Youth Athlete Development Models: A Narrative Review

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Context: Physical activity has shown to be beneficial for the overall physical and mental health of youth. There has been an increasing focus on youth sports moving from a recreational activity to becoming a launching pad for participation at elite levels. Several models of athlete development have emerged to guide specialized and nonspecialized athletes at an age-appropriate level, taking into consideration their physical and mental development. The purpose of this review is to summarize the current evidence and theoretical models regarding youth athlete development and discuss broader initiatives for sports participation and future directions for the field.

Evidence Acquisition: An electronic databases search, including PubMed, Google Scholar, ScienceDirect, National Institutes of Health, UpToDate, and Springer was conducted. Articles from 1993 to 2021 were included. The search terms *long term athlete development*, *LTAD model*, *youth physical development*, *youth athlete development*, *sports specialization*, and *pediatric athlete*, among others, were used.

Study Design: Narrative review.

Level of Evidence: Levels 4 and 5.

Results: Several models of youth athlete development are discussed in this article. More recent models have built on previous models to incorporate more age- and development-specific recommendations; however, no singular model could be identified as the gold standard for youth athlete development, especially given the lack of empirical data to support these models.

Conclusion: Youth athlete development currently consists of several theoretical models, each with their own strengths and weaknesses, that can guide the training of young athletes to maximize their performance. Those involved in this process—physicians, athletic trainers, coaches, physical educators, and parents—should understand these various models and trial their various features to see what works best for their individual athlete with consideration given to factors such as their stage of development. Ultimately, more empirical data are required to definitively state which is the optimal approach.

Keywords: pediatric athlete; athlete development; long term athlete development; youth sports participation; sports advocacy

Physical activity improves overall health in children and young adults by reducing the risk of obesity, cardiovascular disease, diabetes, depression, and suicide, among other chronic medical conditions.[4] Increasing youth physical activity has become a priority for many countries, leading to the development of national policy statements and strategies to promote physical activity in youth.[29,32] The US Department of Health and Human Services and the National Physical Activity Alliance recommend that children and adolescents engage in moderate to vigorous physical activity for at least 60 minutes every day.[23,33] Prior to the COVID-19 pandemic, only 20% of adolescents met these guidelines, and research shows that this percentage decreased even further during the pandemic.[7,11] Although youth may be engaging in more sports and physical activities since the emergence of the COVID-19 vaccine, the trend of decreasing physical activity and increasing sedentary behavior among children and adolescents remains a challenge. This challenge is even greater for girls, racial and ethnic minorities, youth from households of low socioeconomic status, youth living in rural areas, and youth with disabilities, as these population groups have more barriers to accessing sports and physical activities.[32]

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The following author declared potential conflicts of interest: C.L. has received grants from NOCSAE, payments from PEDS365, and royalties from the American Academy of Pediatrics.

DOI: 10.1177/19417381211055396

Youth who participate in organized sports can reap additional benefits beyond those associated with physical activity alone, including "improving confidence, self-esteem, and providing an opportunity to work on social interaction, communication, leadership, and teamwork."[8,24] There has been an increasing focus on youth sports moving from a recreational activity to becoming a launching pad for participation at elite levels. This shift has led more youth to specialize in a single sport at an earlier age.[13,15,16] Recent studies, however, have shown that early sports specialization may be a risk factor for overuse injury and burnout.[22] Several models for youth athlete development (YAD) provide guidance for specialized athletes aiming to achieve elite performance while minimizing risk for injury. These YAD models also include guidance for the introduction and maintenance of physical activity for nonathletes, while emphasizing the importance of providing opportunities for all children to participate in sports.

The purpose of this narrative review is to identify and summarize YAD models, describe the evidence supporting their efficacy, discuss their limitations, and offer directions for future research.

METHODS

Search Strategy

We used the following online databases: PubMed, Google Scholar, ScienceDirect, National Institutes of Health, UpToDate, and Springer, as well as online policy statements from the Department of Health and Human Services in the United States and Canada. The search was conducted in the months of March and April 2021. Keywords used to retrieve publications from January 1993 to April 2021 were *long term athlete development*, *LTAD model*, *LTAD*, *implementation*, *youth physical development*, *randomized control trial*, *comparison*, *qualitative study*, *quantitative study*, *youth athlete development*, *youth athlete*, *adolescent athlete*, *pediatrics*, *sports specialization*, and *pediatric athlete*. Only articles that were available as full text, written in English, and published in peer-reviewed journals were included.

Inclusion Criteria

We included articles on athlete development in the pediatric population. We also included all articles on the effects of athlete development models in the pediatric population.

Exclusion Criteria

We excluded articles on athlete development in other populations such as adults greater than 23 years of age, focused on team building rather than individual athlete training, short-term training programs, and training programs unique to only 1 specialized sport (Figure 1).

