The Youth Physical Development Model: A New Approach to Long-Term Athletic Development

Rhodri S. Lloyd, PhD, CSCS*D[1] and Jon L. Oliver, PhD[2]
[1]Faculty of Applied Sciences, University of Gloucestershire, United Kingdom; and [2]Cardiff School of Sport, Cardiff Metropolitan University, United Kingdom

SUMMARY

THE DEVELOPMENT OF PHYSICAL FITNESS IN YOUNG ATHLETES IS A RAPIDLY EXPANDING FIELD OF INTEREST FOR STRENGTH AND CONDITIONING COACHES, PHYSICAL EDUCATORS, SPORTS COACHES, AND PARENTS. PREVIOUS LONG-TERM ATHLETE DEVELOPMENT MODELS HAVE CLASSIFIED YOUTH-BASED TRAINING METHODOLOGIES IN RELATION TO CHRONOLOGIC AGE GROUPS, AN APPROACH THAT HAS DISTINCT LIMITATIONS. MORE RECENT MODELS HAVE ATTEMPTED TO BRIDGE MATURATION AND PERIODS OF TRAINABILITY FOR A LIMITED NUMBER OF FITNESS QUALITIES, ALTHOUGH SUCH MODELS APPEAR TO BE BASED ON SUBJECTIVE ANALYSIS. THE YOUTH PHYSICAL DEVELOPMENT MODEL PROVIDES A LOGICAL AND EVIDENCE-BASED APPROACH TO THE SYSTEMATIC DEVELOPMENT OF PHYSICAL PERFORMANCE IN YOUNG ATHLETES.

INTRODUCTION

In recent times, scientists and coaches have shown an increasing interest in the long-term development of young athletes (7,23,30,44,63,65,80,100,102). Enhancing the physical abilities of children throughout childhood and adolescence to maximize athletic success at an adult age is not a novel concept, as evidenced by earlier youth-based training programs (20). Researchers have previously documented the importance of not treating children like "miniature adults" owing to clear differences in physical growth and stature (39). Therefore, the content and delivery of youth strength and conditioning provision should be markedly different from that of fully matured adults.

The long-term athlete development (LTAD) model (7) takes into consideration the maturational status of the child and offers a more strategic approach to the athletic development of youth. The LTAD model suggests that there exist critical "windows of opportunity" during the developmental years, whereby children and adolescents are more sensitive to training-induced adaptation (7). The model also states that a failure to use these windows will result in the limitation of future athletic potential (7). However, this concept is largely theoretical and lacks supporting longitudinal empirical evidence (4,44,84). This article will present a new model, which provides a more considered and evidence-based approach to the long-term development of young athletes. The model will demonstrate that most, if not all, components of fitness are trainable throughout childhood and will question some preconceptions of current LTAD theory.

THE EVOLUTION OF LTAD THEORY

Early attempts at objectifying the process of LTAD were based on research that highlighted distinct phases of learning that characterized the development of elite performers: the early years, the middle years, and the later years (18). This early work was extended by Cote (32) who, after interviewing elite junior athletes, identified 3 distinct sport-specific stages of development: the sampling years (ages 6–12), the specializing years (ages 13–15), and the investment years (ages 16+). A common problem with these models is that they are classified in accordance with chronologic age, an approach that has previously been deemed flawed (44),

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owing to differential rates of development of chronologic age and biologic maturity (57,68,108).

Consequently, a more comprehensive LTAD model was introduced that attempted to address the interaction between growth, maturation, and training (7). The model suggests that measures of height and weight are routinely collected to be able to identify peak height velocity (PHV) and peak weight velocity (PWV), which reflect individual maturation rates (68). PHV refers to the maximum velocity of growth in stature and has been used to characterize developments in performance relative to the adolescent growth spurt (68). PWV is a phase of development characterized by rapid increases in muscle mass as a result of increasing sex hormone concentrations (44). By objectively measuring the rates of change in height and body mass, it is suggested that children can be trained according to biologic status as opposed to chronologic age (7).

WINDOWS OF OPPORTUNITY

A review article by Viru et al. (110) examined developmental literature and identified the existence of naturally occurring periods of accelerated adaptation for a range of biomotor qualities. A preadolescent spurt was highlighted for strength, speed, explosive strength, and endurance, in both boys and girls (110). It was suggested that age-related developments in neural properties were responsible for the prepubertal window, characterized by increased intramuscular and intermuscular coordination and improvements in motor control programs (110). An adolescent spurt was also identified in the review, but this differentiated between biomotor qualities (110). Maturity-related adaptations are typically the result of increased androgen concentrations, fiber-type differentiation, resting adenosine triphosphate, and creatine phosphate levels and further architectural development of musculotendon units (73).

