preserving normal body temperature. With respect to altitude, youth athletic events are held at elevations that pose little-to-no health risks. While even modest altitudes can affect sport performance, any decrement in performance is subject to a high degree of sport- and event-specific variation, with influencing factors often being mutually offsetting. Arriving at altitude in advance of competing (~3–5 days) is sufficient for altitude acclimatisation; though, it is not advisable for youth to train at altitude or use passive exposure to hypoxia.

Training or conditioning for, or playing, sports effectively and safely in the heat, is distinctly challenging, especially when participating multiple times on the same day.[178] Notably, the health, safety and performance challenges from sweat-prompted body water and exchangeable sodium losses can be increasingly greater as youth athletes grow, physically develop and mature.[179] Anticholinergic drugs or other medications that affect hydration or thermoregulation (eg, a dopamine reuptake inhibitor to treat attention-deficit/hyperactivity disorder or enhance performance[126] or diuretics), or current or recent illness (especially involving vomiting, diarrhoea and/or fever), can also contribute to decreased exercise-heat tolerance and increased exertional heat illness risk. However, with sufficient preparation (including progressive heat acclimatisation), ample hydration, appropriate modification of known contributing risk factors and close monitoring, thermal and cardiovascular strain can be minimised, and exertional heat illness is usually preventable.[180–183]

YOUTH ATHLETIC DEVELOPMENT

Athlete development frameworks

Despite a predominance of popular frameworks, gaps in the youth athletic development pathway prevail.[184–187] At the initial sports participation stage, inappropriate guidance and developmental activities contribute to compromised fundamental skill acquisition, injury, burnout, dropout and unrealised talent potential of youth athletes.[185 187–190] Furthermore, individual athletic performance and achievement is based on a complementary, and sport-specific, mix of athletic attributes and skills (technical, perceptual, neurocognitive, psycho-social and physical) that are, in turn, altered by environmental, system and chance factors.[68 184 191–194] Because of this complexity and low rate of conversion from youth sport to elite sport success, development frameworks should be inclusive in considering the complement of sports participation, as well as pre-elite and high-performance elements. Athlete development frameworks should also be holistic in embracing the multidimensional nature of athlete development, and predicated on recognised 'best practice' for each developmental phase, rather than age-related prescription based on physical and maturational factors, and flexible to embrace the inherent complexity and non-linearity of athlete development.[185 187 195–197]

An effective integrated approach to athlete development highlights the changing elements of the personal, social and physical features of different activities in sport throughout development.[185 187 196] When overall youth development and skill acquisition are considered as integrated, many personal and environmental factors interact to affect sport involvement. In this integrated approach, the activities of youth in sport become the developmental environment that incorporates specific social relationships and physical features of the setting. The developmental activities of youth in sport can be categorised along two continuums: first, the social structure of the activity (adult-led to youth-led) and second, the personal value the activity provides to the participants (extrinsic to intrinsic).[198] When combined, these two continuums form a matrix in which the different activities of youth sport can be located, resulting in an integrated learning approach. Accordingly, the different activities of this integrated approach offer unique interactions, learning opportunities and potential for growth. A diversity of sport activities during childhood allows young athletes to experience a range of opportunities and then select (or be selected to) a specific path of more targeted training activities during adolescence and young adulthood. Empirical evidence shows that a diversity of activities (including variations of play and practice) in early development is an indicator of continued involvement in more intense activities later in life, elite performance and continued participation in sport.[199]

Talent identification and development

The search for talent in sport at relatively young ages is far more prevalent and systematised than in the past. Formal talent identification programmes can be traced to the former socialist East European countries, often labelled as 'scientific selection'.[200] However, success of these systems predicated on physical parameters and juvenile levels of performance has been limited.[53 54 201–205]