RESULTS

A total of 110 publications (including peer-reviewed journal articles, governmental policies, and books) were identified by the search. Of these 110, 40 met the inclusion criteria and were reviewed. These included 31 peer-reviewed articles, 7 governmental policies, and 2 books. Additional articles on sports specialization, physical activity, and public policy were included for background information as needed.

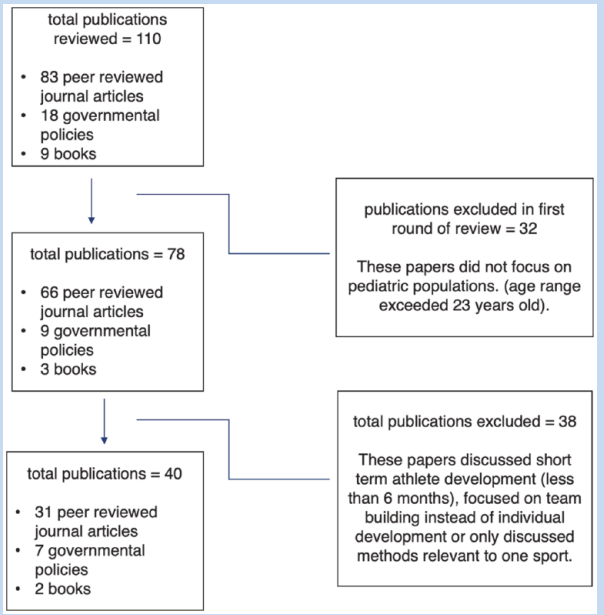

Figure 1. Exclusion criteria for published works reviewed in this narrative review.

Developmental Model of Sports Participation

One of the first YAD models was described by Côté[5] in 1999. This model was based on a qualitative study in which the author interviewed athletes and their families about the athlete's development in sport over time.[5] In his study, Côté[5] built on Ericsson's research from 1993 describing the constraints associated with becoming an elite athlete including motivation, effort, and resource.[8] Côté examined factors in families that contributed to young athletes achieving elite levels in sport. The study included a total of 15 interviews with 3 elite rowers, 1 elite tennis player, and their families (siblings and parents). All athletes were aged 18 years at the time of the interviews.[5] The participants were asked open-ended questions, including recollections on first sport participation ("Looking back can you remember and tell me how you first got involved in sport?"), effort and concentration ("Can you tell me over the years how you managed to invest such a high level of effort and concentration into learning and practicing?") and others identifying the 3 main constraints being evaluated. From these data, the researchers identified 3 time periods of athlete development, which they named the "Developmental Model of Sports Participation": (1) sampling years (ages 6-13), (2) specialization years (ages 13-15), and (3) investment years (ages 15+ years).[5]

Sampling years take place between the ages of 6 and 13 years with emphasis on multisport participation (sampling) and parent responsibility for exposing their children to sports.[5] In the study, it was found that children from the same family were given equal opportunities to participate in various activities during the sampling years. Specialization years take place

