REVIEW ARTICLE

Sex differences in growth, skeletal maturation, and training load in youth sports: Implications for long-term athletic development

Arman Sargsyan . *Independent Soccer Coach. PFSA-Certified Scout. Glendale Community College. US Soccer Federation. United States of America.*

ABSTRACT

Competitive youth sport participation has been shown to benefit physical, psychological, and social development in children and adolescents. However, recent trends involving increased training volume, early sport specialization, and performance-based youth sport systems have elicited questions around youth biological maturation and skeletal development. These concerns include increased susceptibility to injury and overall athlete well-being later in life. This narrative review aimed to discuss sex-specific differences in growth and skeletal maturation as they relate to training load considerations in youth athletes. PubMed, Google Scholar, SPORTDiscus, and Scopus were used to search for peer-reviewed literature related to youth biological maturation, peak height velocity, skeletal development, training loads, risk of overuse injury, and sport participation. Results were synthesized according to themes including biological development and growth, injury susceptibility, training load considerations, and psychosocial implications of youth sport participation. Female athletes were found to mature earlier on average than their male counterparts, experiencing pubertal onset, peak height velocity, and subsequent skeletal maturation around 8–13 years of age. Compared to females, males experience this process later but over an extended period that can continue into late adolescence. Physiological changes during periods of rapid growth can temporarily alter coordination, movement efficiency, and injury susceptibility, especially under conditions of high training load and inadequate recovery. Failure to account for individual differences in training load relative to biological development may increase risk for overuse injury, growth plate injury, and psychological burnout. Researchers and coaches should be aware that training programs based on chronological age may not account for individual variability. Load management, movement competency, recovery, and long-term athlete development should be considered when developing training programs to reduce injury risk and promote healthy athletic development.

Keywords: Youth sports, Growth, Maturation, Sex differences, Skeletal development, Training load, Adolescent athletes, Growth plates.

Cite this article as:
Sargsyan, A. (2026). Sex differences in growth, skeletal maturation, and training load in youth sports: Implications for long-term athletic development. *Journal of Human Sport and Exercise, 21*(4), 1283-1300. https://doi.org/10.55860/kyv10r23

Corresponding author. *Independent Soccer Coach. United States of America.*
E-mail: armsarca@gmail.com
Submitted for publication April 23, 2026.
Accepted for publication June 01, 2026.
Published July 10, 2026.
Journal of Human Sport and Exercise. ISSN 1988-5202.

doi: https://doi.org/10.55860/kyv10r23

INTRODUCTION

Childhood and adolescence represent important time periods during which individuals learn to engage in physical activity, develop fundamental movement skills, and establish social relationships within sport. Participating in sport during youth may have many immediate and long-term health benefits. Outside of promoting physical activity and health, involvement in organized sport may have immediate benefits to confidence and psychosocial well-being, teamwork, and emotional health during childhood and adolescence. Recent trends within youth sport have been characterized by early emphasis on performance outcomes, increased year-round training volumes, and sport specialization at younger ages.

Although early sport specialization and training can be beneficial for some athletes, developing fundamental movement skills at younger ages, there is concern that high training volumes in a single sport during periods of intense growth may increase risk of injury and illness and promote early sport dropout. Though variability in growth, maturation, and development are common among children and adolescents, training doses are often not adjusted to account for individual differences in maturity.

Considerable variability exists in the age at which children reach peak height velocity (PHV), defined as the point at which individuals reach their maximum height growth in a given year. Athletes who mature early or later than their peers can experience relative discrepancies in training load as well as physiological and psychological stress from training and competition. Early maturing athletes may face higher training loads relative to their late maturing peers due to increased size, strength, and skill. Late maturing adolescents may be overlooked by coaches and adults because of their smaller physique and lack of strength despite having the potential to reach similar or higher levels of maturity than early matures.

In addition to absolute differences in maturation between children of the same age, males and females exhibit differences in maturation and growth. On average, girls experience pubertal hormonal changes earlier than males and ultimately reach PHV earlier than their male counterparts. Whereas female growth in height plateaus after PHV, males continue to grow at a slower rate into their late teens and even into early adulthood. These differences in growth and maturation may have implications for injury risk, movement coordination, athletic performance, and training responses in male and female adolescent athletes.

Growth velocity plateaus, particularly rapid skeletal growth, have been of particular interest when considering training load in youth athletes. Growth plates and developing musculoskeletal structures may be more vulnerable to damage from repetitive micro-trauma during periods of rapid growth. Therefore, excessive training volumes, repetitive sport-specific skill development, and high training loads with inadequate recovery periods have previously been associated with increased injury risk in youth athletes. Additionally, temporary changes in coordination have been observed during PHV that may influence movement quality and injury risk.

Increased awareness regarding growth and maturation among youth athletes has led to discussion on modifying athletic training during sensitive periods of development. Although a reduction in training load and sport participation has been suggested during rapid growth phases, research does not currently justify restricting youth athletes from sport during periods of rapid growth.

Thus, this narrative review had three primary objectives: (1) discuss sex-related differences in growth, development, and maturation in youth athletes, (2) discuss training load considerations and injury risk during periods of rapid adolescent growth and maturation, and (3) highlight considerations for evidence-based training and long-term athletic development in youth sport.

METHODOLOGY

The methodology followed a conceptual analysis design, from which an extensive review of current scientific literature across human movement sciences, developmental biology, sport medicine literature and youth training theory was synthesized.

A conceptual analysis was suitable as the topic explored requires consideration of developmental factors that cannot be feasibly or ethically experimented within youth populations.

This topic review took on a narrative conceptual review design. Multiple databases including PubMed, Google Scholar, SPORTDiscus and Scopus were searched in order to review current literature regarding biological maturation, skeletal development, sex differences, training load, and long-term athlete development with youth sport populations.

