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HEALTHY AND SUSTAINABLE YOUTH SPORTS – THE FUTURE OF YOUTH ATHLETE DEVELOPMENT

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- The wide-ranging benefits of healthy youth sports participation are well-recognized, but many challenges are also prominently evident.
- An emerging new culture for youth sports is underpinned by the increasingly recognized importance to set in place critical foundations early, appreciate individual athletic assets, development needs and trajectories, prioritize realistic long-term objectives, and embrace a wider definition of athletic and sport success.
- From youth sport entry to elite participation, a variable, diversified and balanced development program with an athlete-centered emphasis on health, safety and fun is the best pathway to sustainable athletic and sport success and optimal performance.

INTRODUCTION

The positive impacts on health, fitness, psycho-social and character development and numerous other traits contributing to academic and life success from youth sports participation are widely recognized, and increasingly, the supporting evidence continues to mount (Eime et al., 2013; Merkel, 2013; Mountjoy et al., 2011; Pfeiffer et al., 2006; Silva et al., 2013; Tenforde & Fredericson, 2011; Washington et al., 2001). However, many challenges are also prominently evident for all those closely involved in youth sports – especially for the youth athletes. Time-consuming practices, excessive travel and overloaded competition schedules are far too prevalent and characteristic of the continually growing widespread engagement in overly intense specialization in a single sport. This can place unsustainable physiological, psychological and social demands on the youth athlete that too often leads to a cascade of preventable injuries, burnout and eventual dropout from sport. And with an undue importance and priority on winning, the opportunities for children and adolescents to participate in an environment where the emphasis is on fun, learning the fundamental skills of one or more sports, and nurturing individual athletic assets are challenging to find. Accordingly, there is a growing desire and recognized need for more healthy and sustainable models for youth athlete development – particularly those programs that provide more inclusive, diverse and enjoyable participation and opportunities for fulfillment at all levels of individual athletic skill and achievement.

One such effort to advance a more appropriate and optimal, evidence-informed approach to youth athlete development was convened by the International Olympic Committee (IOC) in November 2014. The outcome of this innovative meeting of experts in the field was a published IOC consensus, and the key tenets of this definitive statement were explicitly featured in the document's guiding recommendations (Bergeron et al., 2015). The breadth of the IOC statement and guidelines includes: a) consideration of individual and constantly changing rates of growth, maturation and development, b) holistic and diverse development of the athlete and person, c) individual and flexible frameworks of athlete development, d) mitigating injury risk and promoting health through sport and, e) advocacy for a wider definition of athletic and sport success. Moreover, there are detailed recommendations on youth sport coaching, conditioning and nutrition, as well as a call to action to youth and other sport governing bodies. Similarly, the National Federation of State High School Associations (NFHS) recently launched their new Essentials Initiative (Bergeron & Koester, 2016; National Federation of State High School Associations, 2016). The initiative's goals as defined during the July 2016 NFHS Essentials Summit are to enhance and expand high school sport participation, reduce injury risk and optimize performance for all student-athletes. With a somewhat different emphasis, more focused scope of topics, and less depth of background and cited clinical research than the IOC Consensus, the NFHS Essentials document and guidelines are more practically specific to daily issues that are central to each targeted stakeholder group – high school athletes, coaches, parents, athletic administrators and state associations. Nonetheless, for all levels of play – sport entry to elite – the emphasis from the IOC and NFHS is on youth sport paradigms that are inclusive, healthy, sustainable and fun.

The central theme of this emerging "new culture" for youth sports is underpinned by the increasingly recognized importance to set in place early the holistic, diversified, functional and healthy sound foundations that foster athleticism, wide-ranging movement, creativity and problem-solving, and character (Côté & Vierimaa, 2014; Faigenbaum & Meadors, 2017; Gulbin et al., 2013; Myer et al., 2011). This is followed by a steady individualized progression of healthy and enjoyable athletic and sport development with realistic, youth-centered long-term objectives being the focus. Done right, the lasting positive effects can extend throughout youth sport participation to adult sport and other gratifying physical activity experiences that encourage a lifestyle of fitness and health (Dohle & Wansink, 2013). This Sports Science Exchange article features selected challenges facing youth athletes and identifies key

considerations and "best practices" for mitigating and offsetting these obstacles – with a focus on the youth athlete that will keep kids in the game. The urgent need for innovative research and discovery, using new advanced technology and analytics from within a multi-domain real-world context, that will extend and deepen our insights to the temporal signatures of healthy and sustainable youth athlete development, is also highlighted.