Effective sport talent identification and development in youth for achieving elite performance remains a fundamental challenge for sports institutions, with the allocation of limited resources for the uncertain probability of future international sporting achievement. However, sport is extremely selective; and the probability of elite success is highly unlikely for most. Moreover, accurate talent identification and appropriate athletic development of potentially gifted youth athletes is far too complex to be distilled into a singular, universally accepted process, especially since this is greatly dependent on country, culture and context. The difficulties in effectively utilising valid performance measures (eg, physiological, cognitive, functional motor, psychosocial etc), as well as the interactions from unknown influencing variables, further complicate a very complex task.[206] Elite athletic success is also vulnerable to deviations in sport focus, as well as the impact of normal behavioural development and interactions with adults, which can alter the sport-life balance. Not surprisingly, therefore, there exists an apparent disconnect with discordant results between advocated talent development systems and the evidence of actual outcomes.[66 205 207]

The efficacy of early talent identification predicated solely on physical factors and juvenile levels of athletic performance in predicting future elite sport performance is confounded by maturational factors, which often exclude late developers in demonstrated athletic capacity and sport skill.[208 209] Moreover, when children or adolescents are grouped by age, older individuals generally outperform younger ones. Research specific to elite athletes from multiple sports and in different countries repeatedly revealed that sampling of sport during childhood is not detrimental to adult elite levels of sport achievement in sports where peak performance is achieved during adulthood.[63 190] Data specific to professional German football players affirm that a more inclusive, long-term approach to athlete development, involving recurrent selection and de-selection of athletes, could address the uncertainty involved in and shortcomings of early talent identification.[202]

Success at the elite level of sport performance stems from a combination of factors that vary based on the sociocultural and politicoeconomic context of a country. Intrinsic (eg, body height and rate of maturation, aptitude, adaptation to training, motivation, psychological skills) as well as extrinsic (eg, environment, access and opportunity, athlete development pathway, coaches, family, educators) factors work in synchrony to determine an athlete's success in sport, with the interactions between heritable characteristics and environments thought to be the primary determining factors.[210]

Coaching education and effectiveness

Coaches of youth athletes play a pivotal role in determining whether sport systems provide opportunities for peak athlete performance, promote lifelong participation and shape personal development. Therefore, coach education and mentoring to develop coach competencies should be a priority of sport organisations. Contemporary coaching theory[211] indicates that coach effectiveness should be driven by an understanding that (1) coaching knowledge is multidimensional, (2) there are key athlete assets and several related athlete outcomes and (3) that effective coaching is influenced by the coaching context. It is also essential that coaches understand physical growth, biological maturation and behavioural development, as they affect performance and injury risk.

Coaches' knowledge

Although a major component of coaching effectiveness resides in one's ability to teach sport-specific skills, coaching effectiveness is also reflected in the ability to create and maintain relationships with others, and the ability to learn from one's own practice.[212–214] Therefore, coaches' effectiveness encapsulates coaches' ability to access and use a combination of professional knowledge (eg, sport-specific content, paediatric exercise science, injury prevention and pedagogical knowledge), interpersonal knowledge (eg, relationships with athletes, parents and local community) and intrapersonal knowledge (eg, reflection and introspection).

Athletes' assets and outcomes

The four Cs—Competence, Confidence, Connection and Character—is a set of athletes' assets that should become the focal point of coaching practice.[211] It is the coaches' responsibility to establish positive training and competitive environments, and to create relationships that focus on individual athletes' needs in addition to the long-term objectives of performance, participation and personal development.[215, 216] Repeated positive developmental experiences in sport that result from regular engagement in fun and challenging activities that focus on athletes' four Cs are known to have long-term positive effects on performance and participation.[217–219]

Coaching contexts

The Developmental Model of Sport Participation[65, 66] was used[220] to propose a typology of four different categories of coaches, based on contrasting competitive demands (ie, performance vs participation) and for developmental level (eg, age or maturation). The four categories include *participation* coaches for (1) children and (2) adolescents and adults; and *performance* coaches for (3) young adolescents and (4) older adolescents and adults. This and other similar typologies identify appropriate and differing criteria and expectations for coaching effectiveness.