Search terms included ("*youth athlete maturation*" OR "*peak height velocity*" OR "*skeletal development*" OR "*sex differences in growth*" OR "*training load*" OR "*growth plate injuries*" OR "*overuse injuries*") AND ("*late physical development*" OR "*physical development*" OR "*long term athlete development*"). Articles were primarily limited by date (published between 2000-2025) and peer-reviewed status.

Articles were included if they reviewed youth athletes and covered one or more of the topics of biological maturation, adolescent growth and development, injury risk, training load, or psychosocial implications of sport. Consensus statements, longitudinal studies, cross-sectional studies, as well as paediatric sport science literature were included. Articles were excluded if they focused only on adult samples or did not focus on the clinical topic of interest. Literature was then compiled into themes focused on the following:

1. Biological growth and maturation.
2. Skeletal development and injury risk.
3. Training load.
4. Psychological and developmental implications.

A narrative review was used due to the inability to experimentally isolate coaching, biological, physiological, and psychological factors in youth sport.

Growth patterns and pubertal timing

Puberty typically starts between the ages of 8-11 for girls and 10-13 for boys. Girls go through puberty much earlier than boys which means they experience their linear growth, increases in body mass, and skeletal maturity earlier.

PHV (Peak Height Velocity) is when the athlete experiences their greatest gain in height over a one-year period. Girls reach PHV around 11-13 while boys hit PHV closer to 13-15. This is also when girls will experience rapid increases in leg length, bone mineral accrual, and body proportions.

Since girls hit this peak earlier, they also recover from this point sooner than boys. Most girls will stop growing around 14-16 years old. When it comes to boys, they continue to grow later into their teenage years and even into their early 20's.

These developmental differences have important implications for youth sport participation and training design. During early adolescence, females may temporarily demonstrate advantages in coordination, stature,

and physical maturity due to earlier pubertal onset. In contrast, males often experience delayed but prolonged growth and maturation extending into late adolescence. These differences should be considered when evaluating athletic performance, prescribing training loads, and interpreting physical capabilities during developmental years.

Skeletal development and growth plates

Another thing to take note of with biological sex differences is growth plates (Caine et al.,2006). Growth plates, also known as phases, are areas of cartilage that connect the end of long bones to the epiphysis. They are the last portion of the bone to mature, thus they are responsible for longitudinal bone growth.

Growth plates typically close sooner for girls due to their earlier onset of puberty and oestrogens ability to speed up skeletal maturity. Growth plates for girls usually close between 14-16 years of age. For boys, growth plates take longer to close resulting in a longer timeframe for injury. Growth plates for boys can close anywhere between 16-18 years of age and some boys can even continue growing until they're 20 years old.

Due to prolonged periods of skeletal growth in males, growth plates remain susceptible to repetitive mechanical stress for longer durations during adolescence. Although physical activity itself does not negatively alter bone growth under normal conditions, growth plates are structurally weaker than mature bone and surrounding soft tissue structures during rapid developmental periods. Consequently, repeated exposure to high-intensity sprinting, jumping, cutting, and contact-based activities may increase susceptibility to overuse injuries and physical stress during sensitive growth stages.

This is why sports like football and basketball have high instances of growth plate injuries. These sports require athletes to perform lots of high-intensity movements while also growing at a rapid rate.

Hormonal influences on growth and performance

Oestrogen and testosterone also play a huge role when programming training for boys and girls (Hewett et al.,2006). As previously mentioned, oestrogen causes girls to reach PHV earlier and also quickens the closure of growth plates. During puberty, oestrogen increases a girls bone mineral density.

Testosterone has different effects on boys. Testosterone increases lean body mass, strength, and power. Testosterone also increases bone mineral density and how bone is structured.

Times of accelerated growth, where muscle strength and limb length are increasing at a faster rate than neurological and movement adaptations can occur, the athlete may experience periods of decreased balance, coordination, movement efficiency and motor control. These deficits occur during growth spurts and are normal and expected, so practitioners should not use these fluctuations when determining potential or progression.

In a perfect world, boys would get stronger and faster while maintaining proper coordination and skill. However, this is not always the case during rapid growth. Coaches should focus less on training max output and more on movement quality and coordination during this time.

Sex differences in physical maturity and sport selection

Sex is another factor that can affect sport selection. Many times younger athletes are selected based on their physical ability and not their skill. Since most girls reach puberty earlier than boys, they are often bigger, faster, and stronger than boys of the same age.

This creates a problem for boys who are late bloomers. These late-maturing boys are often overlooked during sport selection despite having the potential to be just as good as the athletes selected.

Many people do not know this, but most elite level athletes were not the best athletes in their youth. They just matured at a later time allowing them to overtake other athletes once they caught up.

Implications for youth sports training

Boys and girls grow and mature at different rates, and awareness of these distinctions in maturation timing allows practitioners to develop safe training systems that maximize biological differences. Programs that do not consider maturation often place both sexes at risk of experiencing inappropriate training loads relative to their individual biological capability, which can contribute to higher injury, burnout and dropout rates. Developmentally-driven training that is relative to athlete biology through manipulations of intensity, training volume, and systemic expectations can help athletes become better skill learners, decrease injury risk, and create safer training environments for long-term athletic development.

Ultimately, growth and maturation should not be seen as barriers to performance but as opportunities to improve movement technique, coordination, and movement skill competency.

RESULTS

Adolescence is a period of increased risk for injury in youth sport because of the mismatch between rapid biological growth and development on one hand, and maturation-independent training loads on the other hand. Organized sport participation can be beneficial from a physical and psychosocial standpoint, however excessive or inappropriate loads during sensitive periods of rapid growth may lead to increased injury risk, maladaptation, or pathologies that extend into adulthood. Adolescent athletes, specifically males between 13–15 years old, often experience rapid linear growth during their peak height velocity that their bones experience years before the required muscular and neuromuscular strength to control and adapt to their new body dimensions catches up.