ATHLETIC AND SPORT CHALLENGES ACROSS ADOLESCENCE

Appropriate individualized youth athlete development, including implementing optimal strategies for training, performance and injury risk mitigation, is challenging. This is in large part, because the developmental base is constantly and uniquely changing (owing to normal physical growth, biological maturation, behavioral development and their interactions) and difficult to accurately assess across the multiple domains and variable stages of athletic and sport advancement (Engebretsen et al., 2010; Malina et al., 2004). Moreover, there are several specific physiological changes and challenges across adolescence that should be deliberately considered in the youth athlete development strategy.

Various components of energy metabolism (e.g., phosphocreatine and muscle glycogen levels) notably increase with age in boys, as do glycogen depletion and muscle lactate buildup during strenuous exercise (Armstrong and Welsman, 2008; Eriksson, 1980). Children are generally well-equipped for long-term moderate-intensity exercise (intermittent or continuous activity characteristic of many team and individual sports), in part, because of their lower ratio of glycolytic (anaerobic) to oxidative enzyme activity and higher relative rates of lipid oxidation and glycogen sparing during exercise (that both decline with maturation through puberty) compared to adults (Armstrong & McManus, 2011; Armstrong et al., 2015; Bergeron et al., 2015). As boys and girls get older, however, percent of peak VO_2 at the lactate threshold decreases. That is, across adolescence, youth athletes have a progressive increase in anaerobic capacity and reliance on anaerobic energy provision during strenuous exercise. While subjective exertion can be equalized, it is recognizably challenging to compare the rate of exercise recovery between youth and adults, because of the complexity of influential differences in exercise performance and output. However, resistance to fatigue and rate of recovery from strenuous exercise, especially during and following high-intensity intermittent repeated bouts in practice or competition, are generally acknowledged to also progressively lessen as a child matures toward adulthood because of the aggregate effect of various changes in recovery kinetics and other contributing physiological and metabolic factors (Armstrong et al., 2015; Falk and Dotan, 2006; Ratel et al., 2006). Yet, it is the older adolescents who are frequently pushed inappropriately harder beyond their ability to tolerate a higher workload (excessive rapid overload) with less concern and allowance for adequate recovery time that is exacerbated by an increasingly lower inherent resistance to fatigue and rate of recovery from demanding physical activity. The misperception is that the older, gifted and motivated athletes can better "handle it." Too often they cannot – and, beyond premature and undue fatigue, the more costly price of repeated overload and overuse is sadly evidenced by halted or ruined sports careers for countless young athletes (Bahr, 2014).

There are also progressively greater challenges in the heat for boys and girls as they advance through their teen years. The long-standing belief that youth athletes have greater difficulty tolerating the heat because of a purported biological maturation-related disadvantage has been clearly countered by more current research and position stands (Bergeron, 2013; Bergeron et al., 2011; Rowland, 2008). However, heat stress, especially when the humidity is high, is not benign, and youth athletes and those overseeing them need to recognize this and suitably accommodate the parallel changing challenges and threats as maturation and athletic development evolve. As a youth athlete physically and physiologically develops and matures, more heat is produced from a greater muscle mass and more mature sweat glands yield increased sweat production during vigorous physical activity (Falk et al., 1992). This results in a greater thermal load and an increase in sweat fluid and electrolyte (primarily sodium) loss. Accordingly, total body water and exchangeable sodium deficits from extensive sweating can be comparatively more substantial in mid- to late-teen athletes. Moreover, longer and physically demanding workouts and contests are characteristic of more physically developed, fit and skilled older adolescent athletes. Potential greater levels of muscle damage and various physiological carry-over effects could increase thermal strain and other clinical risks during the next training session or contest (Fortes et al., 2013). While coaches and event administrators should always provide adequate between-bout/session recovery time (especially in the heat), a greater accommodation for recovery should be anticipated and liberally applied, as young athletes get older, training and competing repeatedly at a higher level. Despite these prevalent heat-related challenges and threats, if youth athletes are well-prepared and other modifiable contributing risk factors are considered and appropriate offsetting measures are applied, most healthy children and adolescents can safely participate in outdoor sports in the heat (Bergeron, 2015; 2017).

