"My Kid Is Going Through a Growth Spurt–What Should I Do?" Taking an Interdisciplinary Approach to Athletic Development During the Adolescent Growth Spurt

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ABSTRACT

Puberty is a critical period for young athletes, characterized by significant physical, psychological, and social changes. During puberty, young athletes experience the adolescent growth spurt at the same time as intensified training regimens, which can affect performance, injury risk, and overall health. Systematic training can improve physiological and performance outcomes, but the increased training volume and changes to the body during adolescence can also heighten the risk of injuries. This article discusses the injury risks associated with adolescent growth and provides comprehensive recommendations to mitigate these risks. Key recommendations include limiting training hours to the athlete's age, monitoring growth and maturation to adjust training loads and content, and incorporating and modifying consistent strength and conditioning prescriptions. In addition, optimal nutrition, sleep, and interdisciplinary planning among coaches, parents, and stakeholders should be emphasized to support young athletes' holistic development and well-being during the adolescent growth spurt.

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INTRODUCTION

Puberty is a dynamic period of the lifespan in which growth spurts in stature and mass occur, secondary sexual characteristics appear, and profound psychological changes take place (97). For most young athletes, this period also marks the initiation of a more structured and intensive approach to training and competition (63). Together, these changes have a profound impact on performance, injury risk, and the overall health of the adolescent athlete (14,27,30).

Although physiological and performance outcomes in young athletes are improved through systematic training (34,61), increased training volume and intensity during the adolescent growth spurt may increase the risk of injury (54). During adolescence, the musculoskeletal system undergoes several

KEY WORDS:

LTAD; growth; maturation; adolescent; injury

changes, which can result in relative weakness and, in turn, increased susceptibility to injury (29,39,56,128). Growth-related injuries, such as Severs and Osgood-Schlatter, are common and can cause prolonged pain and restricted mobility in young athletes, ultimately affecting the athlete's ability to engage in sports and recreational physical activity (99,125). Many adolescent athletes experience injury from playing sports, with some studies suggesting that more than 30% of injuries in this population could be attributable to sports participation (27). In a study of 498 Spanish junior athletes (14–21 years of age), 40% suffered an injury during a year-long study (2.64 injuries per 1,000 hours) (94). Besides the acute trauma associated with injury, there are also potential long-term health consequences of youth sports injuries, such as reduced participation in physical activity (7), negative changes to body composition (79), and osteoarthritis during adulthood (29,39,128). In addition, inadequate nutrition and sleep can lead to illness and injury, maladaptive responses to training, and/or underperformance in the young athlete (71).

Although previous authors have expressed concern regarding the risks associated with intensive participation in sport during adolescence (6), few have provided guidance or recommendations in relation to training young athletes during the adolescent growth spurt. The existing scientific research on the development of young athletes recommends the consideration of biological maturation, consistent engagement in strength and conditioning programs, diversity and variability of athletic exposure, evidence-informed injury prevention programs, dietary education, and the mitigation of sport-related eating disorders (6). Therefore, adopting an interdisciplinary approach, rather than a reductionist perspective, which integrates aspects of growth and maturation, sports coaching, athletic development, sleep, and nutrition, is required to mitigate the risk of injury during the adolescent growth spurt (87). This article aims to provide background and recommendations for training young athletes during the adolescent growth spurt with particular attention to reducing the risk of injury.

GROWTH AND MATURATION DURING ADOLESCENCE: KEY POINTS AND MONITORING

As mentioned, puberty is a dynamic period of physical growth (increase in size of the body) and biological maturation (progress towards the biologically mature adult state) depicted by the hallmark of the adolescent growth spurt–peak height velocity (PHV). The average and variability in key anthropometric measures of the adolescent growth spurt are shown in Figure 1. Notably, Figure 1 highlights that there is considerable interindividual variation in the timing, tempo, and intensity (or magnitude) of physical growth and maturation during puberty that distinguishes early, average, and later maturers. For maturity timing, plus or minus 1 year from the average age of the event identifies an early or late maturer, so if a male reaches PHV at the age of 12.5 years, he is considered an early maturer.