During periods of peak height velocity, bones will grow at a much quicker rate than muscles, tendons, and neuromuscular control can adapt. This results in a temporary shift in movement mechanics, joint loads, and shock absorption capacity. This may lead to athletes displaying poorer coordination and a loss of flexibility while undergoing higher degrees of mechanical stress.

High-load repeated sprinting, jumping, cutting, and contact movements may place high amounts of stress through growth plates, apophyses, and tendon attachments. Apophysitis conditions such as Osgood–Schlatter disease and Sever's disease are common training-related injuries during periods of accelerated growth. These conditions are not caused by a disease but rather represent an overflow of the training stimulus on the ability of the athlete to biologically handle that load at that given time.

Overuse injuries in young athletes

Upwards of 30–50% of musculoskeletal injuries in active youth are overuse injuries. Unlike acute traumatic injuries that occur suddenly when a force surpasses tissue tolerance, overuse injuries are the result of repeated sub-maximal micro-trauma that cumulatively exceeds the tissue's ability to adapt and recover from the imposed load. Risk factors for overuse injuries include high training volumes, low recovery periods, early sport specialization, and playing for multiple teams simultaneously.

Football and basketball are year-round sports for many athletes. This training model often lacks planned rest periods which can lead to overuse or chronic adaptations of bone and soft tissue injuries, particularly when linear growth is at its peak. Due to open growth plates and incomplete physical maturation, adolescent boys between the ages of 13–15 are susceptible to stress reactions from insufficient load management.

Does heavy training during adolescence stunt growth?

One popular belief from parents and the general population is that playing sports and engaging in heavy training will stunt an athlete's growth. Research does not support the claim that growth will be stunted from properly implemented training during adolescence.

Longitudinal research monitoring athletes' height during their active years of sport have shown that athletes retain their genetically predetermined height potential even while being active in sport. With that being said, when yearly training loads are excessive compared with the ability for the body to recover from that load, injuries can happen. These chronic stress injuries to growth plates can alter the growth of that local area of the bone if left unidentified or not properly managed. Energy availability can also play a factor with growth and training. If athletes are not consuming enough calories to support their training volumes, hormone disturbances can occur which can affect growth and bone mineralization.

Should I take my adolescent athlete out of sport?

There is insufficient evidence that athletes should completely stop participating in sport throughout their years of accelerated growth and development. While training should still occur, participants in structured training programs during adolescence can gain important physiological, psychological and social benefits. Modifications in overall training load, competition schedules, and repetitive high intensity movements may benefit the adolescent athlete during their PHV to decrease unnecessary stress to growing musculoskeletal tissues.

Minimizing high intensity training and exposure to competitions may be beneficial during these adolescent years. Modifications can include decreasing number of competitions, limit repetitive maximal sprinting and jump bouts, and including low-impact cross-training activities to help decrease injury risk. Emphasis should be placed on movement quality, coordination, flexibility, skill development, and recovery during these times of sensitive growth.

How does overtraining affect adolescent mental health?

Heavy training loads may not only affect physiological outcomes, but psychological health as well. Chronic fatigue, underperformance, poor sleep, and repeat injuries have been linked to psychological distress, burnout and demotivation in youth athletes. Additionally, adolescence is a time where there is heightened brain development and psychological changes, so adolescents may be especially susceptible to outside pressure to perform and be competitive.

Motivational climates that focus heavily on outcomes can lead to burnout, anxiety and dropout from sport. Creating a more supportive environment for the athlete that focuses on long-term development and skills, autonomy, fun and freedom from fear of failure may promote positive health and sport longevity.

Modifying training loads during adolescence

So you know training shouldn't be stopped during adolescent growth, but how do you actually modify training? Like previously stated, training should be individualized based on the athlete's stage of development.

Although this takes research, time, and knowledge, there are simple ways to modify an athlete's training that does not need to be completed by coaches alone.

Some simple methods to modify training loads during adolescence:

- Track height over years to determine when PHV occurs.
- During PHV, reduce training volume and intensity.
- Emphasize technique, coordination, flexibility.
- Allow for enough recovery time and sleep.
- Monitor dietary habits to ensure energy demands are being met.
- Educate coaches and parents on Adolescent Growth and Development.

Coaching considerations

Coaches can also unknowingly impact how their athletes adapt to their training based on their knowledge of growth and development. Many coaches see results quickly when they start coaching. They expect the same when they start coaching young athletes. These coaches don't understand that paediatric athletes are growing and maturing at different rates.

If coaches are not educated on how growth and maturation can affect athletes, they may become frustrated with athletes that are not progressing like their peers or "*look*" older or younger than the rest of the team. These coaches will often misjudge athletes that are late bloomers and forget about these athletes when long-term athlete development comes into play.

Remember there is always a reason why athletes perform the way they do. Just because they may be underperforming during their growth spurt, doesn't mean they don't have the potential to be a gifted athlete in the long term.

Practical training implications for football(soccer) and basketball during growth and maturation

Understanding of growth and maturation is useless if it does not drive action and decision-making by coaches. Often environments for youth football and basketball place too much emphasis on early success, game playing volume, and physical domination without consideration for variations in maturity status between boys and girls. This article provides translation of growth and maturation science into practice by providing training principles based on evidence that allow for long-term athletic development and a reduced risk of injury and dropout.

Chronological age vs biological age in training design

The biggest issue in youth sport is that maturity is not accounted for when programming training loads, placing kids into competition groups, and selecting who makes the team. Chronological age does not matter when you consider inter-individual differences at any given age can be up to 2 years of biological maturation.