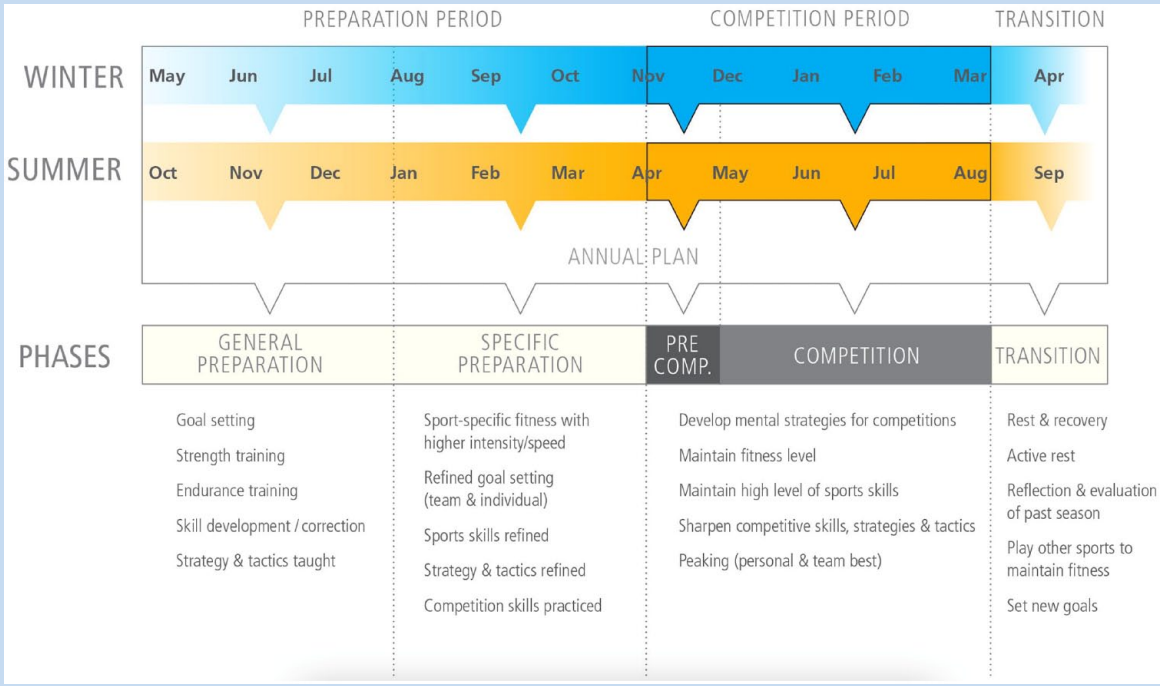

Figure 2. Periods of training throughout the year shown in different phases. Separation into different training types by the months of the year is shown as an example of periodization.

between ages 13 and 15 years. Athletes slowly decrease the number of activities and focus on 1 or 2 specific sports during this time. There is a focus on sport-specific skill development during this period.[5] Children are more likely to pursue one sport over another if they have a positive interaction with a coach, encouragement from an older sibling or friend, success in an activity, or if they find it enjoyable.[5] The investment years are a longer period and occur from age 15 years and older. The emphasis is on commitment to a single sport with the goal of achieving an elite level of play. The age for entering the investment years can vary per sport. In this period, parents provide direction, feedback, and often help fight setbacks (burnout, injury, and fatigue).[5]

While this study provided one of the first structured models for YAD and has served as a framework on which subsequent models were built, it has important limitations. The sample consisted of only 4 athletes and 2 sports. Additionally, the 3 time periods were based on chronological age rather than stage of biologic maturation, which may be a better indicator of readiness for each stage.

Long-term Athlete Development Model

In 2004, Balyi et al[1] described the "long-term athlete development (LTAD) model," which accounts for biological growth and development by using peak height velocity (PHV) to determine readiness for each stage of training.[2,26] PHV is used as an estimate of biological maturation, and the chronological age for achievement of PHV varies from child to child. At the time of PHV, muscle mass, aerobic capacity, energy utilization, and central nervous adaptations increase due to increasing levels of sex hormones.[1,20,25] As such, biologic maturation is likely a more important marker than chronological age for readiness for each training stage. Importantly, this model also includes a pathway for athletes not interested in elite level competition.[2]

The LTAD model has 7 stages[20,29] and provides a variety of pathways for participation, training, and competition throughout childhood and adolescence. The 2 main pathways are the "podium pathway" for development of the elite athlete and the "active for life" pathway for the recreational athlete (Figure 2).

The LTAD model is based on 10 factors summarized below[2,29]:

1. *Physical literacy:* Foundation of participating in sports by developing motivation, ability, and knowledge to understand movement. Skills include locomotor skills (eg, climbing, galloping, hopping), object control skills (eg, catching, kicking, dribbling, striking with different racquets), and balance movements (eg, dodging, floating, ready position).[29]
2. *Specialization:* Sports are classified in this model as either early or late specialization sports. Early specialization sports contain skills that typically peak in performance prior to maturation (eg, gymnastics, diving, figure skating).
3. *Developmental age:* Stage of biologic maturation based on PHV.
4. *Sensitive periods:* Also described as "windows of opportunity" in the LTAD model as the stage of biologic maturity during

which the ability to learn a specific skill is easiest.[2] Sensitive periods for skill, stamina, and strength are based on biologic maturation (estimated by PHV), while speed and suppleness (flexibility) are based on chronological age.[29]

5. *Mental, cognitive, and emotional development:* Factors that are important in addition to physical development that include understanding fair play and ethics within sport, regulating emotion during play, and decision making. Children move from exploring movement to executing movements over the course of their development.[29]
6. *Periodization:* The planning and organization of a training schedule with regard to frequency, duration, and intensity that can be divided into different phases and seasons[29] (Figure 2).
7. *Competition:* Development of a competition calendar and the concept of using training-to-competition ratios for each stage of development.[29]
8. *Excellence takes time:* This encompasses the understanding that athlete development and achievement of an elite level in sport takes many years. There is emphasis on the 10,000-hour rule, which is a theory that a minimum of 10 years of deliberate practice is needed for individuals in any field to achieve the elite level.[29] While commonly cited, this theory is not well-supported by scientific data.
9. *System alignment and integration:* Refers to the idea that LTAD must be integrated into the public health and education systems.[29]
10. *Continuous improvement:* The LTAD model is based on the concept of continuous improvement and evolution of athlete development that requires flexibility, which is credited to the Japanese philosophy, kaizen.[29] Examples include incorporating current scientific evidence into training and ongoing education for everyone involved in training (coaches, athletic trainers, athletes, etc).[29]

Granacher and Borde[12] conducted a prospective study of 45 German fourth graders to evaluate the effects of long-term sport-specific training using the LTAD stages on the following outcomes: physical fitness, body composition, cognitive performance, and academic performance. The study compared children who already took part in competitive organized sports (gymnastics, swimming, soccer, and others) (n = 20) with age-matched peers who were recreational athletes (took part in physical education classes only). The researchers hypothesized that sport-specific training with physical education would enhance physical fitness but would potentially have a negative impact on cognitive and academic development of youth athletes compared with their peers. The study took place over 1 year. The experimental group (n = 20) performed sport-specific training and regular physical education classes 3 times a week. This group included gymnasts, trampoline jumpers, swimmers, track and field athletes, soccer athletes, and 1 BMX cyclist. Like the LTAD model, the intervention used a periodized training schedule. The control group (n = 25) participated only in physical education classes 4 times a week.