It is well-recognized that participation in sports with high-impact loading (e.g., gymnastics, volleyball) or odd (variable)-impact loading (e.g., soccer, basketball, tennis) can have an overall positive effect on bone health in young athletes through higher bone mineral composition, mineral density and enhanced geometric properties in a sport-specific loading pattern (Tenforde & Fredericson, 2011). And these benefits are bolstered when dietary calcium and vitamin D requirements are regularly met (Abrams, 2011). However, sport-related overuse injuries appear to be more prevalent during puberty and the adolescent growth spurt (DiFiori et al., 2014; van der Sluis et al., 2014). A contributing factor for a greater vulnerability to stress fractures during the period of peak linear growth is the coincident dissociation between bone expansion and bone mineralization (Faulkner et al., 2006). Unfortunately, this is also the time

when many parents and coaches feel a falsely opportune sense of urgency to amplify intensive training, practice and competition loads for their "select" athletes. The concomitant greater potential for overuse-related injury suggests otherwise. That is, it would be prudent and wise to reduce (or at least maintain) training and competition intensity, frequency, and/or volume and instead focus on further developing foundational skills and sound biomechanical technique, while going through this particularly vulnerable stage of physical development. Not only will this approach reduce stress fracture and certain other overuse-related injuries risk, but the emphasis on developing skills and technique will help the athlete hold up under the demands of future training and competition.

These maturational and related physical and physiological changes and challenges, individually and collectively, facing developing youth athletes can measurably increase individual injury risk if training, practice and competition loads, and scheduling and recovery strategies are mismanaged. For example, rapidly increasing the training or competition load to accelerate "getting into shape" or to enhance the level of play can quickly lead to undue fatigue, poor performance and a variety of potential injuries (Bahr, 2014; Best et al., 2006). Moreover, adequate rest and recovery between training, conditioning and practice activities (e.g., sets, drills and other bouts of exercise) and sessions, as well as competitions, are vital in minimizing injury risk and achieving or maintaining optimal performance. Rest and recovery (along with various influencing and integrated factors such as proper nutrition and sleep) are central to a variety of regenerative mechanisms and positive adaptation to the applied sport-specific and individual exercise/training stimulus (Minett & Costello, 2015; Peake & Gandevia, 2017). But, the process (and youth athlete) breaks down when there is a short-term or chronic imbalance between training and conditioning, practice and/or competition, and rest and recovery, especially when the young athlete is repeatedly subjected to demanding physical (through high intensity, volume or frequency of exposure) and psychological loading and stress (Bergeron et al., 2015; DiFiori et al., 2014). Youth sports should not be unduly straining, and coaches and parents need to also recognize and promptly respond to the early warning signs (e.g., complaints of pain or undue soreness, uncharacteristic fatigue and poor performance) indicating evolving athletic overload, overuse or apparent injury.

Numerous problems can be averted or minimized by also ensuring a state of sport readiness. This involves closely matching physical, athletic and psycho-social/emotional development, as well as interest and commitment, to the demands and expectations of the sport and environment, for each youth athlete. Coaches, parents and youth athletes all have a responsible role in managing proper preparation and readiness, and appropriately adjusting their approach and behavior to effectively adapt to the changing sport stresses, periods of vulnerability, and injury risks associated with workload and rest/recovery cycles. This is especially important during puberty and the adolescent growth spurt. Without proper accommodation, a variety of detrimental consequences can readily result from an unintended unsustainable overload or imbalance of physical, physiological, psychological, academic, social, and sport demands and expectations.