The assessment (and subsequent calculations) of key anthropometric variables is relatively simple yet it needs to follow standardized procedures to ensure reliable and accurate data (82,112). Height and weight can be taken every 3–6 months because more frequent measurements may fall within the technical error of measurement (TEM). Given diurnal variation in height and weight, the most stable values are obtained in the morning after an overnight fast and after voiding; however, this is not always feasible. Thus, establishing a consistent time of day is preferable. Another consideration regarding data quality is to establish the intrarater reliability and the TEM; notably, if more than 1 person is doing the assessments, interrater reliability should also be determined (82). Measurements can be plotted on standard growth charts to determine the percentile, but greater insight is gained when longitudinal data are converted into growth rates (cm/y) and plotted on a velocity curve (Figure 2). A few technical matters that are worth addressing include: (a) the mid-age of the measurement interval (e.g., 10.39 + 9.90 years/2 = 10.1 years), not the age at the time of the measurement, should be used because this represents the growth rate between 2 timepoints, and (b) unless measurements are taken exactly 1 year apart, the growth increment needs to be adjusted to reflect yearly growth (e.g., [2.8 cm/178 days] × 365 d/y = 5.7 cm/y). It should also be noted that although the shape of the adolescent growth spurt is typically shown as a smoothed curve, growth can be episodic and sporadic, nonuniform and nonlinear with mini-spurts (called saltatory growth) followed by very slow or no growth in short periods (60).

The calculation of growth rates can alert the practitioner to a potentially heightened risk of injury, which in turn may call for introducing holistic interventions (e.g., reducing the overall training load, modifying strength and conditioning programming, and reanalyzing dietary approaches). A few studies have identified that a growth rate in height of ≥7.2 cm/y increases the risk of injury. In the initial study, Kemper et al. (55) reported that a growth rate of >0.6 cm/mo was a risk factor for injury in male adolescent academy soccer players. This has been extrapolated to ≥7.2 cm/y; however, it is important to note that the TEM for height was 0.3–0.4 cm. Two recent papers have confirmed an increased likelihood of injury in players, with players growing more than 7.2 cm/y (54,75). In addition, due to the differential rates of growth in the legs and torso, leg length should also be assessed independently, as Rommers et al.(102) found a growth rate in leg length of >3.6 cm also increases the risk of injury.

Although one can directly determine the growth rate and age at PHV, as shown above, this approach requires longitudinal data and does not allow practitioners to predict when a growth spurt might occur, thus limiting day-to-day or short-term decisions

	Age at takeoff (years)	Age at PHV (years)	PHV (cm/year)
Males	10.0-12.1 (7.8-13.5)	13.3-14.4 (11.9-16.2)	8.2-10.3 (5.6-12.4)
Females	8.5-10.3 (6.6-12.9)	11.4-12.2 (9.3-15.0)	7.1-9.1 (5.0-10.1)

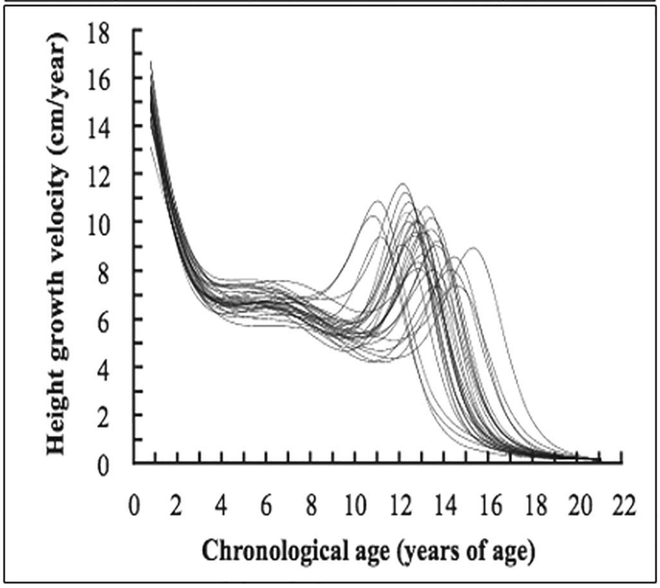

Figure 1. Variation in the timing, tempo, and magnitude during the adolescent growth spurt (17,65).

regarding training modifications in adolescents. To overcome this issue, prediction equations that estimate maturity status from cross-sectional assessments have become popular in youth sports (69). Among English football academies, estimation of maturity status had a high perceived importance for injury prevention, player development, load management, and coach and player feedback (105). The 2 most widely used methods are the *Khamis-Roche* (KR) (57) and *maturity offset* (73,76) equations. The maturity offset, defined as the time before or after PHV (i.e., calculated values of −0.4 years equals 0.4 years before PHV), requires child age, height, body mass, and sitting height (which is used to derive estimated leg length = standing height minus sitting height), and thus can offer an advantage to the KR method when the biological parental height is unknown. Using this value, the predicted age at PHV is estimated as chronological age minus the predicted maturity offset (i.e., 12.2 − [−0.4] years = 12.6 years, predicted age at PHV).