Pre- and posttests were done for each group evaluating physical fitness, relative body fat mass, skeletal muscle mass, and cognitive and academic performance, including assessments of reading, mathematics, spelling, attention, and concentration. Physical fitness tests included evaluation of speed (20-m sprint), muscle power (1-kg ball push up, standing long jump), agility (star agility run test), flexibility (stand and reach test for back and hamstring flexibility), endurance (6-min run test), and balance (single-leg stand test). Body measurements (sitting, standing height) and body composition was measured using a bioelectrical impedance analysis system. Academic performance included 4 tests in reading, mathematics, spelling, and attention/concentration. Biologic maturity was estimated by evaluating years from PHV, which was attained using sitting and standing body height, body mass, and age using previously defined criteria.[12] Children were categorized into 3 categories: pre-PHV, PHV, and post-PHV.

All students were classified as PHV in this study. At baseline there were significant differences between the groups in body height, body mass, body mass index, and body composition but there were no differences in cognitive and academic performance. The experimental group had significantly more sport-specific training compared with the control group. After the intervention, 6 out of 7 physical fitness test results were better in the experimental group. The additional hours of sport-specific training did not negatively affect cognitive or academic performance compared with the control group. Academic performance was assessed using standardized testing in German, mathematics, and English through the ELFE 1-6 reading test, the DEMAT 4 mathematics test, and the HSP 4-5 spelling test. Additionally, cognition (focusing on attention and concentration) was evaluated through the standardized d2-test. There was no difference after 1 year in measures of body composition or growth. The sport-specific training and physical education volumes were feasible and safe with no injuries over 1 year. This study demonstrates that structured training models are safe and feasible and may have added benefit to physical fitness and that there is no negative impact on cognitive or academic performance, growth, or body composition.

Stages of the LTAD Model[2,29]

Physical literacy is developed in the first 3 stages of this model. An additional 2 prestages were initially added for athletes with disabilities but are now emphasized for all athletes.

Prestages

Awareness. Develop awareness around what activities, sports, and physical activity opportunities exist.[2,29]

First involvement. First participation in sport. This should be positive, welcoming, and fun, as a negative first experience may lead to long-term disinterest in physical activity.[2,29]

Common Pathway (Learning Fundamentals)

Active start. The goal of this stage is to learn fundamental movements and link them in play.[2,29] Physical activity during this stage should be fun and a part of everyday life for the

child (eg, running around at the playground or at home).[2,29] It is important for the parent or other guardian to give access to unstructured play time. The "Active Start Checklist" provides example items for this stage, which include providing physical activity every day regardless of weather, encouraging such basic movement skills as running, jumping, kicking, and throwing and ensuring games focus on participation and not competition.[2,29]

FUNdamentals. The FUNdamentals stage is focused on skill development, structured play, and an atmosphere of fun. Programs developed for children in this stage should be structured and monitored. The skills learned in this stage help with future sports and recreational activity participation. The "FUNdamentals Checklist" includes examples such as introducing basic flexibility exercises, encouraging participation in a wide range of sports, including strength training using body weight and introduction of the child to simple rules and ethics of sports.[29]

Learn to train. This is described as the "most important period before peak height velocity"[2] and occurs generally between the ages of 9 and 12 years. This is thought to be a sensitive period for learning specific skills in the LTAD model. Therefore, the learn to train stage includes general sports skills, learning the concepts of warm-ups, cooldowns, stretching, and mental preparation for sports.[30] The main focus of this stage is development of physical literacy, which is defined as the physical competence, confidence, and motivation of an athlete to enjoy various types of physical activity including sports.[35] The "Learn to Train Checklist" includes examples such as the introduction of hopping and bounding exercises; development of speed with focus on agility, change of direction, and warming up; development of mental skills, including focus and visualization and the commencing of age-appropriate competition.[29]

Podium Pathway

Train to train. The goal during this stage is to introduce aerobic training before PHV, to develop speed and strength while specializing further into 1 or 2 sports of the athlete's choice.[2,29] There is a focus on applying skills learned in previous stages into competition.[2] Athletes in this stage play to win; however, the focus is still on applying skills learned as well as on having fun.[2] The "Train to Train Checklist" includes examples such as considering sensitive periods of accelerated adaptation to strength training (after PHV or onset of menarche for females; 12-18 months after PHV for males), and changing the competition-specific training ratio to 60:40 (devoting 60% of time to development of technical skill and 40% to competition-specific training).[2,29]