Strength and speed differences in football and basketball are usually more pronounced during early maturation. Consequently, early-maturing athletes may be seen as better coaches and placed under higher loads and expectations. On the other hand, late-maturing athletes may appear less talented due to their lack of size and strength, even though they have the technical or tactical qualities necessary to be successful.

If we consider these aspects of maturation in our training programs we can:

- Create homogenous groups based on maturation for certain training activities.

- Increase or decrease training load in response to growth spurt.
- Benchmark performance against players biological age not final score.

Training considerations for female athletes aged 8–13

Puberty begins earlier for most female athletes. Some may even begin puberty by age 8. Due to rapid increases in muscle and fat gain, torso length, and limb growth, girls may temporarily suffer decreases in coordination and movement efficiency. As coaches, we cannot allow early physical development to cloud our judgement of these players (Côté et al.,2007).

During this stage of development, coaches should focus on:

- General movement skills.
- Basic posture and balance.
- Coordination.
- Building technical skills.
- Fostering confidence and independence.

Strength training is perfectly safe and beneficial for girls who are taught proper exercise technique and provided proper supervision. While too much volume, intensity, or early specialization can lead to injuries and burnout.

Additionally, some girls may feel more pressure from coaches and parents during early maturation. These athletes need to feel supported by their coaches and safe to express themselves.

Training considerations for male athletes aged 13–15

Most male athletes will experience their peak height velocity between ages 13 and 15. Because the skeleton often grows faster than nerves can adapt to new limb lengths, coordinative abilities and skill expression may temporarily regress or fluctuate. Some athletes may even show decreases in performance during this time. Let athletes know that this is normal and does not mean they are regressing or aren't trying (Lloyd & Oliver,2012).

Between the ages of 13-15, coaches should focus on:

- Movement Quality
- Posture and Balance
- Flexibility
- Restoring load after growth spurt

Male athletes should take caution with their training volume during this time. Too much sprinting, maximal strength, or year-round competition can lead to injuries or mental burnout.

Instead of taking time off, reduce load and allow the body time to adapt.

Early specialization vs diversified athletic development

Allowing athletes to sample different sports is something that has been discussed at length. However, early sport specialization is still common among football and basketball coaches. While research is limited, early specialization has been linked with overuse injuries, burnout, and dropout from sport.

Sampling allows athletes to learn new movement skills and enhance their abilities in multiple movement patterns. Motor learning is improved when children are exposed to different sports. In turn, they can become better athletes and less prone to injury. While early sport specialization does not guarantee poor performance in the future, encouraging athletes to participate in multiple sports during childhood and early adolescence can only benefit them (Ford et al., 2011).

Coaches and sport organizations can discourage early specialization by:

- Allowing athletes to participate in multiple sports during their early stages.
- Periodizing their off season and season training to focus on different sports.
- Help athletes develop skills that transfer across sports.
- Avoid year round competition.

This is especially important during peak growth periods because sports that require a high amount of repetition may overload tissues.

Monitoring training loads & recovery

Monitoring training loads during periods of growth is difficult because there is no cookie cutter program that works for every athlete (Frisch, 1994). Athletes are experiencing multiple changes that can influence their training capacity. Some signs of taking on too much load are:

- Fatigue.
- Inconsistent performance.
- Irritability.
- Recurrent or increased pain.
- Loss of motivation.

Coupled with a training diary, coaches can use simple tools like questionnaires, rating of perceived exertion, and even measuring their athletes growth to try to identify athletes who are at risk. Although sometimes the best tool is just asking your athletes how they feel.

Regardless of how you monitor your athletes, here are some recovery strategies to implement during periods of high growth:

- Sleep.
- Use reload weeks.
- Nutrition.
- Foster psychological recovery by giving athlete's freedom and fun.

The coach's responsibility

Coaches have the ability to influence youth athletes' experiences and impact athletic performance as well as physical and psychosocial health. Educating coaches about the relationship between biological age, training load, and fluctuations in development may help to facilitate training environments and skill development that focus on the athlete's long-term development rather than on short-term performance goals. Understanding that children's and adolescents' development does not occur on a fixed schedule can help coaches realize that fluctuations in coordination, movement quality, and sports performance are normal and may not be reflective of athletes with low sporting potential or lack of motivation. Coaching practices grounded in motor development and human growth principles should value technique, movement skill, injury prevention, psychological well-being, and progression based on biological age. If coaches understand how factors related

to growth and maturation can influence sports performance, they may be better prepared to aid athletes through these sensitive periods and minimize unnecessary stress.

Ethical responsibility in youth sport training

When you decide to coach or train children you are taking on the responsibility of that athlete's development. Some coaches will make decisions that they think are in the best interest of the athlete and program. But we have to ask ourselves, is it really in the best interest of that child?

As coaches, parents, or administrators, we can change the way we think about training children. The decisions you make can alter someone's health for the rest of their life, but it can also change who they believe they are (Malina et al., 2004).

If we take these stages of growth and development into consideration, we can start building better athletes that will stay healthy and happy playing the sport they love.

DISCUSSION

Integrating growth, maturation, and training load in youth sport development

Results/Concepts presented above have demonstrated the importance of viewing training in youth sport with a development and maturation approach. Sports such as football and basketball are high intensity intermittent sports that require the body to perform mechanically demanding tasks while also coordinating complex movement patterns. As a result, if we ask these athletes to participate in football and basketball without taking into account their biological age, maturation rate, and sex-related growth characteristics there can be a high potential for maladaptation (Rowland, 2005).