The maturity offset method has been critiqued for its limitations, especially among early and late-maturing youth who are often of interest in youth sports (66,67). In a study of 17 male academy soccer players (120), the predicted age at PHV was equivalent to the observed age at PHV in none of the players, and a significant and meaningful difference was noted in 87% of the predictions. Given such limitations, many practitioners use the KR method, which provides the percentage of predicted adult height (%PAH) from a child's age, height, body mass, and parental heights. This method has shown that %PAH has moderate concordance with skeletal age in 9- to 14-year-old American football players (68) and 11- to 14-year-old male soccer players (67). Although various cut-points have been used, a common guide for an average maturer is as follows: pre-growth spurt (%PAH <85%); take-off/early phase of growth spurt; pre-PHV (85–89%); mid-late growth spurt (89–95%); and post-growth spurt (>95%). A worked example is shown in Figure 3, and more information to calculate %PAH can be found in Towlson, Salter, Ade, Enright, Harper, Page, and Malone (124). Again, this is a general guideline for the average maturer where PHV occurs at ~91% PAH. This scheme is shifted to the left for the early maturer (PHV ~88% PAH) and to the right for the late maturer (PHV ~93–94% PAH). The highest rates of growth will generally occur for most, if not all, youth between 88 and 94% PAH (54,74). The initiation of the growth spurt should be confirmed with accelerated growth rates in height and leg length. Furthermore, the key is calculating % PAH and growth rate (cm/y) and considering as many sources of information as possible (i.e., visual inspection, symptomology, bone age, etc.).

An alternative low-cost method is using the coach's perception of maturity based on visual observation. This highly feasible approach has been found to have a strong correlation with measured maturity timing (62,101). However, using subjective coach assessments alone to evaluate a player's maturity timing is not recommended in practice unless objective data are unavailable. Instead, these assessments can be beneficial when combined with standard objective diagnostics. Another recent technology that uses ultrasound to measure skeletal maturation may have promise. The BAUSport system performed well in comparison with the established radiographic methods (Fels, Greulich-Pyle, and Tanner-Whitehouse III) for the categorization of youth as advanced, on-time, and delayed in maturation based on skeletal age (21). This device is also relatively feasible, with measurements and real-time data completed in less than 5 minutes.

Date	CA (yrs)	Mid-year age	Ht (cm)	Interval (days)	Increment (cm)	Growth Rate (cm/yr)
1/14/2019	9.90		143.1	-	-	-
7/11/2019	10.39	10.1	145.9	178	2.8	5.7
1/12/2020	10.90	10.6	148.5	185	2.6	5.2
7/1/2020	11.37	11.1	151.1	171	2.6	5.5
12/11/2020	11.81	11.6	154.4	163	3.3	7.4
6/4/2021	12.29	12.1	160.4	175	6.0	12.5
12/16/2021	12.83	12.6	165.7	195	5.3	10.0
7/6/2022	13.38	13.1	169.8	202	4.1	7.4
12/18/2022	13.83	13.6	172.7	165	2.9	6.5
7/2/2023	14.37	14.1	175.3	196	2.6	4.8
1/4/2024	14.88	14.6	177.2	186	1.9	3.7
6/18/2024	15.33	15.1	178.2	166	1.0	2.2