MONITORING TRAINING AND DEVELOPMENT

At the core of youth athlete development are numerous entry programs to introduce the fundamental skills, rules and basic strategies of a sport. These are supplemented by a variety of school-based and community settings and facilities, volunteers and professionals, organizations, leagues, and competition formats providing progressive instruction and focused plans and opportunities for learning and achieving new levels of athletic and sport-specific competencies and success. Each early stage and advanced model is usually complemented by various practice/training strategies and competition progressions designed and intended to enhance athletic attributes and sport performance and achievement across the sequential athlete developmental phases (Gulbin et al., 2013). While this is a highly integrated, multi-dimensional, complex, individual and uncertain process, there remains a common belief in and commitment to traditional assumptions and practices regarding generalized athlete responses and adaptation trajectories during pre-defined periods of training and conditioning, practice and competition across age-related timeframes. Moreover, it is common for these purported "proven" specific training methods to be based simply on personal experience and/or observation of others. It is further expected that periodic planned manipulation of program variables (e.g., training and practice mode, intensity, frequency and volume) over time can predictably advance athlete and sport development similarly across individuals and youth populations (Naclerio et al., 2013). Although this simplified approach is convenient, the efficacy is generally not scientifically supported or empirically validated (Ford et al., 2011; Kiely, 2012).

Appropriate variation in sport-development activities (training and conditioning, practice and competition) is key for reducing injury risk, maintaining athlete focus and engagement, and optimizing athletic progress and sport performance (Bergeron et al., 2015; DiFiori et al., 2014). However, individual athletes respond uniquely to training and conditioning, practice and competition formats, loads and schedules. Accordingly, the vital component to all youth athlete development programs is sensitive and early detection (primarily through careful observation of and close listening to each athlete) of advancement opportunities and emerging threats, and the prompt response with relevant, suitable and specific individualized redirection (Kiely, 2012; Weissensteiner, 2015).

SAFELY NAVIGATING SPORT SPECIALIZATION

Encouraged by escalating and widespread competitiveness, professional-like development programs and support teams, and media and marketing directed to young athletes and parents, youth sport is increasingly characterized by an early, intense single-sport focus. This pathway is often reinforced by rigorous sport-specific physical training

and year-round, high-frequency competition with insufficient allocation of time for rest, regular recovery and other non-sport activities important to developing youth. Not surprisingly, the cost for many boys and girls is illustrated by the disturbing prevalence at all levels of youth sports of preventable sport-related injuries and health problems, including overuse injury, overtraining and burnout (Bridge & Toms, 2013; DiFiori et al., 2014; Jayanthi et al., 2013, 2015).

Especially at entry to and during the early stages of sport participation and learning, diverse athletic exposure and sport sampling has recognized advantages. These include enhanced motor development, more firmly established foundational movement skills, and improved athletic capacity. This approach can arguably also reduce injury risk and increase the opportunity for a child to discover the sport(s) that he/she will enjoy and possibly excel at (Bergeron et al., 2015; Côté & Vierimaa, 2014; Goodway & Robinson, 2015). However, claims abound citing how select high-profile athletes got to the top because they were multi-sport athletes in their youth and through high school (Gardner & Hallenbeck, 2017). While there are clear opportunities to pick up a wider range of athletic and social skills from varied sport exposure, is multiple-sport participation the determinant in boys and girls exceling as athletes, or do the better athletes play multiple sports simply because they can? Would the level of athletic and sport success be similar or even better had these cited examples of popular athletes specialized early in their primary sport the right way? That is by following a progressive, long-term, healthy, supportive, sustainable, diversified, balanced, holistic and individually responsive training and competition model that fosters fully developed, functionally sound and movement-based athletes. Current youth sport development and specialization schemes are too often not appropriately designed or applied, while recognizing and being responsive to individual variability in readiness, needs, tolerance and times of developmental (physical and psychological) vulnerability. Numerous examples are unfortunately evident where youth sports academies and programs are dysfunctional and counterproductive in fostering enjoyment and sustainable balanced athletic success. In these scenarios, it would not likely be beneficial or benign to go from one dysfunctional sport to another, even seasonally each year. Simply put, multi-sport participation per se may not be the solution to enhancing athletic and sport development or mitigating injury risk, especially if each sport program is not practically individualized and managed well.