Growth-related variability as a central developmental factor

Probably the biggest theme to come from the previous sections is that growth and maturation is not linear. Children and adolescents do not grow consistently or predictably in their physical capabilities. Instead, their performances ebb and flow based on a wide variety of growth related factors. Too often these fluctuations are attributed to a lack of effort, poor discipline, or lack of talent (Malina et al., 2015).

For boys especially, the months before and after their peak height velocity is reached can be very frustrating. Simply put, their limbs are getting longer quicker than their bodies can adapt to. This creates temporary weaknesses in leverage, joint loading, and muscle coordination. In girls, early matures can appear to be further ahead than they actually are. This sometimes leads to training and competition volumes that are too high too early.

Understanding that growth related variability is normal is an important step in avoiding premature athlete classification and minimizing unnecessary dropout.

Talent identification and selection should be questioned

Many talent identification programs in football and basketball reward the most physically dominant athletes at a young age. This has created a system that favours athletes who mature early and punishes athletes who mature later. Research has shown again and again that early physical dominance does not translate into late adolescence and that technical, perceptual, and cognitive qualities separate elite athletes from their competition (Vaeyans et al., 2008).

But early selection does more than miss out on late bloomers. It also places a larger training load on young athletes during periods where they are more susceptible to injury and burnout. Late blooming boys and early blooming girls are put under greater physical and mental stress during these sensitive growth periods.

A better framework for selection would focus less on current physical prowess and more on an athlete's capacity to learn and develop. Factors like adaptability and decision-making ability should be valued over purely physical traits.

Load accumulates rapidly and injury risk is high

Training load increases have been shown to increase injury risk dramatically during adolescence. Growth changes adolescents undergo cause fluctuations in bone density, muscle-tendon stiffness, and neuromuscular coordination which decrease the tolerance to repetitive stress. When volume, intensity, and frequency of training are all increased at once like they often are in competition settings, accumulated load can reach dangerous levels.

Another thing to note about injuries during periods of growth is that they can have long-term consequences. Adolescents who experience injuries that affect their movement patterns can suffer from chronic pain, fear of movement, and lack of confidence years down the road. These types of injuries don't just affect their athletic performance, but their overall activity levels throughout their life (DiFiori et al., 2014).

This evidence lends support to a model of load regulation that bases training load off of growth rather than arbitrary age categories.

Psychological implications of growth-sensitive training

Physical development is inherently linked to psychological development. Periods of significant growth can make athletes feel more self-conscious and aware of their peers. Adolescents who may not be performing up to their physical peak during these growth periods can be subjected to frustration, loss of confidence, and fear of failure.

Training programs that normalize growth variability and emphasize effort, learning, and autonomy help to reduce some of these negative psychological responses (Meyers et al., 2017). But training environments that make athletes feel as though their worth is solely based on their performance can cause some serious issues. These issues range from temporary stress to burnout and dropout.

Is temporary reduction or modification of training necessary?

Alteration to training load may be warranted during periods of accelerated growth and maturation. Emerging research indicates that high training volumes, repetitive loading, and inadequate recovery during periods of peak height velocity may contribute to an increased risk of overuse injuries and movement impairment in youth athletes. Withdrawal from sport does not have to be the method used to alter training load.

Participation in training that is technically and developmentally sound may have benefits for skill development and psychological growth during adolescence. Movement quality, coordination, technical skills, flexibility, and recovery should be emphasized during these critical periods of development while competitive stress and high-volume training may be reduced.

Implications for coaches & sport organizations

Ideally new information like this would cause coaches to throw out all of their training programs and start over. But realistically coaches, sport organizations, and parents are stuck in a system that reinforces poor

training practices. Programs don't change because they've been around for a long time, institutions don't change because "*that's how they've always done it*," and coaches don't change because win-loss records do (Cumming et al., 2017).

As long as these things continue to be the case, there will be coaches trying their best to provide athletes with developmentally appropriate training but feeling defeated by outside sources.

Early specialization can be thought of as a high training volume in one sport prior to pubertal maturation , typically exclusive of other forms of physical activity. Although early specialization may give children who specialize an advantage early on in their athletic careers (primarily those who mature early), longitudinal studies have found that early sport specialists are more likely to suffer from injury, burnout, psychological stress and dropout from sport.

From a biological perspective,, early specialization loads skeletal and neuromuscular structures during windows of increased biological growth. Sport-specific stresses, such as directional changes, jumping, sprints, and movements on one leg place large amounts of force on immature structures such as growth plates and connective tissue. If continued without proper rest these high amounts of stress can alter normal bone modelling, which coupled with improper technique can lead to ongoing musculoskeletal issues later in development. This problem is prevalent in boys between the ages of 13–15 due to their increased training load from playing sports at this age coupled with their peak height velocity. Conversely, research has shown that exposure to a variety of sports during childhood and early adolescence has been shown to promote better coordination into later adolescence and early adulthood. Playing multiple sports promotes consistent loading of the musculoskeletal system, allows for better perceptual motor development and challenges athletes to problem solve in multiple movement scenarios. There is no benefit to early specialization if the goal is to be successful in that sport. Many experts have found that elite athletes actually specialize later than non-elite athletes. For this reason long-term athletic development models recommend waiting on specializing until late adolescence.

Implications for policy, coach education, and athlete retention

Competitive sport programs that group children based on their date of birth alone need to be reformed. Grouping by chronological age does not account for the different rates at which children develop, leaving late matures at a distinct disadvantage. This is especially true in early to mid- adolescence where the late maturing boy is often mistaken for being uncoordinated or not trying hard enough. Education of coaches is one of the easiest ways to try and inform athletes during these sensitive times of growth. Many coaches are not aware of the effects of growth and maturation on athletic performance. If coaches knew how to better identify signs of growth, they could use that information to their advantage when dealing with athletes. Implementing education that focuses on biological age vs. chronological age, monitoring of growth, and training techniques that alter training load based on the athletes' stage of maturation can help to better equip coaches to make informed decisions.