Train to compete. The focus during this stage is to optimize performance in competition. This stage is largely devoted to optimizing skills for specific sports and positions in each sport.[29] It is important that athletes have mastered the goals of previous stages prior to progressing to the "train to compete" stage.[29] These athletes will be highly specialized, which is defined as year-round, high-intensity single-sport training. The "Train to Compete Checklist" includes examples such as placing special emphasis on competition preparation and changing the competition-specific training ratio to 40:60 (devoting 40% of time to development of technical skill and 60% to competition-specific training).[29]

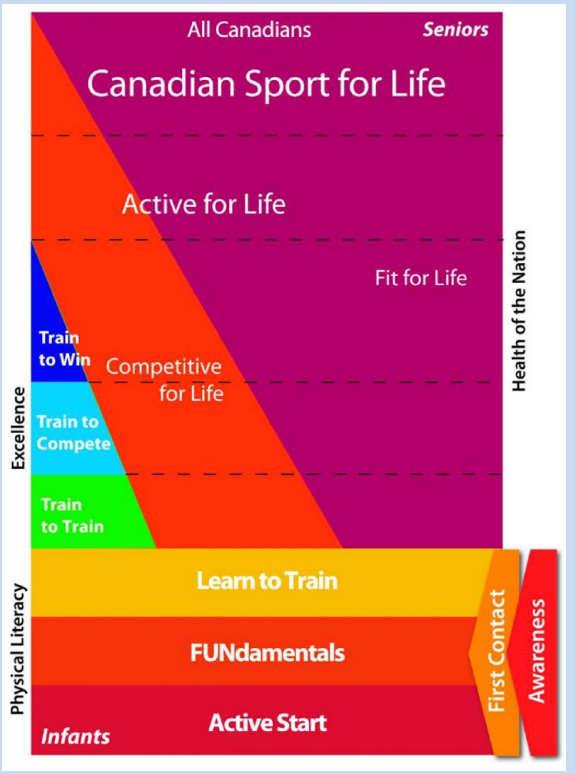

Figure 3. The "sport for life" diagram for long-term athlete development based on the long-term athlete development model by Balyi et al.[2,29] The figure highlights 2 pathways from building a foundation and developing physical literacy to the podium pathway (green and blue) and active for life, which divides into competitive for life (pink) or fit for life (red).

Train to win. This is the final stage of the LTAD model. This is focused on athlete preparation for high-level sport-specific training, competition, and recovery.[3] This stage emphasizes the mastery of skills such as decision making, position-specific and sport-specific technical skills, and fitness skills.[2] The goal is to maximize physical and mental fitness as well as recovery. The "Train to Win Checklist" includes examples such as ensuring training is year-round high intensity and high volume, changing the training-competition ratio to 25:75, and allowing breaks to reduce stress and prevent overuse injury.[29]

Active for Life Pathway

Three pathways fit under the umbrella of being active for life (Figure 3).

Competitive for life. Individuals in this group have a minimum of 60 minutes of moderate daily activity or 30 minutes of vigorous daily activity.[29] They may participate in multiple sports and transition from a highly competitive level (eg, collegiate) to lifelong competitive sport (eg, high-level age group competitions).[29]

Fit for life. Individuals in this group are physically active for a similar amount of time to the competitive for life group. They move from competitive sports to recreational activities and may be involved in sports careers or volunteering.[29] They also may participate in recreational sports and/or explore new physical activities (eg, a hockey player trying rock climbing for the first time).[29]

Sport and physical activity leaders. Individuals in this category move from competitive athletics to volunteering or working in athletic leadership or support roles (eg, coaches, officials, administrators).[29] They use their own previous experiences to ensure sports are a positive experience for athletes.

Sport for life. The Sport for Life organization in Canada is a movement to improve the quality of sport and physical activity. Sport for Life uses the LTAD model while emphasizing systems implementation within the community to promote lifelong participation in sports and physical activity. It recommends the integration of competitive sports, recreational activity, and physical education in school and school-based sports within the same system.[2,29] Each stage has an accompanying checklist to ensure children are meeting the goals of each stage. Like the LTAD model, the Sport for Life model has 2 separate pathways: one for athletes with the goal of achieving elite-level competition and another for recreational athletes whose goal is to participate in sports and physical activity to maintain an active and healthy lifestyle without entering high-level competition. Sport for Life also provides specific examples of the LTAD model applied to different sports (eg, hockey, baseball, soccer).[29]

Indigenous sport for life. The Sport for Life organization in Canada partnered with Aboriginal Sport Circle to adapt their framework to "define a pathway for Indigenous athletes into high performance sport and increase the number of Indigenous peoples who are active for life."[14] This adaptation considers cultural and societal norms within the community and was created in collaboration with local Indigenous organizations. This adaptation serves as a model for other youth athlete development model modifications for various groups including LBGTQ youth, youth of different ethnicities and race, and different community groups.