Viru et al. (110) identified that spurts in speed and endurance occurred before and around PHV, respectively, whereas accelerated gains in strength qualities occurred after PHV (110). Using PHV as a key reference marker of maturation, the LTAD model proposes that these periods of accelerated adaptation offer windows of opportunity where training responses will be maximized (7). In the LTAD model, it is assumed that these periods of rapid natural development represent a time of increased sensitivity to training, although empirical evidence supporting this suggestion is lacking (44). Furthermore, according to the LTAD model, should a child not engage in the appropriate training during the specific window, then their ceiling potential may never be reached. This concept would appear to be too simplistic and has recently been questioned by researchers (4,44,85). Conversely, research would suggest that most fitness components are trainable throughout childhood and should not be restricted to specific "windows" at various stages of development (3,44,94). Another weakness of the current LTAD model (7) is that its inclusion of stamina, suppleness, speed, strength, and skill presents a somewhat limited approach to the holistic development of young athletes. Despite the importance of power, agility, and hypertrophy to human performance (56,98,120), no guidance is offered as to when and why these qualities should be trained throughout childhood and adolescence.

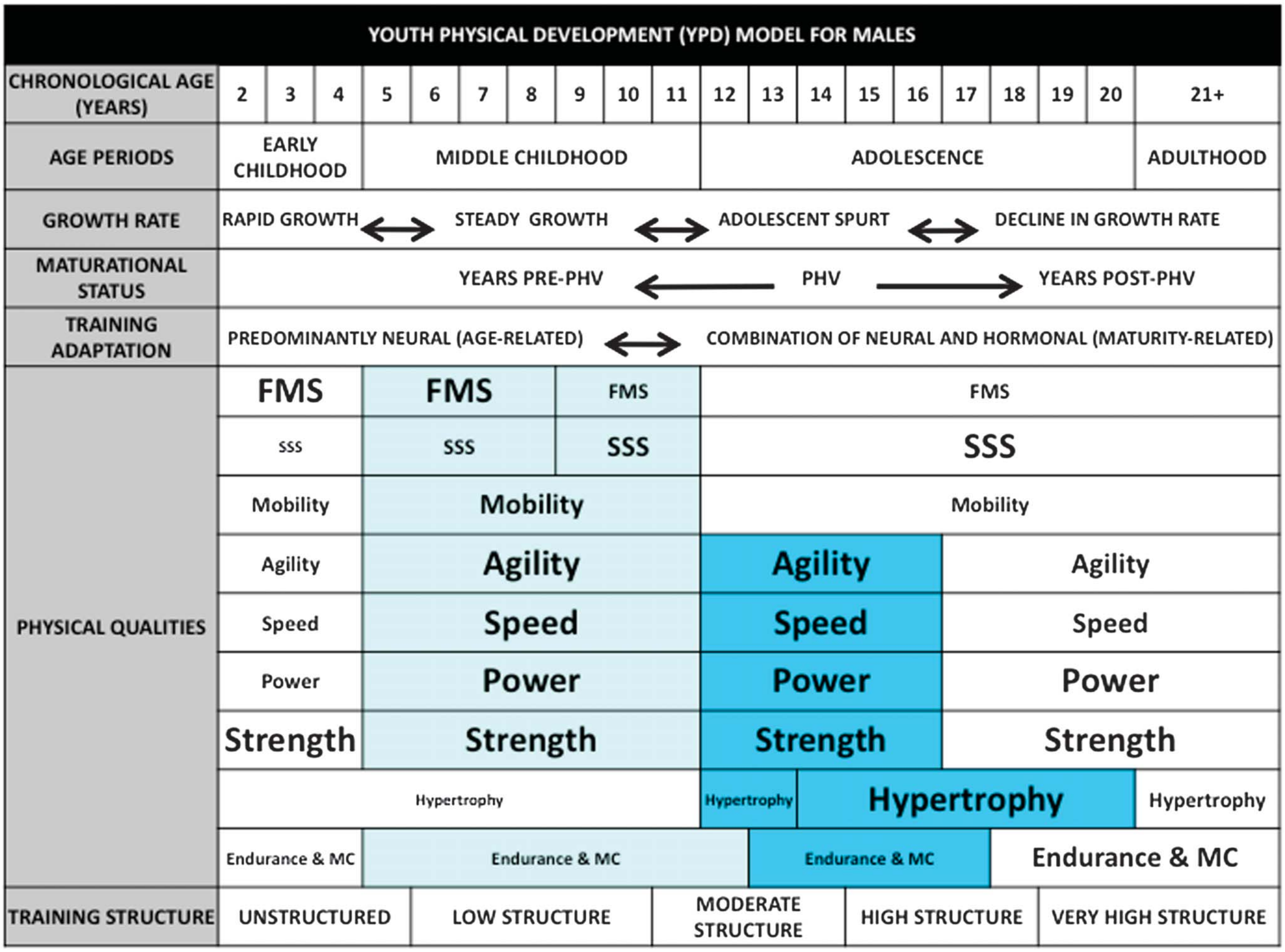
THE YOUTH PHYSICAL DEVELOPMENT MODEL

Given the limitations of previous athletic development models, the present article introduces a new alternative model that encompasses athletic development from early childhood (2 years of age) up to adulthood (21+ years of age). The model has been titled the Youth Physical Development (YPD) model and offers a comprehensive approach to the development of young males (Figure 1) and females (Figure 2), respectively. It is expected that the new model will provide strength and conditioning coaches, sports coaches, physical educators, and parents with an overview of total physical development, while identifying when and why the training of each fitness component should be emphasized.