Coaches who understand that many athletes will display poorer coordination or fluctuations in performance are growth are more likely to work with the athlete through these difficult stages (Myer et al., 2015). Ensuring that athletes feel safe and comfortable is one of the best ways to keep them participating in sport. Adolescents who feel as if they are constantly being evaluated on their athletic abilities during these tough stages of growth are more likely to drop out of sport. Sport programs should strive to keep kids active by rewarding them for things other than their athletic ability. If kids are praised during their participation for factors such as learning, improving or even their effort, less kids will quit sports.

Is it okay to get young athletes injured if they want to become professional?

Ideally, training programs take injury prevention into account and consider periodizing for training load as well as considering general long-term athlete development (LTAD) guidelines. Unfortunately, some youth sport settings have unhealthy values that applaud early specialization and high workload despite the years of research demonstrating that high loads during sensitive periods can contribute to injury risk, burnout, and dropout. Furthermore, early relative age effects in sport can lead to young athletes playing sports who are less mature being at risk for poor psychosocial experiences from negative sporting environments. For example, late-developing athletes may lack confidence from fewer playing opportunities or poor taste coaching with early developers being taken advantage of their physique and not learning proper technique.

Future directions for research and applied practice

There is potential for future work to assess biological age concurrently with biological, psychological and performance variables longitudinally to investigate interactions between maturation and training exposure over time. Future studies may consider following cohorts over time to determine how altering training loads during youth impacts adult performance outcomes, injury rates, and sport attrition rates. Qualitative data from athletes can also be used to contextualize the experiences that athletes face throughout development.

Additionally, future applied work may consider implementing bio-banding, alternative competition structures, and individualized training into youth sport programs as the foundation rather than as an alternative option. If youth sport scientists, coaches, paediatric sport medicine doctors and policymakers work together to bridge the gap between research and practice, we can design better future studies and start moving toward a youth sport system that is based on evidence.

Remember kids grow, plan their training accordingly. Although female athletes may mature earlier than males, they both grow and should be trained differently than elite adult athletes.

As coaches, parents, and mentors we can control the training that we are giving our athletes. If we continue to train young athletes like elite adult athletes we are putting them at risk for injury and early dropout. By programming appropriately for their age we can help ensure that athletes can have long and healthy careers in the sports they love.

Growth, training loads, and injury potential

This article highlighted that growth isn't the injury cause, but when growth is paired with excessive or inappropriate training loads can increase injury risk. During growth spurts athletes can get much taller overnight and their limbs can lengthen rapidly. This drastically changes an athlete's biomechanics, coordination, and how their body handles load through muscles, bones, and tendons.

If an athlete's training load (intensity, volume, and competition load) does not decrease during these time periods while they are growing, they become susceptible to overuse injuries, growth plate injuries, and increased neuromuscular risk.

Maturation is characterized by different patterns in boys and girls. Girls mature faster than boys. Girls start puberty earlier and finish puberty earlier as well. In girls there is a rapid development of height, weight, and skeletal age between ages 8 and 13 years old. Girls have a performance advantage over their younger counterparts and opposite sex early on due to advanced coordination and size. Girls also experience higher risks of ligament injury due to increased laxity during this time of accelerated growth. Hormonal changes also impact training load tolerance and recovery. Boys experience this rapid development later than girls which

can shift the age of these pros and cons. Increased muscle mass and strength continues into young adulthood for males. Training could be adjusted based on sex to avoid unfair workload expectations. If biological sex is considered a moderator for maturation there can be more individualized training and development can occur while reducing the risk of overloading young athletes.

The article is not implying that youth athletes should take time off from their sport to allow themselves to grow, especially boys who are between the ages of 13-15. What we can do is alter how we train these athletes by appropriately manipulating training load, exercise selection, and competition volume to accommodate their growth (Philippaerts et al., 2006).

Implications for coaching practice

If you coach youth athletes, it is your responsibility to train them in a way that will help them grow as athletes while not risking their health or development. These athletes, just like any other athlete you have coached, want to get better at their sport.

However, just because two athletes are the same age does not mean they are the same maturity level. Two athletes can be the same chronological age but one may still be growing while the other has stopped growing. As a coach, you should:

- Keep track of your athletes growth and maturation.
- Take unnecessary training load out of their workouts when they are growing.
- Use growth as an opportunity to really focus on athletes technique and decision making.
- Help your athletes move better.
- Ensure your athletes are in a positive environment that values their mental health.

Not only can this decrease injury and dropout but also can allow athletes to continue to play the sport they love for longer.

Directions for future research include conducting prospective longitudinal studies that combine data on biological growth and maturation, biological assessments, psychological measures, and athletic performance outcomes. This will allow researchers to better examine the relationship between maturation and training over time. Longitudinal studies can also provide insight into how different training interventions during adolescence may impact performance outcomes, injury rates, and sport participation later in life. Researchers should also consider using a mixed-methods approach that incorporates qualitative interviews with athletes to better understand their experiences. From a practical standpoint, sport organizations can consider adopting bio-banding, tournament play, and individualized training as the normative approach instead of utilizing them as an alternative method. Sport scientists, coaches, paediatricians, and sport governing bodies should work together to implement findings into practice.

Implications for parents and sport organizations

Parents can help by helping set reasonable expectations for their children. The growth phases that we talked about can cause athletes to have good days and bad days. This unknown fluctuation in performance can be frustrating to both the athlete and parents. As parents we want our kids to be the best they can be, but setting unrealistic expectations can cause stress to the athlete and lead to burnout.