Unquestionably, there is great value in diversified healthy sports experiences for youth entering sport and through the foundational stages and sometimes beyond. But, it is important to not give in to an oversimplified binary solution – that is, multiple-sport participation is healthy for kids, while single-sport specialization is not. The recent IOC Consensus on Youth Athletic Development emphasizes that "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 minimize injury risk and optimize performance, along with consistent adequate rest and recovery and a balanced emphasis on other priorities (e.g., 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" (Bergeron et al., 2015). From this perspective, sport specialization can be done in a healthy, sustainable and rewarding way for those youth athletes who choose and love a certain sport… even beginning at an early age.

HOW CAN TECHNOLOGY AND ADVANCED ANALYTICS HELP?

The traditional approach to applied sport science research (and youth athlete development, performance and injury risk research is no exception) is commonly based on a hypothesis of "convenience." That is, depending on available equipment, personnel support, experience and available funding, a hypothesis is developed. This is followed by a process of reverse engineering to determine a viable methodology to prove or dismiss the research question(s). Unfortunately, this too often leads to an experimental setting that is limited and observations and conclusions that are far removed from a more real-world context.

Complex human systems in youth sports (or other scenarios) cannot be fully interpreted by evaluating discrete measures, especially when the young athletes under observation are removed from the natural environment of daily multiple stressors and wide-ranging influencing factors. Moreover, with the natural selectivity process of sport, research generally focuses on the choice young athletes. Accordingly, far less is known about the characteristics and circumstances of the injured boys and girls, or those who are systematically cut or who simply drop out. More comprehensive, real-world, multi-domain integrated evidence not only provides greater insights and practical perspectives, this approach also helps to close the gap between research discovery and practical acceptance and uptake of related recommendations and guidelines.

With the rapid evolution of advanced technology (including sensors, imaging and high-performance computer systems) and analytics, efficiently and effectively collecting, managing and analyzing massive amounts of structured and unstructured information from multiple (even disparate) domains is no longer the limiting factor. Moreover, artificial intelligence (AI)-driven, machine learning algorithms and advanced analytics can be expertly guided to reveal valuable new insights and a deeper appreciation for the true temporal signatures (pace and pattern) in youth sports specific to health, injury risk and athletic performance within and across disciplines.

THE FUTURE OF YOUTH ATHLETE DEVELOPMENT

The recent IOC consensus and new NFHS initiative have established the definitive tenets of healthy and sustainable youth sports participation and athlete development (Bergeron & Koester, 2016; Bergeron et al., 2015; National Federation of State High School Associations, 2016). While the scope of recommendations featured in each document is extensive, with explicit details and categorized organization directed to respective concerns and stakeholders, there are several notable

overarching principles that underscore the primary concerns and considerations outlined here:

- Sustainable sport development takes time, and the youth sports experience will always be on an individual trajectory and evolving on an unpredictable continuum.
- Early achievement or struggle is not always predictive of future performance, engagement or enjoyment.
- Fitness, athleticism, skill, and physical and psychological resilience must adequately support the expectations and demands of sport training and competition.
- Appropriate variation and diversity in progressively introduced athletic loading and sport-development activities, whether across multiple sports or within one, with adequate rest and recovery between training, conditioning and practice activities and sessions, as well as competitions, is key for reducing injury risk and optimizing performance.
- Coaches and parents need to recognize and promptly respond to the early warning signs indicating evolving athletic overload, overuse or apparent injury, and no youth athlete should train or compete hurt.
- Above all, youth athlete development programs and priorities must be youth athlete-centered.

The tenets of healthy and sustainable youth sports participation and athlete development described here (and recognizing others who similarly embrace and implement these principles) are already setting new best practices standards. A growing volume of increasingly higher quality, readily available and intelligently aggregated, analyzed and interpreted information is also rapidly changing the way youth sports are described and examined. The breadth and depth of these data coupled with rapidly evolving new advanced technology and analytics will be instrumental in better understanding and visualizing patterns across youth maturation and development never conceived previously. The necessary culture change, where these best practices, realistic expectations and acceptance of a wider definition of athletic and sport success for all youth athletes are deeply engrained, is not an easy task. However, we are beginning to witness a new paradigm for advanced discovery and transformational changes that will minimize preventable injury risk, promote more inclusive and sustainable athletic participation, foster health and enjoyment, and optimize performance and a wide range of rewarding achievement for all youth involved in sports.

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