Youth Physical Development Model

In 2012, the youth physical development (YPD) model proposed by Lloyd and Oliver[20] also emphasized a development-based over aged-based approach and the importance of starting with fundamental movement skills in training young athletes. However, compared with the LTAD model, YPD provides more detail regarding which type of training should be emphasized during each developmental stage and accounts for additional gender differences.

YPD stages are early childhood (ages 2-4 years), middle childhood (ages 5-9 years), adolescence (ages 10-19 years), and adulthood (ages 20-21 years).[20] Growth rates are divided into rapid growth, steady growth, adolescent growth spurt, and decline in growth rate, which correspond with the developmental stages described. The YPD model also takes into account maturation status (pre-PHV and post-PHV), training adaptation (neural or neural + hormone phases), training structure (structured vs unstructured), and physical qualities of training (fundamental movement skills, sport-specific skills, mobility, agility, speed, power, strength, hypertrophy, endurance, and metabolic conditioning)[20] (Figure 4). YPD emphasizes that it is possible to train an athlete in any of these physical qualities at any stage throughout childhood and adolescence, in contrast to the "windows of opportunity" described by Balyi et al.[1,2] However, the YPD model does recognize that there may be optimal times to train each physical quality (Figure 4 and Table 1). For example, for an adolescent female (ages 10-19 years), at PHV and in a phase of neural and hormonal maturity, training should focus on agility, speed, power, strength, hypertrophy, and endurance and be moderately to highly structured.[20]

The YPD model is easy to understand and encourages participation in sports for all youth.[21] The YPD model is not geared solely toward reaching a certain level of competition but focuses on the holistic development of young athletes at all levels and therefore may be more generalizable than the LTAD model.

LIMITATIONS

Scarce Data

During our search, we were unable to find large studies comparing these various models. It is important to recognize that the description of athlete development stages by Côté[5] was the foundation for the future models we discuss in this review. However, Côté's model has significant limitations, including the small number of athlete participants[4] and inclusion of only 3 sports, as well as recall bias because of retrospective study design. The more recent models, including LTAD and YPD, have been included in very few prospective or retrospective studies to provide objective data on their effectiveness. It may be more appropriate to label them "frameworks" until they can be rigorously tested and supported by empirical data.[6] A great deal of data are derived from subjective observations lacking in empirical data. Additionally, there is no evidence that these models raise the maximal athletic potential of those participating. These models could simply be bringing youth to their maximal athletic potential at a different time course than other training regimens.[10]