Coaching effectiveness definition

The integration of these three components (coaches' knowledge, athletes' assets and outcomes and coaching contexts) led to a definition of coaching effectiveness:

> The consistent application of integrated professional, interpersonal and intrapersonal knowledge to improve athletes' competence, confidence, connection and character in specific coaching contexts.[211]

Accordingly, coaches across the continuum of youth athletic progression require a unique mix of professional, interpersonal and intrapersonal knowledge to effectively cultivate athletes' competence, confidence, connection and character (4 Cs). Although all effective coaches require a high level of professional, interpersonal and intrapersonal knowledge, there will be great variation between each context as to the nature of the knowledge and strategies required to appropriately nurture athletes' assets respective to their developmental and competitive levels. Ultimately, this definition of coaching effectiveness provides the foundation to develop coaching education programmes specifically emphasising sport-specific coaching knowledge, a coach's ability to maintain high-quality relationships with athletes and coaching peers, and reflection on personal experiences. Coaches who are able to improve their athletes' four Cs are making an enormous contribution to the development of sport and society.

Developing fitness, athleticism and a functional foundation

Despite a compelling body of scientific evidence that supports regular participation in age-related strength and conditioning activities,[27, 221, 222] secular declines in measures of muscular strength, fundamental movement skills and neuromuscular fitness in the general population of youth have been reported.[223–227] The observed regressions in muscular fitness may be, in part, due to worldwide reductions in frequent varied exposure to moderate-to-vigorous intensity physical activity in school-age youth.[228, 229] Participation in organised sports, however, does not ensure a suitable level of integrated strength, neuromuscular fitness and other essential characteristics (eg, biomotor abilities, including coordination and balance) to adequately meet the physical and functional demands of sport consistent with elite, and sustainable, athletic performance. In contrast, sports participation with appropriate preparatory strength and fitness conditioning decreases the risk of sports-related injuries, and enhances the likelihood of achieving and sustaining an enjoyable, high level of performance.[230–232]

Muscular fitness and effective movement skills serve as the foundation for achieving optimal and sustainable long-term athletic performance; accordingly, a suitable emphasis on developing muscular strength, power, speed and agility of young athletes with appropriate age-related interventions is essential.[233, 234] Early exposure to strength and conditioning can improve markers of health, enhance physical performance, and reduce injury risk in children and adolescents.[27, 231, 235] Indeed, the IOC encourages early identification of individual deficits in physical fitness in young athletes and the qualified prescription of training programmes specifically designed to address individual limitations.[236]

To optimise training adaptations and manage fatigue, youth conditioning should be considered a long-term process that involves the sensible integration of different training methods and the periodic manipulation of programme variables (eg, training intensity and volume) over time, while providing regular opportunities for rest and recovery. Integrative neuromuscular training is specifically designed to improve essential athletic elements for sport, and foster positive skill development with the intent to make organised youth sports more engaging, enjoyable and safe for all youth athletes.[237, 238] Extensive evidence suggests that young athletes who are not exposed to this type of strength and conditioning early on in their athletic careers will inevitably need to address neuromuscular deficiencies to enhance athletic development or in rehabilitation following an injury.[94, 97, 104, 239] The desired result encompasses having sufficient physical capacities of balance, coordination, flexibility, agility, strength, power, endurance, variable speed and the ability to read (through various senses and experiences), integrate and interpret a wide range of athletic scenarios and challenging situations, and respond efficiently and effectively with confidence, anticipation and optimal decision-making.

Physiological monitoring and sport-specific performance testing

A rationale for the assessment and monitoring of youth athletes might include purportedly identifying talent, predicting future performance, determining strengths and weaknesses, informing the selection process, evaluating the effectiveness of training programmes, monitoring current health and performance, motivating the athlete, enhancing the athlete's (and coach's) understanding of the demands of the sport, and improving present and future performance.[240 241] The sport physiologist, as a member of the athlete-integrated science and medical support team (psychology, biomechanics, medicine, nutrition and physiotherapy) works collaboratively to choose appropriate testing, and to interpret and communicate test results and their application to performance to the coach and athlete. Those who work with youth athletes (coaches, physiologists, physicians, dieticians, etc) should also be knowledgeable of methods for assessing and interpreting the growth and maturity status of youth athletes.

