Long-term Athlete Development and Trainability during Childhood: a Brief Review

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Introduction

Maximising the development of young athletes is the goal of many coaches and sports systems, with the aim to ultimately increase future sporting success at the elite senior level.[39] Consequently, the requirement to identify methods by which talent can be nurtured is of paramount importance for coaches and practitioners.[25] Although talent development is recognised as a multidisciplinary concept, encompassing the need for biological, social and psychological factors to be considered,[1] talent development programmes predominantly focus on the development of physical athletic abilities throughout childhood.[15] Such an approach has been widely criticised in contemporary literature[1,4,25,40] due to the need to promote the holistic development of youth athletes. However, this should not detract from the importance of maximising physical fitness development of young athletes, but simply act as a reminder that coaches should also consider other aspects of talent development.

Developing the fitness and performance of child athletes can be a complex issue; factors such as the growth and maturation of anatomical, neurological, hormonal and musculoskeletal structure and function should be considered in the planning and design of physical training programmes.[37] Although long-term athlete development models are not a novel concept (e.g.[11,42]), only recently have attempts been made to incorporate the interaction of training, growth and maturation within a model.[3] In the popular Long-Term Athlete Development (LTAD) model of Balyi and co-workers,[2,3] training principles are combined with a scientific knowledge of childhood development. The LTAD model prescribes the objective measurement of individual maturation rates, via measures such as peak height and peak weight velocity, to allow training to be associated with the timing and tempo of maturation. The LTAD model has provided a greater scientific basis to the structure of training programmes for child athletes, and has advanced previous practice based around chronological age classification, which has been suggested to be inherently flawed.[25]

The suggested link between childhood development and training responsiveness presented in the LTAD model is an appealing concept, as it provides coaches with a prescriptive model of how to maximise physical fitness development. Consequently, the LTAD model has received global popularity and has been adopted by most

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National Governing Bodies within the UK and is promoted by Sports Coach UK. Although contemporary coaching texts have advocated the implementation of the LTAD model,[4,5] academic reviews of the model have been much more critical.[1,25] Criticism of the LTAD model is based on the lack of empirical evidence, particularly longitudinal data, to support claims suggested by the model. These claims include that there are "windows of opportunity" when training gains can be maximised and that a failure to exploit these windows will limit future potential. The strength and conditioning coach should have an awareness of the limitations of the LTAD model and an appreciation that this model should continually be evolved and adapted with advancing scientific knowledge. An additional criticism is the narrow focus of the model, which only identifies five components of fitness to be developed during childhood; skill, suppleness, speed, stamina and strength.[25,34]

The theory of long-term athlete development: accelerated adaptation and "windows of opportunity"

Development during childhood generally follows a non-linear process, with periods of little or no change interspersed by periods of rapid development, with the latter reflecting a process of accelerated adaption. Such a process can easily be observed with height, but is also clear in the development of components of physical fitness.[37] In a comprehensive review of childhood literature, Viru *et al*.[51] identified two periods of rapid development either side of the onset of puberty in various components of fitness (endurance, strength, explosive strength and speed). In the 'pre-adolescent spurt' boys and girls rapidly improved all areas of fitness from five to nine years old, whereas in the 'adolescent spurt', the timing of gains were observed before (speed), around (endurance) and post (strength and explosive strength) the occurrence of peak height velocity (PHV). Subsequently, the preadolescent spurt has been associated with rapid neural development and the adolescent spurt with a trigger provided by the onset of sexual maturation and subsequent alteration to the endocrine system.[25]

Accelerated improvements in physical fitness during childhood will be underpinned by the rapid development of neural, biological and hormonal systems.[37] It is believed that while these systems are experiencing rapid natural development, they will be most sensitive to extraneous influences, such as the environment, nutrition and training.[46,51] Consequently, Balyi and co-workers[2,3] present these periods of naturally occurring accelerated adaptation as a "window of opportunity" when training gains can be maximised. In fact, it is claimed in the LTAD model that a failure to fully utilise these windows will limit future potential, although this is a claim that has previously been questioned[1,25] and is almost impossible to investigate experimentally. Therefore, it must be recognised that the LTAD model is a theory driven model that assumes an association between natural developmental rates and training responsiveness. Although the theory may appear robust, practice should be evidence-based wherever possible.