Within the model, training emphasis is highlighted by increasing font size (i.e., the greater the font size, the more important it is to train for that fitness quality). For example, the model shows that a 12- to 13-year-old boy should primarily focus their training on strength, power, speed, agility, and sport-specific skill (SSS) development, with a reduced focus on hypertrophy, mobility, fundamental movement skill (FMS), endurance, and metabolic conditioning. Discussion of how maturational status, sex, and initial training level affect the application of the model will be discussed later in the article. Below is a detailed overview of the rationale behind the emphasis of targeting various fitness components at different stages of a child's development.

FUNDAMENTAL MOVEMENT SKILLS AND SPORT-SPECIFIC SKILLS

The topic of FMS development has received considerable interest owing to the close association between FMS competency, health and well-being, physical activity, and to a lesser degree physical performance (29,38,66,82,83,103). Previous research has indicated that FMS development is essential to ensure that correct movement patterns are mastered in a safe and fun environment to ensure safe and effective performance of more complex sports movements at a later stage (85). FMSs have been viewed as the building blocks for sport-specific movement patterns and should typically be the focus of physical development programs for children from early childhood to develop gross motor skills (35). From the onset of puberty, adolescents can then be introduced to more SSSs, whereby FMSs are tested within more competitive scenarios.



<table>
<tr><th colspan="21">YOUTH PHYSICAL DEVELOPMENT (YPD) MODEL FOR MALES</th></tr>
<tr><td>CHRONOLOGICAL AGE (YEARS)</td><td>2</td><td>3</td><td>4</td><td>5</td><td>6</td><td>7</td><td>8</td><td>9</td><td>10</td><td>11</td><td>12</td><td>13</td><td>14</td><td>15</td><td>16</td><td>17</td><td>18</td><td>19</td><td>20</td><td>21+</td></tr>
<tr><td>AGE PERIODS</td><td colspan="3">EARLY CHILDHOOD</td><td colspan="7">MIDDLE CHILDHOOD</td><td colspan="9">ADOLESCENCE</td><td>ADULTHOOD</td></tr>
<tr><td>GROWTH RATE</td><td colspan="20">RAPID GROWTH ↔ STEADY GROWTH ↔ ADOLESCENT SPURT ↔ DECLINE IN GROWTH RATE</td></tr>
<tr><td>MATURATIONAL STATUS</td><td colspan="20">YEARS PRE-PHV ← PHV → YEARS POST-PHV</td></tr>
<tr><td>TRAINING ADAPTATION</td><td colspan="20">PREDOMINANTLY NEURAL (AGE-RELATED) ↔ COMBINATION OF NEURAL AND HORMONAL (MATURITY-RELATED)</td></tr>
<tr><td rowspan="9">PHYSICAL QUALITIES</td><td colspan="3">FMS</td><td colspan="4">FMS</td><td colspan="3">FMS</td><td colspan="10">FMS</td></tr>
<tr><td colspan="3">SSS</td><td colspan="4">SSS</td><td colspan="3">SSS</td><td colspan="10">SSS</td></tr>
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<tr><td colspan="10">Hypertrophy</td><td colspan="2">Hypertrophy</td><td colspan="7">Hypertrophy</td><td>Hypertrophy</td></tr>
<tr><td colspan="3">Endurance & MC</td><td colspan="8">Endurance & MC</td><td colspan="5">Endurance & MC</td><td colspan="4">Endurance & MC</td></tr>
<tr><td>TRAINING STRUCTURE</td><td colspan="4">UNSTRUCTURED</td><td colspan="5">LOW STRUCTURE</td><td colspan="4">MODERATE STRUCTURE</td><td colspan="4">HIGH STRUCTURE</td><td colspan="3">VERY HIGH STRUCTURE</td></tr>
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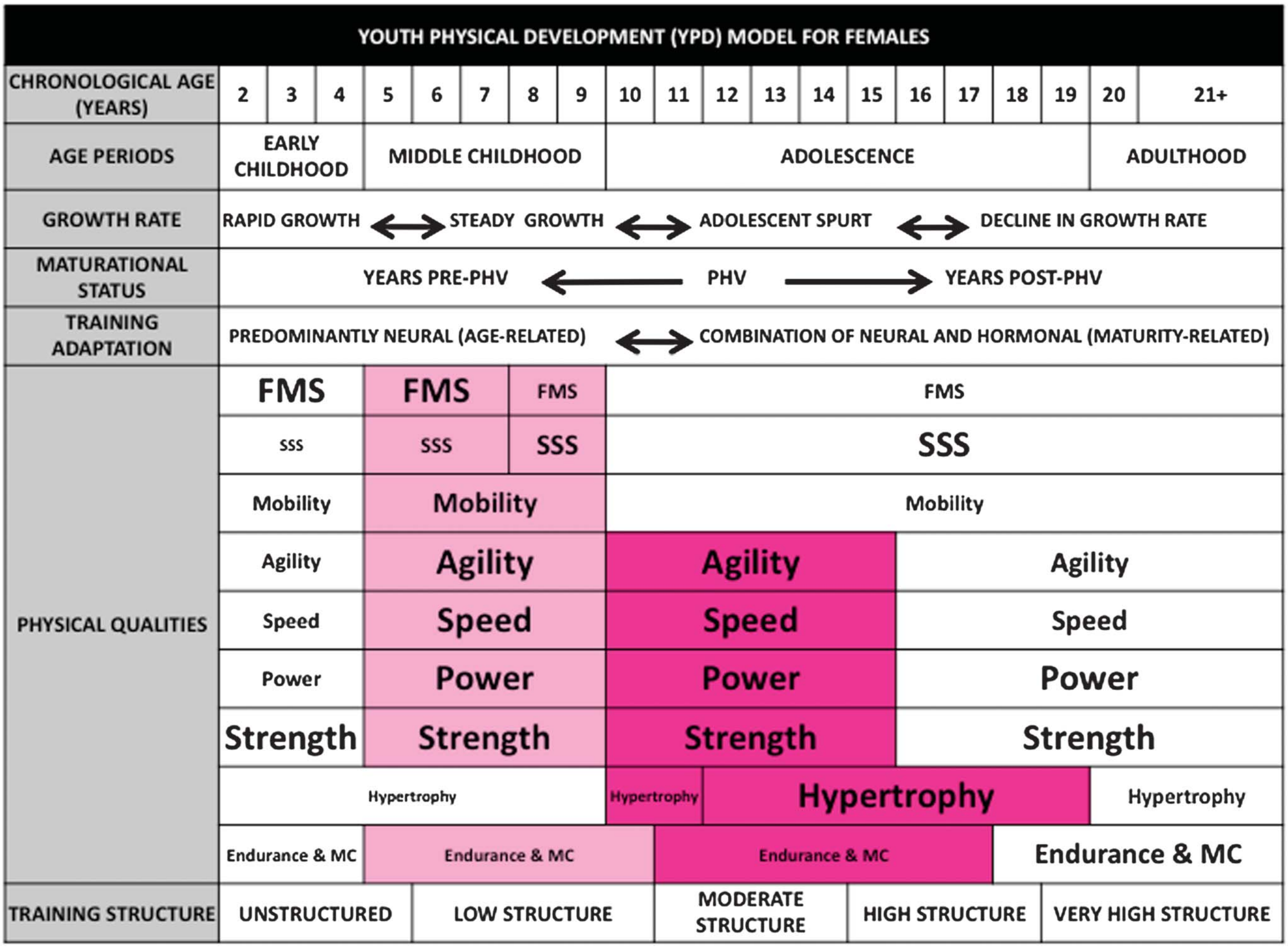
Figure 1. The YPD model for males. Font size refers to importance; light blue boxes refer to preadolescent periods of adaptation, dark blue boxes refer to adolescent periods of adaptation. FMS = fundamental movement skills; MC = metabolic conditioning; PHV = peak height velocity; SSS = sport-specific skills; YPD = youth physical development.