Ethics of testing youth athletes

The ethics of non-therapeutic testing of minors are well-documented.[242 243] Sport physiologists should also be aware of power differentials and coercion in the recruitment process, as it is unlikely that a youth athlete will refuse to participate if the coach gives proxy permission on his/her behalf. To protect all parties, written informed consent (or parental/guardian consent and child assent for children <18 years) should be obtained following an explanation, appropriate to the athlete's level of comprehension, of the purpose, procedures and potential benefits and risks of the tests. It is advisable that a contract clearly outlining the role the sport physiologist is signed by all parties.

Testing youth athletes

Clear rationales and guidelines for the physiological assessment and interpretation of, for example, young people's body composition,[244] muscle strength,[245] aerobic fitness[20] and anaerobic performance[246] are well-documented. A body of knowledge on assessing the kinetic responses to rapid changes in exercise intensity is also emerging.[247] As well, the interpretation of exercise testing data in relation to body size has been comprehensively addressed.[248] To be effective, physiological testing of youth athletes should be as sport-specific as possible. Several well-documented sport-specific tests for adult athletes[249] can be applied to youth athletes. A number of sport-specific field tests designed for youth athletes have recently emerged; but, more research is required to establish their effectiveness.[250–252]

The precise influence of a change in a laboratory or field test outcome on sport performance during youth is unknown. A single change in a physiological variable may have little effect on subsequent performance, as it is often an accumulation of related changes that enhance performance. Moreover, it may take several years of training for some factors related to performance (eg, running economy) to significantly improve, and this is compounded during youth by the asynchronous development of aspects of physiology (eg, the interplay of anaerobic and aerobic metabolism). Although laboratory testing provides a gold standard for physiological variables and enables close control over extraneous factors, sport-specific field tests have greater specificity and ecological validity. Laboratory and field tests can both play valuable roles in monitoring progress, and the balance of use and frequency is best made on a sport-by-sport basis.

IOC RECOMMENDATIONS FOR YOUTH ATHLETIC DEVELOPMENT

While the field of youth athletic development has advanced considerably, new research and validated practical solutions to effectively improve current practices are of paramount importance. There is also an urgency to address the 'culture' of specific sports and youth sports in general, which have become disproportionately both adult and media centred. The much maligned 'specialisation' in youth sports is a related recognised concern that also needs to be addressed appropriately *and* realistically. Appropriate diversity and variability of athletic exposure within a single sport, while supporting sufficient learning of foundational skills and sport-specific technique and biomechanics to minimise injury risk and optimise performance, along with consistent adequate rest and recovery and a balanced emphasis on other priorities (eg, family and school, life skills and social development), *can* be acceptable and healthy, so long as the youth athlete is enjoying and benefitting fully from the experience.

While recognising the broad challenges, and lack of sufficient sport-specific and athletic development stage-specific data, evidence-informed best practices should be emphasised to minimise illness and injury risk, enhance well-being and promote sustainable, enjoyable, long-term athletic development, performance and success in all youth athletes. To this end, the IOC authors recommend these guiding principles:

General principles

- Youth athlete development is contingent on an individually unique and constantly changing base of normal physical growth, biological maturation and behavioural development, and therefore it must be considered individually.
- Allow for a wider definition of sport success, as indicated by healthy, meaningful and varied life-forming experiences, which is centred on the *whole* athlete and development of the *person*.
- Adopt viable, evidence-informed and inclusive frameworks of athlete development that are flexible (using 'best practice' for each developmental level), while embracing individual athlete progression and appropriately responding to the athlete's perspective and needs.
- Commit to the psychological development of *resilient* and *adaptable* athletes characterised by mental capability and robustness, high self-regulation and enduring personal excellence qualities—that is, upholding the ideals of Olympism.
- Encourage children to participate in a variety of different unstructured (ie, deliberate play) and structured age-appropriate sport-related activities and settings, to develop a wide range of athletic and social skills and attributes that will encourage sustained sport participation and enjoyment.
- Make a commitment to promote safety, health and respect for the rules, other athletes and the game, while adopting specific policies and procedures to avert harassment and abuse.
- Across the entire athletic development pathway, assist each athlete in effectively managing sport-life balance to be better prepared for life after sport.

Coaching

- Provide a challenging and enjoyable sporting climate that focuses on each athlete's personal assets and mastery orientation.
- Coaching practices should be informed by research-based developmental guidelines that promote flexibility and innovation, while accommodating individual skills and athletic development trajectories.
- Coaching should be context-specific (eg, participation vs performance focus) and aligned with individual athletic readiness.
- Coaching education programmes should assist coaches in establishing meaningful relationships that enrich the personal assets of their athletes and foster their own intrapersonal and interpersonal skills (eg, reflection and communicative skills).

- Coaches should seek interdisciplinary support and guidance in managing a youth athlete's athletic development, fitness and health, and mental and social challenges and needs.

Conditioning, testing and injury prevention

- Encourage regular participation in varied strength and conditioning programmes that are suitably age based, quality technique driven, safe and enjoyable.
- Design youth athlete development programmes comprising diversity and variability of athletic exposure, to mitigate the risk of overuse injuries and other health problems prompted by inappropriate training and competition that exceed safe load thresholds, while providing sufficient and regular rest and recovery, to encourage positive adaptations and progressive athletic development.
- Maintain an ethical approach to, and effectively translate, laboratory and field testing to optimise youth sports participation and performance.
- Develop, implement and continue to evaluate knowledge translation strategies and resources that will enhance injury prevention and promote health in youth athletes, such as the *Get Set—Train Smarter* injury prevention app developed by the IOC for the 2014 Youth Olympic Games.[253]
- Promote evidence-informed injury prevention programmes, protective equipment legislation and rule changes that are context specific, adaptable and consistent with maintaining the integrity of the sport and participation goals.
- Strictly adhere to a "No youth athlete should compete—or train or practice in a way that loads the affected injured area, interfering with or delaying recovery—when in pain or not completely rehabilitated and recovered from an illness or injury".

Nutrition, hydration and exertional heat illness

- Dietary education for young athletes should emphasise optimal eating patterns to support health, normal growth and sport participation demands, with emphasis on a balanced intake of nutrient-dense carbohydrates, high-quality protein and sufficient dietary calcium, vitamin D and iron.
- Youth athletes and their support personnel should be educated on the risks associated with dietary supplements and energy drinks.
- Emphasise and mitigate the risks of sport-related EDs, DE and RED-S, by raising awareness through education, improving screening and treatment, and implementing applicable rule modifications.
- Education and training on exertional heat illness risks and effective prevention and risk-reduction strategies (including practical preparation, offsetting measures and management and immediate response protocols) and policies should be regularly provided and emphasised to youth athletes, coaches and staff, and others overseeing or assisting with children and adolescents participating in outdoor sports.
- A written emergency action plan and effective response protocols should be in place and practiced ahead of time with trained personnel, as well as readily available facilities on-site for managing and treating all forms of exertional heat illness and other medical emergencies, for all youth athletic activities, especially in the heat.

Sport and sports medicine governing bodies and organisations

- Sport and sports medicine governing bodies and organisations should protect the health and well-being of youth in sport by providing ongoing education, and fully implementing and monitoring practical, and effective, athlete safeguarding policies and procedures in all youth athlete programming.[254–256]
- Youth athlete selection and talent development philosophies should be based on the physiological, perceptual, cognitive and tactical demands of the sport, and a long-term, individually variable developmental context.
- Diversification and variability of athletic exposure between and within sports should be encouraged and promoted.
- Competition formats and settings should be age and skill appropriate, while allowing for sufficient rest and recovery time between multiple same-day contests.