Trainability during Childhood

While the LTAD model presents windows when it is suggested a child will be more responsive to specific types of training, direct evidence to support this claim is limited. Ideally, research would examine the training gains made by child populations differing in age and maturation to successfully identify developmental interactions with training. The existence of such research is limited and is experimentally difficult to control (for example to match training loads across populations). Consequently, coaches, practitioners and scientists are largely limited to considering a range of evidence provided by discrete cross-sectional studies that examine some aspect of training in childhood.[25] A brief review of the trainability of the major components of fitness during childhood is provided below.

Endurance

Growth related changes in the central and peripheral cardiovascular system, muscle function, cellular capacity, body composition and metabolic capability will influence endurance development during childhood and will interact with training stimuli.[43] Conflicting results have been reported with regards to trainability of endurance in childhood. For instance, Weber *et al*.[53] reported greater responsiveness to training in the years surrounding PHV, as opposed to at the time of PHV, while Rowland[43] identified large training gains in the years prior to PHV. Variations in findings are inevitably associated with experimental design, often failing to control for factors such as initial fitness, magnitude of the training stimulus and genetics.[25] Consequently, Ford *et al*.[25] recently concluded that current evidence limits direct investigation of a window of opportunity for endurance training, meaning that current application of any window by practitioners is inappropriate. Baquet *et al.*[6] provided a comprehensive review of the trainability of maximal oxygen uptake during childhood, although their study highlighted the lack of studies incorporating participants around the time of PHV, the exact period when a window of opportunity is suggested to exist.[3] The review of Baquet *et al*.[6] revealed that pre, circum and post-pubescent children could all make similar gains in peak oxygen uptake. Additionally, factors such as initial fitness, training intensity, duration and frequency of training were all shown to influence the training response. It is possible that the adaptations which facilitate any improved function or performance vary with maturation, so whereas all children may be able to make gains, the training-induced adaptations which underpin these gains may vary. Unfortunately, research examining the biological mechanisms underpinning training adaptations is extremely sparse. Given the above, the authors of this review agree with the recommendations of both Baquet *et al*.[6] and Shephard,[48] that endurance should be actively developed throughout childhood and adolescence.

Speed

Windows of opportunity for developing speed are associated solely with chronological age in the LTAD model, probably aligned to the role of central nervous system development in speed gains.[12] However, it seems likely that maturational changes in muscle-tendon size, structure and function will also influence the training response.[25,51] In a recent review, Rumpf *et al.*[44] examined the effect of maturation and different training modalities on trainability during childhood. From the limited number of studies available, (n = 15) the authors concluded that children pre-PHV benefited most from plyometric and then sprint training, children circum-PHV benefited most from plyometric and then strength training, and children post-PHV benefited most from combined training methods (e.g. strength + plyometric training) and then strength training alone. The findings from the Rumpf *et al*.[44] review partly support and partly refute the theory of windows of opportunity. The review demonstrated that speed was a trainable entity throughout childhood, suggesting there are no specific windows of opportunity. However, the differential response to different training regimes with maturation suggests that training adaptations appear to align themselves to mechanisms that are believed to underpin natural development at different stages of childhood. Children who were pre-PHV benefited most from training that has a primarily neural basis, whereas children post-PHV benefited from training that aims to strengthen the muscle and adapt morphological characteristics. However, the fact that some training-induced benefits in speed that are linked to maturation can be rapidly lost with a period of detraining,[13,26] questions the need to maximise gains within a specific window. Instead, it is more likely that training history needs to be continually accumulated to maintain and progress any training benefits achieved during each stage of development.