However, it must be noted that FMS should always be present within any strength and conditioning program, for any athlete, of any age (65). For example, the main emphasis of a training session for an inexperienced 7-year-old boy may revolve around a series of FMS development exercises, whereas a young, elite, 21-year-old man may integrate FMS maintenance exercises within a dynamic warm-up. This logical approach is reflected in the YPD model (Figures 1 and 2), where an emphasis is placed on FMS development up to the onset of puberty, and subsequently, focus is given to SSS from adolescence onward. However, the YPD model also shows that both FMS and SSS are present at all times throughout childhood and adolescence, but the emphasis placed on both components varies according to developmental stage.

STRENGTH

Despite previous concerns, it is now accepted that children can safely and effectively participate in strength training, when prescribed and supervised by appropriately qualified personnel (6,11,39,62,88,105). The LTAD model (7) suggests that a "window of opportunity" for strength development in youths occurs 12–18 months after PHV, which is typically commensurate with PWV (14,15). The rationale behind this window is that around the time of PWV, adolescents will undergo periods of rapid gains in muscle mass resulting from increased circulating androgen concentrations (110).

However, by limiting the period of trainability to coincide with maturity-related increases in muscle mass would suggest that children can only become stronger as a consequence of muscle fiber hypertrophy and subsequent increases in muscle cross-sectional area. Despite this, it has previously been established that strength development is multifaceted and results from a combination of muscular,



YOUTH PHYSICAL DEVELOPMENT (YPD) MODEL FOR FEMALES

CHRONOLOGICAL AGE (YEARS)	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21+
AGE PERIODS	EARLY CHILDHOOD			MIDDLE CHILDHOOD					ADOLESCENCE										ADULTHOOD	
GROWTH RATE	RAPID GROWTH ↔				STEADY GROWTH ↔					ADOLESCENT SPURT ↔						DECLINE IN GROWTH RATE				
MATURATIONAL STATUS				YEARS PRE-PHV ←							PHV					→ YEARS POST-PHV				
TRAINING ADAPTATION	PREDOMINANTLY NEURAL (AGE-RELATED) ↔										COMBINATION OF NEURAL AND HORMONAL (MATURITY-RELATED)									
PHYSICAL QUALITIES	FMS			FMS			FMS		FMS											
	SSS			SSS			SSS		SSS											
	Mobility			Mobility					Mobility											
	Agility			Agility					Agility						Agility					
	Speed			Speed					Speed						Speed					
	Power			Power					Power						Power					
	Strength			Strength					Strength						Strength					
	Hypertrophy								Hypertrophy		Hypertrophy								Hypertrophy	
	Endurance & MC			Endurance & MC						Endurance & MC							Endurance & MC			
TRAINING STRUCTURE	UNSTRUCTURED				LOW STRUCTURE					MODERATE STRUCTURE				HIGH STRUCTURE				VERY HIGH STRUCTURE		