Sport federations and academies should take a look at their current early age sport specializations and high competition volumes. In many sports, athletes are selected very early on and rewarded for being talented when they are young. Naturally, this tends to select for athletes who mature early and not necessarily who

will be the best athlete. Until sport federations and academies change their athlete groupings to be based on maturity and limit the amount of competition that youth athletes are facing during growth sensitive times, they are failing their athletes.

Ethical responsibility in youth sport training and selection

This article took a lot of different articles and combined their information to get a better understanding of how growth affects training. However, there is always more research that can be done on a topic. Some suggestions for future research would be:

- Track athletes training load while measuring their growth.
- Look at injuries in male vs female athletes during growth stages.
- Study the effects of training based on athletes maturity level.
- Look at the psychological effects that these growth phases have on athletes.

The current training practices used in youth sport systems place undue emphasis on early performance outcomes at the expense of health and relative age equity. There is an ethical obligation to protect the health and well-being of youth athletes and allow for their long-term development. Selecting against late bloomers and training athletes through growth stages without considering individual rates of maturation has ethical implications of justice, fairness, and autonomy. Youth athletes are unable to fully grasp what high training loads will mean for their development in the long-term and do not understand why they may not make a team or play as much during growth years. For this reason, there is an ethical responsibility of the adults in youth sport to make decisions in the athlete's best interest.

To practice ethically in youth sport there are many considerations. Parents and coaches should be transparent with their athletes about their decision-making. They should continue to monitor athletes' growth and overall well-being. Parents, coaches, and sport organizations should avoid putting pressure on young athletes to play through growth or tie their self-worth to sport performance. Athletes should not perceive taking time off during a growth spurt as being unfair to the team or a sign of weak work ethic. If we can alter coaching certification programs and the policies of youth sport to think more ethically, we can change the culture of youth sport to one that values human development.

CONCLUSION

The purpose of this article was to share important information about growth and development as it relates to safely and successfully participating in sports. The research discussed within this article reaffirms the notion that growth and development are imperative when understanding how to safely and successfully participate in sports at a young age. Growth and development vary between boys and girls, with girls experiencing their growth spurt and skeletal maturity at a younger age (around 8-13 years old) while boys continue to develop later into their teenage years and even into early adulthood. By not taking this into consideration, you open young athletes up to unfair training expectations and potential injuries that could have long-lasting effects.

While some may see this as an advantage to push young girls to perform at higher levels for longer amounts of time, there is a negative feedback loop that occurs when girls stop developing at a young age. What you may see as a performance plateau or physical disadvantage during adolescent years (especially in boys 13–15 years old) is not a reason to give up on the child. Instead, we know that too much stress from training loads, early specialization, and chronic overuse can lead to injury (fatigue to bone), affect final height, and alter musculoskeletal health. A better solution would be to scale the workload (developmentally appropriate training) versus quitting the sport.

As you can see, youth sport needs to move from a win-at-all-cost philosophy to a long-term development approach. Parents, coaches, and sport organizations should all take responsibility for providing proper training loads and recovery based on the athlete's level of development and not their age. If we can keep young athletes healthy and training smart we can continue to see them grow not only as athletes but also as lifelong enthusiasts of sport.

Summary of key findings

In conclusion, this article found that females mature faster than males between the ages of 8–13 years old. However, males experience more growth than females between the ages of 13-15 years old and continue to develop physically into their early twenties.

Since this information directly relates to training load management, injury susceptibility, athlete well-being, and long-term development, we can better cater our training practices to athletes based on this information. For example, many coaches misinterpret early success in female athletes and early maturing boys as signs of talent. On the contrary, many coaches may misinterpret the physical setbacks that some athletes experience during growth spurts as a lack of motivation or poor work ethic.

Adolescents experience significant changes in height, weight, and limb length that affect biomechanics and muscle activation patterns (Rogol et al., 2000). Adolescents also experience phases of rapid growth that can result in transient decreases in motor skills, joint stability, and movement efficiency. Applying high training loads during these times without proper accommodation can increase risk of overuse injury, movement breakdown, and fatigue. Additionally, athletes are more susceptible to these effects during periods of rapid growth so it is important to take consideration of biological age versus chronological age when developing training programs. While being easily injured during growth may seem like a weakness, it is part of the natural development process (Till et al., 2017). Coaches should not perceive an athlete hitting a growth spurt as weakness or lack of motivation. Adding more stress on the athlete while they are more prone to injury can lead to increased risk of both physical and mental injury. Load management, movement assessments, and tracking growth should all be implemented into training to help reduce unnecessary stress and risk of injury while allowing athletes to reach their full potential.

In conclusion, this article found that females mature faster than males between the ages of 8–13 years old. However, males experience more growth than females between the ages of 13-15 years old and continue to develop physically into their early twenties.

Since this information directly relates to training load management, injury susceptibility, athlete well-being, and long-term development, we can better cater our training practices to athletes based on this information. For example, many coaches misinterpret early success in female athletes and early maturing boys as signs of talent. On the contrary, many coaches may misinterpret the physical setbacks that some athletes experience during growth spurts as a lack of motivation or poor work ethic.

Adolescents experience significant changes in height, weight, and limb length that affect biomechanics and muscle activation patterns. Adolescents also experience phases of rapid growth that can result in transient decreases in motor skills, joint stability, and movement efficiency. Applying high training loads during these times without proper accommodation can increase risk of overuse injury, movement breakdown, and fatigue. Additionally, athletes are more susceptible to these effects during periods of rapid growth so it is important to take consideration of biological age versus chronological age when developing training programs. While being easily injured during growth may seem like a weakness, it is part of the natural development process.