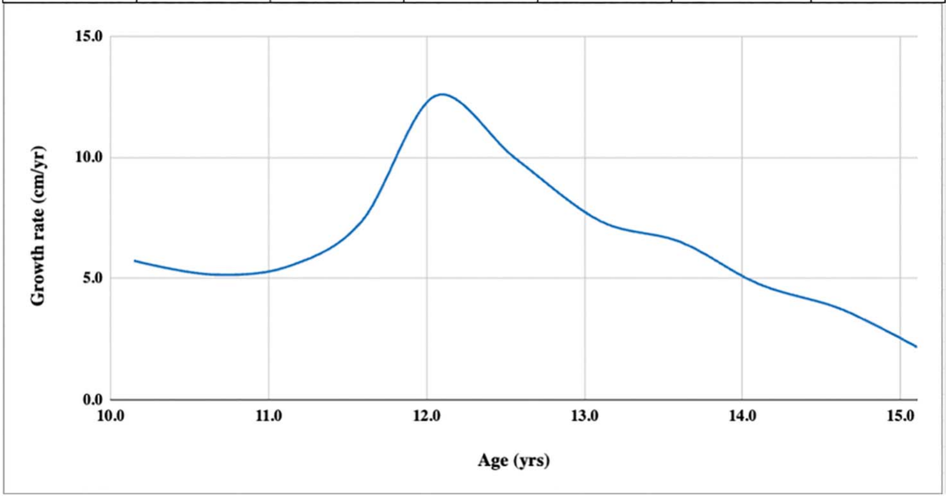

Figure 2. Longitudinal growth record of a male athlete from about age 10–15 years. Height was measured about every 6 months or 182 days, and growth rate (cm/y) was calculated (growth increment [days]/interval between measurements [days]) $\times$ 365 days.

MONITORING AND MANAGING TRAINING LOAD AND WELLNESS IN ADOLESCENT ATHLETES

Monitoring and managing training load and general wellness are important to decrease the risk of injury (38,50) and enhance performance, especially during the adolescent growth spurt (52). To maximize the adaptive response and minimize injury risk, coaches and practitioners need to manage the overall stress applied to the athlete at an individual level through precise monitoring and manipulation of the training load to achieve the desired training effect (44). Training load is often quantified using indicators of external and/or internal training load; external load is what the athlete does, and internal load is how the body responds to a training session or competition stimulus (45,50). External load enables the quantification of a diverse range of measures and metrics. For example, using global positioning systems (GPS) technology, speed, acceleration, and distance can be quantified (50). Internal load is measured using psychological (e.g., Rating of Perceived Exertion [RPE]) or physiological (e.g., heart rate) responses during exercise (50). There is no single, definitive marker that can accurately quantify the fitness and fatigue responses to training (50). Although external loads can be measured with increasing ease because of the emergence of GPS and related technologies, the priority should remain on quantifying the internal load response to exercise because this ultimately determines the training outcomes and enables the training prescription to be individualized (43).

The outcomes of a given training dose (i.e., training effects) can be categorized along the continuum of acute (i.e., lasting up to 1 week) to chronic (i.e., cumulative effects over weeks, months, or years). Acute or chronic effects can further be categorized into positive or negative effects depending on whether they improve or impair sports performance. Training effects can be quantified using functional, physiological, subjective, and biomechanical measures influenced by the training stimulus provided during session(s) (50). The accumulation of training load stress may result in a decrement in performance, notably functional and nonfunctional overreaching and overtraining (36,132). A study of young soccer players showed that nonfunctional overreaching and overtraining were recurring problems,

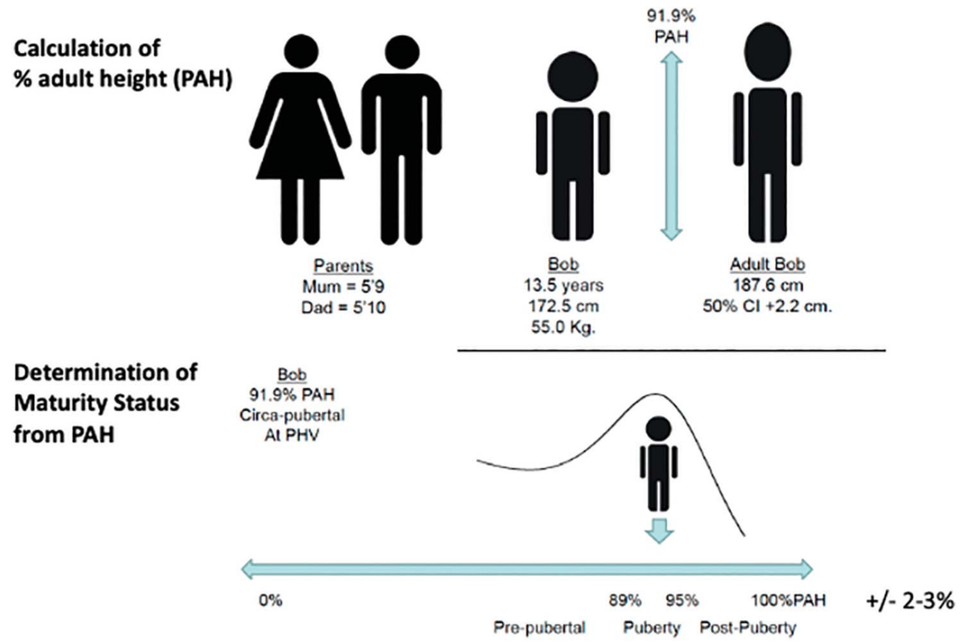

Figure 3. A worked example of calculating the percentage of predicted adult height using the Khamis and Roche (57) method.