Figure 2. The YPD model for females. Font size refers to importance; light pink boxes refer to preadolescent periods of adaptation, dark pink boxes refer to adolescent periods of adaptation. FMS = fundamental movement skills; MC = metabolic conditioning; PHV = peak height velocity; SSS = sport-specific skills; YPD = youth physical development.

neural, and mechanical factors (1,34). Owing to the neural plasticity associated with the prepubertal years, where development of the neuromuscular system naturally accelerates (21), it is suggested that strength development should be targeted during childhood in addition to after the adolescent spurt. This notion is reinforced by research and meta-analytical reviews that have proven that both prepubertal children and adolescents can achieve training-induced improvements in muscular strength (12,13,40,42,48).

The YPD model shows that the development of muscular strength should be a priority at all stages of development for both males and females (Figures 1 and 2). This notion is based on previous research that has revealed close associations between muscular strength and running speed (114), muscular power (104,116), change of direction speed (78), plyometric ability (71), and endurance (53). Additionally, it has been speculated that muscular strength is indeed critical for successful FMS development (12). Consequently, it is reasonable to suggest that developing levels of muscular strength should be a priority of any athlete development program, as strength would appear to transcend all other fitness components. Although not all these relationships have been validated in pediatric populations, early research has indicated that muscular strength (in addition to stature) could account for up to 70% of the variability in a range of motor skills including throwing, jumping, and sprinting in 7- to 12-year-old boys (106).

The development of muscular strength should also be viewed as an integral component of youth strength and conditioning programs not only for performance enhancement but also for reducing the risk of sport-related injuries (39). It has been reported that high aerobic fitness and low levels of muscle strength heighten the risk of fracture in children participating in exercise protocols (26), highlighting the importance of strength within an athletic development program. It is now accepted that the risk of sports-related injuries in youths can be reduced by regularly engaging in an appropriately designed strength training program that is supervised by appropriately qualified personnel (42,73). In 2011, the National Athletic Trainers' Association suggested that approximately 50% of overuse injuries within youth sports could be preventable in part with appropriate preparatory conditioning (109). However, it must be stressed that strength development sessions should not simply be viewed as an addition to a young athletes' development program but as a replacement for another form of training (e.g., endurance training or skill development session).

HYPERTROPHY

The YPD model depicts that an emphasis on training for hypertrophy may begin around the ages of 14 years in male and 12 years in female athletes. As mentioned previously, these phases of development will typically occur after PHV, at a time where levels of circulating testosterone and growth hormone rapidly increase in accordance with the adolescent growth spurt (68,110). Increases in serum concentrations of testosterone, estradiol, and progesterone have been directly linked with the stimulation of protein synthesizing pathways (45) and are responsible for the pubertal growth spurt and adaptations to muscle and skeletal tissue (19). Although not proven with direct evidence, it is reasonable to assume that because of a lack of circulating androgens, significant training-induced increases in muscle size before adolescence would appear limited. Consequently, within the YPD model, it is suggested in terms of resistance training that a focus should be geared toward strength development before adolescence, and after the adolescent spurt, strength training should be interspersed with bouts of hypertrophy training to make further gains in muscular strength and overall performance.

POWER

The ability to generate high levels of power is essential for sporting success (119); however, power is omitted from the current LTAD model (7). Vertical jump height is an indirect measure of muscular power, and owing to its simplicity, most developmental literature has used the test modality to assess pediatric lower limb muscular power (50,55).

The YPD model shows that the key period of power development starts at the onset of adolescence and continues throughout adulthood, largely because of rapid improvements in muscle power during adolescence being attributed to maturational influences (15). However, although power development is emphasized primarily after the onset of puberty, the YPD model does suggest that some training focus should also be given to developing power during the prepubertal phase. This is in response to research that shows that both children and adolescents can make worthwhile training-induced improvements in measures of muscular power (25,41,64,69,92,97,118). As is the case with muscular strength, the research would therefore suggest that muscular power is trainable throughout childhood, although the magnitude and rate of development may differ before and after the onset of puberty.

SPEED

Currently, the LTAD model advocates that windows of opportunity for speed development are entirely age related (7). According to the model, any training effects will therefore result from neural adaptations, which have previously been highlighted as significant factors in speed gains (21). However, alternative research has indicated that speed development in young athletes might also be influenced by maturation (94), which suggests that as is the case with many fitness components, speed is indeed trainable throughout childhood and adolescence. Interestingly, the review of Rumpf et al. (94) revealed that prepubescents benefited most from training requiring high levels of neural activation (plyometrics and sprint training), whereas adolescents responded more favorably to training modes that targeted both neural and structural development (strength and plyometrics). This might support the concept of windows when different training adaptations predominate reflecting natural development; however, trainability per se remains throughout childhood. From a practical perspective, this would suggest that prepubescent children should focus their speed development around plyometrics, technical competency, and sprint work to develop existing physical qualities, whereas adolescents should focus more on strength training, plyometrics, and sprint training, to maximize overall speed gains.