Coaches should not perceive an athlete hitting a growth spurt as weakness or lack of motivation. Adding more stress on the athlete while they are more prone to injury can lead to increased risk of both physical and mental injury. Load management, movement assessments, and tracking growth should all be implemented into training to help reduce unnecessary stress and risk of injury while allowing athletes to reach their full potential.

FUNDING

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

CONFLICT OF INTEREST

The author declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this manuscript.

AI USE DISCLOSURE

In accordance with current publishing ethics and transparency recommendations, artificial intelligence (AI) tools were used solely to assist with translation and language editing, with the aim of improving clarity and readability. No AI tools were used in the generation of scientific content, including the study design, data collection, analysis, interpretation of results, or the formulation of conclusions. The author retain full responsibility for the content of the manuscript and confirm its originality, integrity, and accuracy.

REFERENCES

Baxter-Jones, A. D. G., Eisenmann, J. C., & Sherar, L. B. (2005). Controlling for maturation in pediatric exercise science. Pediatric Exercise Science, 17(1), 18-30. https://doi.org/10.1123/pes.17.1.18

Beunen, G. P., & Malina, R. M. (2008). Growth and biological maturation: Relevance to athletic performance. In The Young Athlete (Vol. 3, pp. 3-17). https://doi.org/10.1002/9780470696255.ch1

Brenner, J. S. (2016). Sports specialization and intensive training in young athletes. Pediatrics, 138(3), e20162148. https://doi.org/10.1542/peds.2016-2148

Caine, D., DiFiori, J., & Maffulli, N. (2006). Physeal injuries in children's and youth sports: Reasons for concern? British Journal of Sports Medicine, 40(9), 749-760. https://doi.org/10.1136/bjsm.2005.017822

Côté, J., Baker, J., & Abernethy, B. (2007). Practice and play in the development of sport expertise. In G. Tenenbaum & R. C. Eklund (Eds.), Handbook of sport psychology (pp. 184-202). Wiley. https://doi.org/10.1002/9781118270011.ch8

Cumming, S. P., Lloyd, R. S., Oliver, J. L., Eisenmann, J. C., & Malina, R. M. (2017). Bio-banding in sport: Applications to competition, talent identification, and strength and conditioning of youth athletes. Strength and Conditioning Journal, 39(2), 34-47. https://doi.org/10.1519/SSC.0000000000000281

DiFiori, J. P., Benjamin, H. J., Brenner, J., Gregory, A., Jayanthi, N., Landry, G. L., & Luke, A. (2014). Overuse injuries and burnout in youth sports. British Journal of Sports Medicine, 48(4), 287-288. https://doi.org/10.1136/bjsports-2013-093299

Ford, P. R., De Ste Croix, M., Lloyd, R. S., Meyers, R., Moosavi, M., Oliver, J., Till, K., & Williams, C. A. (2011). The long-term athlete development model: Physiological evidence and application. Journal of Sports Sciences, 29(4), 389-402. https://doi.org/10.1080/02640414.2010.536849

Frisch, R. E. (1994). Body fat, menarche, fitness and fertility. Human Reproduction, 9(12), 2272-2278. https://doi.org/10.1093/oxfordjournals.humrep.a138427

Hewett, T. E., Myer, G. D., & Ford, K. R. (2006). Anterior cruciate ligament injuries in female athletes. The American Journal of Sports Medicine, 34(2), 299-311. https://doi.org/10.1177/0363546505282619

Lloyd, R. S., & Oliver, J. L. (2012). The youth physical development model. Strength and Conditioning Journal, 34(3), 61-72. https://doi.org/10.1519/SSC.0b013e31825760ea

Malina, R. M., Bouchard, C., & Bar-Or, O. (2004). Growth, maturation, and physical activity (2nd ed.). Human Kinetics. https://doi.org/10.5040/9781492596837

Malina, R. M., Rogol, A. D., Cumming, S. P., Coelho e Silva, M. J., & Figueiredo, A. J. (2015). Biological maturation of youth athletes. British Journal of Sports Medicine, 49(13), 852-859. https://doi.org/10.1136/bjsports-2015-094623

Meyers, R. W., Oliver, J. L., Hughes, M. G., Lloyd, R. S., & Cronin, J. B. (2017). The influence of maturity status on sprint speed and power in youth soccer players. Journal of Strength and Conditioning Research, 31(2), 439-445. https://doi.org/10.1519/JSC.0000000000001507

Myer, G. D., Jayanthi, N., DiFiori, J. P., Faigenbaum, A. D., Kiefer, A. W., Logerstedt, D., & Micheli, L. J. (2015). Sports specialization, part I: Does early sports specialization increase negative outcomes and reduce the opportunity for success in young athletes? Sports Health, 7(5), 437-442. https://doi.org/10.1177/1941738115598747

Philippaerts, R. M., Vaeyens, R., Janssens, M., Van Renterghem, B., Matthys, D., Craen, R., Bourgois, J., Vrijens, J., Beunen, G., & Malina, R. M. (2006). The relationship between peak height velocity and physical performance in youth soccer players. Journal of Sports Sciences, 24(3), 221-230. https://doi.org/10.1080/02640410500189371

Rogol, A. D., Clark, P. A., & Roemmich, J. N. (2000). Growth and pubertal development in children and adolescents. Journal of Adolescent Health, 26(2), 75-89.

Rowland, T. W. (2005). Children's exercise physiology (2nd ed.). Human Kinetics.

Till, K., Jones, B., Geeson-Brown, T., & Highton, J. (2017). Maturity-associated variation in training load in youth athletes. European Journal of Sport Science, 17(5), 626-635.

Vaeyens, R., Lenoir, M., Williams, A. M., & Philippaerts, R. M. (2008). Talent identification and development in sport. Sports Medicine, 38(9), 703-714. https://doi.org/10.2165/00007256-200838090-00001