A CALL TO ACTION

We challenge all youth and other sport governing bodies to emphasise awareness, education and implementation of these IOC recommendations and to support the promotion of evidence-informed perspectives to coaches, the athlete entourage, medical providers and administrators involved in youth sports to ensure an enjoyable, safe, healthy and sustainable experience for all participants.

Author affiliations
[1]Youth Sports of the Americas, Birmingham, Alabama, USA
[2]Lemak Sports Medicine, Birmingham, Alabama, USA
[3]Department of Family Medicine, Michael G DeGroote School of Medicine, McMaster University, Hamilton, Ontario, Canada
[4]IOC Medical Commission—Games Group
[5]Children's Health and Exercise Research Centre, St Luke's Campus, University of Exeter, Exeter, UK
[6]Physical Education & Sports Science, National Institute of Education, Nanyang Technological University, Singapore
[7]Queen's University, School of Kinesiology and Health Studies, Kingston, Ontario, Canada
[8]Alberta Children's Hospital Research Institute for Child and Maternal Health Pediatrics and Community Health Sciences, University of Calgary, Calgary, Alberta, Canada
[9]Department of Health & Exercise Science, The College of New Jersey, Ewing, New Jersey, USA
[10]Hallway Consulting, Los Olivos, California, USA
[11]Institut für Epidemiologie, Biostatistik und Prävention, Gruppe Children, Physical Activity and Health (CHIPAH), Universität Zürich, Switzerland
[12]International Gymnastics Federation (FIG), Paris, France
[13]University of Texas at Austin, Austin, Texas, USA
[14]Tarleton State University, Stephenville, Texas, USA
[15]Department of Coaching and Psychology, Norwegian School of Sport Sciences, Oslo, Norway
[16]International Basketball Federation (FIBA), Switzerland
[17]Medical & Scientific Department, International Olympic Committee, Lausanne, Switzerland
[18]Department of Sports Medicine, Norwegian School of Sports Sciences, Oslo, Norway
[19]Department of Public & Occupational Health and EMGO+ Institute, VU University Medical Center Amsterdam, Amsterdam, The Netherlands
[20]School of Human Movement and Nutrition Sciences, University of Queensland, Brisbane, Australia
[21]Division of Exercise Science and Sports Medicine, Department of Human Biology, University of Cape Town, Cape Town, South Africa
[22]Athlete Pathways and Development, Australian Institute of Sport, Bruce, Australia
[23]Orthopaedic Center, Ullevaal University Hospital, Oslo, Norway

Acknowledgements The group acknowledges the contribution and support of IOC Medical and Scientific Director, Richard Budgett, during the IOC Youth Athletic Development Consensus Meeting.

Contributors MFB and MM made substantial contributions to overall and detailed conception, planning, design and coordination of the paper, drafting and critically revising the manuscript, and approval of the final version to be published. NA, MC, JC, CAE, AF, SK, RMM, AMP, TS, JS-B, WvM and JRW made substantial contributions to drafting and critically revising the manuscript. GH, ML and AS contributed to conceptual and content development. LE made a substantial contribution to overseeing manuscript development and overall final approval of the final version to be published.

Competing interests None declared.

Provenance and peer review Not commissioned; internally peer reviewed.

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Michael F Bergeron, Margo Mountjoy, Neil Armstrong, Michael Chia, Jean Côté, Carolyn A Emery, Avery Faigenbaum, Gary Hall, Jr, Susi Kriemler, Michel Léglise, Robert M Malina, Anne Marte Pensgaard, Alex Sanchez, Torbjørn Soligard, Jorunn Sundgot-Borgen, Willem van Mechelen, Juanita R Weissensteiner and Lars Engebretsen

Br J Sports Med 2015 49: 843-851
doi: 10.1136/bjsports-2015-094962