AGILITY

Agility is arguably one of the most underresearched fitness components within the pediatric literature, despite the acknowledgment that a high degree of agility is required for optimal performance in the majority of sports (56). Furthermore, a window of opportunity is not present within the current LTAD model (7). Consequently, it is difficult to determine whether age, maturation, or both are determinants of agility performance. There is a lack of research that identifies appropriate time frames to target agility-specific training. Therefore, the YPD model makes inferences in relation to the development of the subcomponents of agility, as defined previously (99,120): *change of direction speed* (inclusive of technique, straight sprinting speed, lower limb strength, and anthropometry) and *cognitive function* (perceptual and decision-making processes).

Change of direction speed. When examining the literature surrounding these components, the YPD model suggests that agility should be targeted during both prepubescence and adolescence. As lower limb strength and straight running speed are components of agility (120), it is logical to look to develop agility and reinforce coordination and movement pattern accuracy during the early years. The prepubertal years have already been shown to represent an opportunity for children to enhance strength (12,48) and speed (94), resulting from enhanced neural contribution to rate of force development (110). Once a child reaches adolescence, they will typically experience further gains in strength through continued neural maturation and also significant increases in lean muscle mass, owing to increased serum androgen concentrations (110). It is reasonable to suggest that adolescence will therefore serve as an opportune time to further develop agility, as peak force and peak rate of force development are likely to increase because of the adaptation in muscle structure. Prepubescence has also been identified as a period that sees children undergo rapid developments in the neuromuscular system (21), with the rates of brain maturation peaking between 6 and 8 and 10 and 12 years (90). Naturally, owing to the neural plasticity associated with prepubescence, this would seem an ideal opportunity to develop motor control programs inclusive of basic change of direction techniques in the first instance and then progressing to more sport-specific agility movements as the child approaches adolescence.

Cognitive function. According to Sheppard and Young (99), a number of perceptual variables influence agility. Specifically, the authors state that visual scanning, knowledge of situations, pattern recognition, and anticipatory qualities influence individual agility performance (99). Minimal literature exists examining the influence of growth and maturation on these components and their subsequent effects on agility performance. Outside sporting situations, research suggests that cognitive capacities increase during late childhood and adolescence and that throughout these phases of development, repeated exposure to a given stimulus will result in faster response times because of an apparent strengthening of existing synaptic pathways (24). Whether these theories translate to actual sporting situations, in which athletes will need to react rapidly to fluctuating stimuli (e.g. body position, bounce of ball, opposition movement), remains to be seen.

It is expected that the locomotive vocabulary developed during the prepubertal phase will continuously be enhanced as the child progresses through adolescence and into adulthood, through an increase in experiential learning opportunities within sports-specific environments. Given the lack of existing developmental literature, it is suggested that the training focus of agility should be made more challenging as the individual progresses through childhood and into adulthood, with the use of more open and unplanned training methods to continually overload the training stimulus. Additionally, with an increase in training demands within an overall athletic schedule, it is expected that agility development (and maintenance) will be garnered from specific sports skill-based sessions, where movement demands replicate the exact locomotive demands of the sport.

As per speed development, a caveat should be noted for agility development during adolescence, as children learn to move with longer limbs. The rapid gains in limb length during the adolescent growth spurt can lead to decrements in motor control performance, a concept commonly referred to as "adolescent awkwardness" (87). During this stage of development, researchers have suggested that many of the previously acquired movement patterns will need to be reperfected (37). Through regular monitoring of growth rates, periods of adolescent awkwardness can potentially be identified and strength and conditioning coaches should be aware of the underlying processes attributable to such disruptions in motor control and adjust the content of training sessions accordingly.

MOBILITY

Despite highlighting "suppleness" as one of the key components to develop through training (7), the LTAD model fails to suggest an appropriate window of opportunity for its development. The YPD model purports that at no stage is mobility the main emphasis of a training program during childhood or adolescence. However, it should be noted that as authors, we recommend that mobility development and maintenance should be an essential part of any athletic program to ensure athletes are capable of reaching the requisite ranges of motion required for their sports.

Specifically, the YPD model proposes that middle childhood (ages 5–11) serves as the most important time frame for an individual to incorporate flexibility and mobility training. The rationale for this selection is that it incorporates a period that has previously been termed a critical period of development for flexibility (67,96). Sex differences are apparent within the research, suggesting that boys show a reduction in trunk forward flexibility between 9 and 12 years (16), whereas girls demonstrate accelerated improvement beginning at 11 years of age (22). It is therefore suggested that prepubescence serves as an opportunity to develop mobility, whereas maintenance of the acquired levels should be the focus for adolescents and adults.

ENDURANCE AND METABOLIC CONDITIONING

Early research produced conflicting results with respect to the trainability of youths, with studies suggesting that children who were circa-PHV possessed greater training responsiveness (113) or, conversely, that large training gains were possible for children who were pre-PHV (93). It is suggested that inconsistencies in research design have been attributable to these confounding results and that a lack of longitudinal empirical evidence refutes the claims of the existence of a window of opportunity as defined in the LTAD model (44). Regardless of the lack of evidence, growth-related changes in central and peripheral cardiovascular systems, neuromuscular function, and metabolic capacities are expected to influence endurance and metabolic conditioning development throughout childhood (93). As physiological components are continuingly developed throughout childhood and adolescence, it is not surprising that prepubertal, circumpubertal, and postpubertal children have all been reported as being able to make worthwhile improvements in endurance performance as indicated by $\dot{V}O_2$max responses (3).