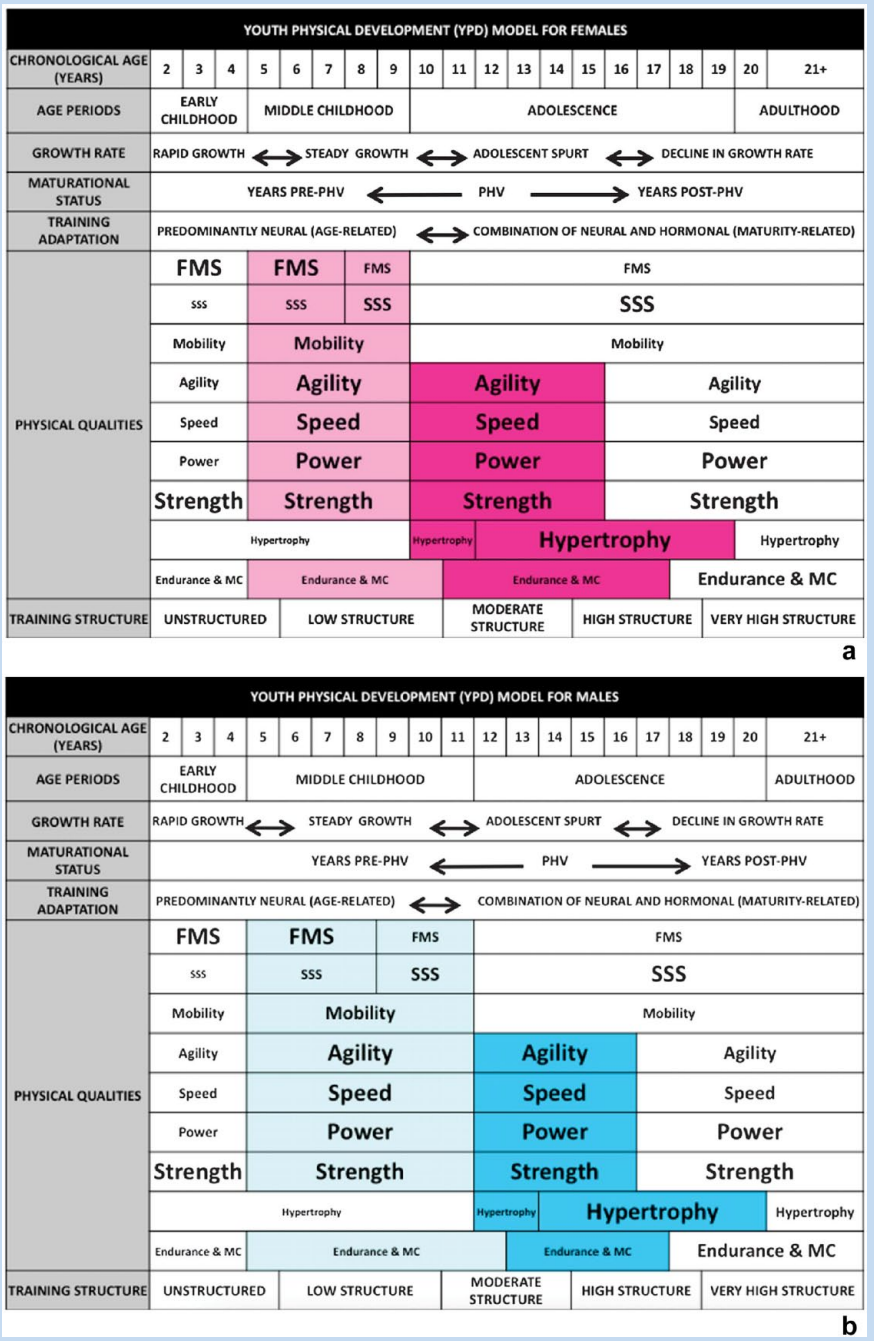

Figure 4. Youth physical development (YPD) model for females (pink) and males (blue).[14] The physical qualities emphasized at different stages of development are shown in both charts. The size of the text correlates with the physical quality that should be emphasized (eg, larger text should be more emphasized, smaller text is less emphasized). FMS, fundamental movement skills; MC, metabolic conditioning; PHV, peak height velocity; SSS, sport-specific skills.

Consideration of Recreational and High School–Level Sports Participation

These models are geared toward training and developing youth athletes with the goal of achieving elite levels in sport. Although some of the new models provide alternative training stages for youth interested in high school sports, recreational sports, and lifelong physical activity, there is still a larger emphasis on the elite-level athlete.

Table 1. The Physical Qualities of the Youth Physical Development (YPD) Model

Physical Quality	Description	Incorporation in Relation to Developmental Stage
Fundamental movement skills (FMS)	Building blocks for sport-specific movements with a focus on gross motor skills	Emphasized during early and middle childhood prior to peak height velocity (PHV); for older age groups it becomes integrated into dynamic warm-ups[20]
Strength	The maximal muscular force that can be generated	Should start in early childhood before PHV, as there is rapid neuromuscular development during this time[20]; it is a complement to FMS; increased strength is associated with improved FMS, speed, power, and endurance[14]; high aerobic fitness with low strength may increase risk of overuse injuries[20]
Hypertrophy	Starting period differs by gender (age 12 years for girls and age 14 years for boys)[20]	Hypertrophy is linked to increased levels of circulating sex hormones[25]; this type of training should be incorporated with strength training after PHV[20]
Power	The product of strength and speed of muscular movements[19]; vertical jump height is an indirect measure of lower body muscular power	Middle childhood before PHV and during adolescence[20]
Speed	Speed training is associated with neural adaptation and maturation and is trainable through childhood and adolescence[18]	Preadolescents should focus on neural activation with plyometrics, technical competency, and sprint work; adolescents should focus on neural and structural development with plyometrics, strength training, and sprint training[18]
Agility	Agility includes the ability to change direction of speed and cognitive function[28]; neuromuscular and structural development during adolescence contribute to change in direction of speed[18]	Can be trained regardless of developmental stage; however, true increases are seen in late childhood[20]
Mobility	The body's ability to control movement through a range of motion	Throughout childhood, but best incorporated at middle childhood
Endurance	Set percentage of VO_2max that can be maintained as long as possible[3]	Specific endurance training should occur in adulthood, but there will be sport-specific endurance training exposure throughout childhood (although never the primary focus)

Rethinking "Windows of Opportunity" and Different Stages of Training

It is unknown whether the "windows of opportunity" in the LTAD model are generalizable or whether there are individual differences. Van Hooren and De Ste Croix[34] suggested that breaking down athletic training into manageable constructs is reductionist logic that discredits the overall complexity of the field. The LTAD models tend to focus on a singular attribute to train during a specific "window of opportunity," but often attributes, such as flexibility, speed, strength, and so on, are all interconnected in their training. They question whether it is possible to increase overall speed without concurrently giving

attention during training to other necessary attributes, such as coordination and balance. Focusing on specific windows of opportunity may be discouraging to young athletes, sports providers, coaches, and educators if missed and ultimately result in a negative experience or discouragement of achieving a certain level in sport. Van Hooren and De Ste Croix go on to note that these models point out what should be trained at each developmental stage, but they do not provide frameworks for how best to train these qualities—that is, resistance, plyometric, or other forms of training—as certain motor skills may respond better to specific training techniques. More specific questions regarding skill-specific training, such as timing (during or after warm-ups), number of days per week, repetitions, and duration of rest period, are also important to answer to fully understand the practical application of LTAD models.[34]