Strength

Strength has been defined as a multifaceted, performance-related fitness component that is underpinned by muscular, neural and mechanical factors.[20] In the LTAD model, a window of opportunity for strength development is given in the period immediately post-PHV, which would coincide with peak weight velocity and a time when children are naturally experiencing rapid gains in muscle mass.[37] Therefore, it seems likely that the LTAD model is actually presenting a window of opportunity for hypertrophy rather than strength development. A focus on hypertrophy would be a limited perspective as the assumption that muscle cross-sectional area is the most important parameter in strength development throughout childhood and adolescence does not hold when examined with other variables.[19] For instance, increases in stature and limb length and subsequent changes in the muscle movement arm will have a substantial affect on strength development.[54]

It seems logical to speculate that the absence of circulating androgens will limit the ability to make training-related increases in muscle size prior to adolescence, although direct evidence to support this statement is limited. However, the belief that strength gains are not achievable with training prior to the biological trigger provided by sexual maturation[32] seems unfounded. For instance, it has been demonstrated that children as young as five can achieve strength gains with training.[23] Granacher *et al*.[30] reported that gains in leg strength in pre-pubescent children following a 10-week training programme were neural in basis, rather than being caused by hypertrophy. Even though these findings are largely as expected, it should be noted that the authors included 3-4 minutes rest between sets, and given children are known to recover rapidly, it seems such a programme

would provide an insufficient stimulus to cause hypertrophy. Of three experimental studies available that have examined the influence of maturation on training related strength gains, two reported no maturational effect,[33,41] while one, reported maturational influences that differed with the muscle group tested.[52] Consequently, these limited studies provide little support for the window of opportunity for strength given in the LTAD model, although it may be more justified if solely focused on hypertrophy.

Power

Although power is deemed a prerequisite for successful performance in many sports, it is absent from the LTAD model. This may be because the component parts of power (speed and strength) are included in the model. However, given that the goal of many training programmes is to specifically increase power, arguably this should be a key component of any long-term strength and conditioning plan. A strong relationship (r=0.95) has been reported between growth rates of 11-13 year old children and vertical jump performance, which is an indirect measure of lower limb power.[16] Rapid improvements in muscle power during adolescence have therefore been associated with maturational influences.[10] Unfortunately, there are very few studies which have specifically examined the trainability of power with respect to age and maturation. This has led to the conclusion that it is difficult to identify whether a window of opportunity exists to maximise power development.[25] What seems clear is that younger and older children can experience training induced gains in power.[14] Chiodera *et al*.[17] reported that boys and girls aged 6-10 years old were able to make significant improvements in long-jump distance following a 33-week training programme. Similarly, a 10-week plyometric training programme has been shown to significantly increase the upper and lower body power of adolescent basketball players.[45] A study by Lloyd *et al*.[35] found plyometric training could improve reactive strength and leg stiffness in as little as four weeks in 12 and 15 year old boys. Consequently, evidence suggests that power is, at least to some extent, trainable throughout childhood.

Fundamental Movement Skills

The development of fundamental and sport-specific movement skills enhances physical literacy, and enables children to move confidently in a wide range of physical activity, rhythmic and sporting situations.[31] Fundamental movement skills provide the basic building blocks for developing physical literacy, and incorporate activities designed to enhance stability (e.g. balancing, twisting, turning), locomotor skills (e.g. walking, running, hopping) and manipulative skills (e.g. throwing, catching, kicking).[31] Development of fundamental movement skills is typically considered from birth until 12 years of age,[27,31] which is reflected in the LTAD model. Accelerated gains in movement skills may coincide with peak rates of brain maturation in children,[25] with motor skill ability related to brain development in childhood.[24] However, there is limited evidence regarding the influence of age and maturation on the trainability of movement skills. Research in music shows that continued piano practice is associated with cerebral development.[8] The level of development is correlated to the total amount of practice time. Children, adolescents and adults all experience gains in cerebral development but the underpinning mechanisms associated with these gains vary dependent on maturation.[8]