The YPD model proposes that more attention is given to endurance and metabolic conditioning as the child approaches adulthood, and at no stage, it is seen as the main focus of an individual's training. Although this may appear controversial, the rationale is based on the assumption that an individual will be exposed to sport-specific endurance development while participating in organized matches or competitions and potentially within a technical skill session of their given sport. Additionally, remarkable levels of endurance are not necessarily required in the majority of sports, and endurance appears to remain trainable in adulthood. Within the education sector, cardiovascular endurance is inadvertently the most commonly developed fitness component, as asking a child to perform some form of submaximal locomotion would appear safer to teachers than asking them to participate in some form of resistance training. This is especially the case within the primary school setting in the United Kingdom, where not only have strength levels in children diminished in the last decade (31) but also it is recognized that teachers are inappropriately prepared through their teacher training to teach physical education and that statutory requirements for physical education are routinely not achieved (59).

THE NEED TO INDIVIDUALIZE LONG-TERM ATHLETIC DEVELOPMENT PROGRAMS

The YPD model is presented for both males (Figure 1) and females (Figure 2) displaying what would be classified as an average maturing child (i.e., not an early or late maturer). However, strength and conditioning coaches will habitually come into contact with athletes of varying stages of maturation, age, sex, and training history. Although previous models have alluded to these variables (7), it is not apparent that the impact of the individual variables on training prescription has been addressed. Consequently, the following section will examine how the YPD model should be manipulated when considering sex-dependent factors, timing and rates of maturation, and the training history associated with different athletes.

SEX DIFFERENCES

Despite more boys engaging in youth sports than girls, there has been an increase in the overall number of children and adolescents actively participating in organized youth sports over the past decade (77). With participation numbers increasing, it is imperative that any strength and conditioning coach is aware of the physiological and maturational differences that exist between males and females and design-specific programs accordingly.

During the prepubertal years, boys and girls will follow similar rates of development in growth and maturation, and despite consistent sex differences, strength, speed, power, endurance, and coordination will develop at similar rates for both sexes throughout childhood (14). Consequently, from a training perspective, both boys and girls can follow similar training programs during the prepubertal years. The YPD model advocates a prepubertal focus of training for both boys and girls that centers on FMS, strength speed, and agility development.

The prepubertal years are a period where children will experience rapid gains in bone mass because of modeling and remodeling (9). Exposure to appropriately designed weight-bearing exercise of moderate- to high-load intensity (with appropriate technical competency) is an osteogenic stimulus (60,61,111,115). Such training can result in large increases in bone mass and density (5,10,17,46,117), and research has suggested that this adaptive response is most sensitive during the prepubertal years (8). Due to women possessing a greater risk of osteoporosis in later life (58) and that strength training has previously been deemed to offer the potential of reducing osteoporotic fractures in older women (79), the importance of strength training for women at all stages of development should not be underestimated.

Upon the onset of the adolescent growth spurt, clear maturational differences are apparent for nearly all components of fitness, with men making greater improvements in most physical qualities, with the exception of flexibility (14,68). Typically, the onset of the adolescent growth spurt occurs around 2 years earlier in girls (about 10 years of age) than in boys (approximately 12 years of age) (14), and in the majority of instances, girls experience PHV at an earlier age than boys (12 years versus 14 years) (15). Despite an earlier attainment of PHV in girls, the magnitude of the growth spurt is greater in boys (15).

During the adolescent spurt, female athletes will undergo sex-specific physiological processes that may affect performance: increased fat mass, differential rates of development of neuromuscular strength, and height and weight; commencement of menstrual cycle, increased joint laxity, increased knee valgus angle; and increased reliance on quadriceps-dominant landing strategies, all of which have been associated with an increased risk of noncontact anterior cruciate ligament injury (2,43,51,52,72,75,86,89).

Consequently, the YPD model suggests that training strategies designed to reduce the risk of noncontact anterior cruciate ligament injuries, such as plyometrics, core strengthening, strength training, and balance and perturbation training (74), should be implemented within the strength and conditioning program of female athletes and maintained into adulthood.

EARLY VERSUS LATE MATURING INDIVIDUALS

Because of the highly individual timing of maturation, it is imperative that any LTAD model contains a degree of flexibility (65). An early maturing child has previously been defined as a girl or boy who starts their adolescent growth spurt approximately 1.5 or 2 years earlier than a late maturing child (47).

Although research has indicated that eventual adult height is not affected by early or late maturation (49), strength and conditioning coaches must appreciate that an early or late maturing child will need to be treated somewhat differently than an "average" maturing child, when prescribing long-term athletic development programs. For example, if a child is routinely monitored for stature and body mass every 3–6 months throughout childhood, growth rates, percentage of adult height, and predictions of age from PHV can be calculated (70). Using these measurements, the maturational status of a child can be approximated, thus providing a more robust estimate of their biological age.