Examples of elite athletes who were late specializers may be a proof of concept that these windows of opportunities are not as rigid as presented in current models. Falk et al[9] studied female rugby players (ages 18-23 years) that were considered at the "training to perform stage" (eg, training to win stage). They studied anthropometric and fitness characteristics, including height, body mass index, grip strength, flexibility, endurance, and others. Overall, they found little to no improvement in these qualities when tracking individual performances across multiple seasons while implementing the appropriate LTAD steps at the training to win stage. This study demonstrated that despite their expected developmental stage, participants were already considered "elite athletes" and the use of the LTAD model was only effective in maintenance of current fitness level and did not increase athletic ability.[9] Finally, the YPD model does not explicitly differentiate the stages of training that are mentioned in the LTAD model.

Impact of Extrinsic Factors

The LTAD and YPD models place a large focus on classifying children's overall developmental/athletic stage to provide the most effective training possible. Although this is critical, it may not be the only factor worth considering. There are nutritional, environmental, and psychological factors that also influence an athlete's readiness for a certain stage.[10]

Notably, race, ethnicity, socioeconomic status, and youth who identify as LGBTQ (lesbian, gay, bisexual, transgender, queer or questioning) were not accounted for within any of the models discussed.[32] Limited data exist on the generalizability of these models across diverse populations of athletes. The LTAD model does offer a systems approach to integrating the physical education system, school sports, elite-level sports and recreational sports, which provides a framework for other public health systems and equitably encourages lifelong participation in sport. The LTAD model also has been adapted to become a holistic model specific to Indigenous peoples across Canada and has been adapted to various specific sports. However, in general, these models do not directly account for financial constraints of different components (for example, public school education system vs elite competitive team) or that not all athletes have access to the same resources (for example, a young athlete from a household of low socioeconomic status that does not have access to sports leagues or other physical activity programs for the development of physical literacy skills).

The development of broader policy initiatives is important to solve inequity in accessing sports. The National Youth Sports Strategy (NYSS) was developed by multiple experts in the area of sports medicine and provides a framework for holistically understanding youth sports participation in the United States.[32] At the base of this framework, there is emphasis on addressing equity and inclusion for accessing sports, developing physical literacy and creating opportunities for sports sampling.[32] A 2017 study quoted in the NYSS revealed that only 58% of youth ages 6 to 17 years participated in sports after school or on weekends in that year.[32,33] "The rates of participation were lower in racial and ethnic minorities, youth from lower income households, youth with a disability and those who identify as gay, lesbian, bisexual or not sure."[17,31,32] From a public health perspective, designing easily accessible parks and recreational facilities for community engagement in athletics may reduce this participation gap. It may also increase awareness and exposure to youth sports to allow positive first and ongoing experiences in sports, which have been emphasized in the LTAD model as key drivers to lifelong participation.

Providing a framework for youth with disabilities is another area where these models can be expanded. The additional steps identified by Balyi et al[1,2] in the LTAD for youth with disabilities require system-wide changes to be successful.[29] Without additional resources, even with the additional prestages of awareness and first involvement, athletes with disabilities may have a difficult time progressing through the various stages of athlete development because of lack of programming, equipment, transportation, adapted facilities, and coaching.

The Canadian Sport for Life model recognizes the importance of integrating all levels of recreation (physical education in schools, school sports, recreational, and elite-level sports) to equalize opportunities for all youth.[29]

FUTURE DIRECTIONS AND RESEARCH

Research is needed to measure the effectiveness of these youth athlete development models and whether they achieve their stated goals of improving physical literacy, promoting long-term success in sport, and promoting lifelong physical activity. Further study must also be carried out to assess the applicability of each model to specific sports or types of sport (eg, early vs late specialization sports, team vs individual sports) and diverse populations (all levels of socioeconomic status, various races/ethnicities, youth with disabilities, and LGBTQ youth). It may be the case that not 1 singular model is ideal for all youth, and that a combination of models and/or an individualized approach may be the most effective for maximizing athletic potential and promoting lifelong participation in sports and physical activity.[27]

CONCLUSION

The models of youth athlete development discussed in this review can be used to guide the development and training of youth athletes. Although there are limitations to each of these models, they are an important resource for physicians, athletic trainers, coaches, physical educators, parents, and others interested in the development of youth athletes. An individualized approach is important to consider when implementing the models discussed to ensure inclusion and applicability for all athletes.

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