In a more sport-specific context, fundamental movement skill interventions have proven successful in the short-term at improving motor proficiency, but follow-up examination of long-term improvements in motor abilities and physical activity levels is equivocal.[7,29,49] These results question the long-term benefits achieved by discrete training periods during "windows of opportunity" and suggest a need to continually reinforce and progress movement skills with training. While intuitively it seems appealing to accept that movement skills are more easily learnt during the first decade of life, it is difficult to find direct evidence to support this. What research does seem to support is that fundamental movement and sports-skills should be systematically coached to children.[27,49] Additionally, fundamental movement skills need to be learnt during childhood to prevent a proficiency barrier impeding progression to the learning of more complex skills.[28] While older children and adults may still be receptive to learning new movement skills it seems desirable to promote the development of fundamental movement skills from a young age.

Training Volumes

How much training a child athlete should engage in is a contentious issue. The LTAD model of Balyi and co-workers[2,3] adopts the philosophy of Ericsson,[21] believing that it takes 10,000 hours or 10 years of deliberate practice to achieve mastery and reach the elite level. Recently, Moesch *et al*.[38] used athlete recall to examine childhood training volumes in elite and near-elite senior athletes involved in sports measured in centimeters, grams and seconds; sports that would be considered to have a strong association with physical development. Their research revealed that those who reached an elite status trained less in earlier childhood than those who failed to reach an elite level, but increased their training more than their non-elite counterparts in late adolescence. Although only a single study, the research of Moesch *et al*.[38] suggests an important role for the organisation of training; with a preference towards late specialisation and a crucial period for increasing training volumes in the mid teenage years to progress to an elite level. This finding supports the model of Côté and Hay,[18] which suggests youngsters sample a variety of sports between 6-12 years old, begin to specialise in a chosen sport(s) between 13-15 years old and then invest heavily in a sport from 16 years onwards if committed to achieving excellence. However, it should be noted that this approach may be less applicable to those sports considered to be early specialisation sports.

Practical Applications: Implementation Of The Youth Physical Development (YPD) Model

In an attempt to address the limitations associated with current LTAD theory, the authors have recently proposed a new model for long-term athletic development, termed the Youth Physical Development (YPD) model.[34] The new model was designed to enable a more holistic development of the young athlete, including those qualities already identified by previous models, but also other important aspects of human performance, including mobility, agility and power. The YPD model takes into account the most up-to-date research, which suggests all fitness components are trainable throughout childhood. The model acknowledges that prepubertal adaptations in performance will be primarily attributed to neural developments, while those occurring around the onset of, during, and post-puberty will be a combination of both neural and architectural changes.[34] Central to the model is a large emphasis on the development of muscular strength and movement competency throughout both childhood and adolescence, which challenges previous LTAD theory.[3] Muscular strength development via resistance training has previously been associated with physical performance enhancement,[22] improving markers of health and wellbeing,[9,47] and reducing the risk of sport-related injury.[50] Furthermore, motor skill competency has previously been associated with higher physical activity levels and improved well-being.[36] Consequently, these qualities are viewed as the major fitness commodities within the YPD model.[34]

Summary

Current practice in developing the physical fitness and talent of young athletes in the UK is heavily influenced by the Balyi LTAD model. While the introduction of the Balyi model provided a greater scientific basis for the training of children it has to be recognised as a largely theoretical model. The content of the Balyi LTAD model has remained largely unchanged over the last decade, although it has come under more scrutiny in recent academic reviews.[1,25] A body of evidence is currently not available to demonstrate that children are more responsive to training during "windows of opportunity", that failure to maximise development during these windows will limit future potential, or that it takes 10,000 hours or 10 years of training to reach the elite level. Consequently, some skepticism has to be applied. From the various discrete studies that are available on training responses during childhood, there is a promising trend that suggests children of all ages and maturation can make training induced gains in fitness and this is reflected in the contemporary Youth Physical Development model.[34] The mechanisms that underpin these gains may vary with maturation, but this is a speculative suggestion. Consequently, the strength and conditioning coach can have a positive impact on developing all aspects of fitness throughout childhood, although consideration must be given to the developmental status of the child and likely training adaptations when designing the relevant training programmes.

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