In relation to the YPD model, if a child is deemed to be an early maturer, then the components of the model will need to be moved to the left, thus enabling the child to commence more advanced training techniques at an earlier chronologic age. In contrast, a strength and conditioning coach must allow the components of the YPD model to be moved to the right for a child who is deemed a late maturer, thereby introducing them to more advanced training at a later chronologic age, when they are physiologically ready to cope with the increased training stimulus. In either of these instances, although training prescription will vary according to chronological age, it should allow greater consistency and more accuracy in terms of the child's biological age.

INITIAL TRAINING STATUS

Irrespective of chronological or biological age, a strength and conditioning coach must give thought to the training age of any athlete that they start working with. Training age can be defined as the number of years an athlete has been participating in formalized training and is an important factor to consider when designing long-term athletic development programs. Such an approach is particularly pertinent when a strength and conditioning coach begins to work with an athlete who is approaching adulthood that has missed the initial stages of the YPD model.

In such an instance, the athletes should begin with early development of FMS and muscular strength before embarking on the training content that is commensurate with their chronological age. Conversely, should a strength and conditioning coach begin working with an early maturing 10-year-old boy who can display exceptional strength, speed, and power while maintaining the requisite technical competency, then they should not be restricted to the introductory training methods more akin to his chronological age. This concept has previously been discussed in relation to both plyometric (63) and weightlifting (65) development models.

THE YPD MODEL AS A VEHICLE FOR ATHLETE WELL-BEING

Well-being has been defined as a positive and sustainable state that allows individuals, groups, or nations to thrive and flourish (54). The philosophy of the YPD model is that it permits individualization, is athlete centered, and promotes the development of the child over performance outcomes. This may sacrifice short-term performance success but should maximize the opportunity to foster a sense of well-being and provide long-term gains. This philosophy will help the child to appreciate the benefits of training and develop intrinsic motivation for participating in training, which is a strong predictor of well-being (95) and is associated with positive behaviors (112). Additionally, provided the coach can deliver the content of the model in a positive manner the child should recognize the gains they are achieving (e.g., technical, physical, developmental), leading to increased perceived competence, which is a primary determinant of a sense of well-being in child athletes (91). This will increase the likelihood of the child being able to persist in the face of adversity and to sustain continued interest in sport (4,36).

The YPD model advocates the development of FMS from a young age, which are associated with physical and psychologic health benefits in children (66). Furthermore, the progression provided throughout the YPD model will enable the children to experience continued mastery of new tasks throughout their developmental years.

Task mastery is associated with increased enjoyment, perceived competence, satisfaction, and beliefs that effort causes success (81,101,107). Such positive experiences should also provide valuable and highly transferable life skills (33). The continued and overlapping development of a number of fitness components in the YPD model should also provide the strength and conditioning coach with the ability to develop training programs containing a high degree of variation, something that has been suggested to be important in maintaining the interest of and promoting the well-being of child athletes (85).

DESIRED CREDENTIALS FOR STRENGTH AND CONDITIONING COACHES WORKING WITH YOUTH ATHLETES

It is important to realize that the success of any long-term development program will be dependent largely on the level of education and quality of instruction received by the athlete from the responsible coach (73). Within the literature, cases of training-induced injury in children and adolescents are reported only in instances where a young athlete has been exposed to excessive, unfamiliar, and poorly prescribed training, which in both cases have led to exertional rhabdomyolysis and hospitalization (27,28). Research suggests that outside these isolated cases, most incidences of resistance training-related injuries tend to be accidental in nature, with the number of accidental injuries decreasing with age (76). However, to minimize the chances of such isolated instances occurring, it is imperative that those coaches who actively coach young athletes possess the appropriate credentials.

First, a coach must hold a relevant strength and conditioning qualification (e.g., Certified Strength and Conditioning Specialist in the United States or Accredited Strength and Conditioning Coach in the United Kingdom). Second, a coach must have a sound underpinning knowledge of pediatric exercise science, ideally at an undergraduate or postgraduate level. Finally, a coach should have a strong pedagogical background to ensure they have an appreciation of the different styles of communication and interaction that they will need to adopt with athletes, who might range from early prepubescent to late adolescent. Satisfaction of these criteria will hopefully ensure that young athlete development models are delivered in a safe and effective manner, underpinned by appropriate individual program design (inclusive of exercise selection and progressions, volume loads, rest, and recovery), realistic goal setting, and a coaching philosophy that is tailored toward the holistic development of the young athlete.

SUMMARY

The present article has provided a sound rationale for the YPD model. This approach to the development of young athletes appears to be more realistic in terms of acknowledging that most fitness components are trainable throughout childhood. Central to the YPD model is that during prepubescence, strength, FMS, speed, and agility should be the main physical qualities targeted and that adaptive responses to the appropriate training methods will be neural in nature. Once the child reaches adolescence, additional components (SSS, power, and hypertrophy) become more important owing to the increased androgenic internal environment associated with this stage of development. The need for individualization of the model should not be underestimated when dealing with athletes of different sex, maturity status, and training history. Crucially, appropriately qualified personnel should always be responsible for the implementation of the YPD model, to ensure the holistic development of children and adolescents.

Rhodri S. Lloyd *is the program director for the Sport Strength and Conditioning degrees at the University of Gloucestershire.*

Jon L. Oliver *is a lecturer in Sport and Exercise Physiology at Cardiff Metropolitan University.*

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