with 60% of this population reporting multiple bouts (131). Therefore, a balance is necessary between providing adequate exposure to progressive training programs that yield a range of beneficial physiological adaptations versus an excessive training load that could have negative consequences, such as increased risk of overuse injuries, illness, and burnout (11).

The relationship between training load and training outcome can be influenced by individual and contextual factors such as growth, maturation, genetics, environment, diet, sleep, recovery, and psychological state (87,124). Individual factors that influence the relationship between training load and injury include both the tempo and the timing of growth in stature (54). Changes in body composition during adolescence influence power-to-weight ratio, strength, flexibility, and cognitive functions such as emotional control and motivation (25,87). Muscle mass growth occurs during adolescence in both sexes, but it is greater in males, accompanying a linear increase in muscle strength, whereas overall flexibility tends to decrease in males. In females, there is a slight increase in muscle mass and an increase in fat mass during adolescence, which can negatively influence relative strength and power-to-weight ratios (12).

Contextual factors include the training environment, coaches' adaptability, travel requirements, and the large volume of multi-sport activity common in young athletes, highlighting the need for holistic load monitoring (51,87,109). Multiple commitments, particularly for talented players selected at various levels, can lead to excessive training loads without proper collaboration among coaches and other stakeholders, thereby increasing the risk of negative performance and development outcomes (2). Being an adolescent student-athlete can be particularly challenging, and an increased life load and a predisposition to high stress can further impede training and performance, affecting cardiovascular and power adaptations, fitness gains, and muscle recovery (31,70). To address these challenges, youth sports coaches, clubs, and parents must adopt a player-centered approach, supporting athletes' education and communicating effectively during periods of high stress (51).

The initial steps for training load management in adolescent athletes are to start tracking the intensity, duration, and type of activities using training diaries to monitor daily, weekly, and monthly activities in which the athletes participate (110). In doing so, the session rating of perceived exertion (s-RPE) method (32) can be calculated, which, although not perfect, provides a generic monitoring tool that can be applied in a multitude of training environments and modalities. This approach involves multiplying the athlete's RPE for a given session (typically using a 1–10 scale, ranging from "very, very easy" to "maximal" intensity) by the duration of the session (in minutes) to derive an s-RPE load in arbitrary units (e.g., RPE = 6 × 90 minutes session = 540). It is vital that only validated versions of the scale are used as modifying the descriptors or using colors or visual aids may bias the response (9), which could be especially prominent in young athletes, although this has not been tested directly. The key benefit of a training diary is that it offers a simple, low-cost solution for tracking the training loads imposed on the athlete while also serving as a useful education tool for the players and others involved in their development (e.g., parents, coaches). From this basis, other objective measures of internal (e.g., heart rate) and/or external load (e.g., GPS metrics) can be layered onto the athlete monitoring system to provide more granular insights into the demands of the development program.

It is suggested to avoid rapid increases in volume and intensity during the growth spurt because this has been shown to increase the risk of injury in young athletes, including young baseball pitchers and gymnasts (84,88). A recent intervention study focused on young male academy soccer players with growth-related symptoms or risk factors (such as being 88–93% of their predicted adult height, having a growth rate of ≥7.2 cm/y, or a lower limb growth rate of ≥3.6 cm/y) and demonstrated substantial reductions in injury incidence and burden for the high-risk players (52). Conducted over 2 seasons with 77 male academy soccer players, the study identified players at risk based on somatic maturity and growth rates. During the second season, those exhibiting injury symptoms or multiple risk factors underwent an intervention strategy that included modified training loads by substituting a high-intensity academy soccer session with soccer-specific skills, balance, coordination, and landing drills, along with an individualized strength training program. This protocol significantly reduced injury incidence and burden, suggesting that such interventions can mitigate injury risks during the adolescent growth spurt in high-risk athletes (52). Moreover, it has been recommended to (a) avoid playing a sport for more than 8 months per year, (b) participate in no more than 16 total hours of organized sport activity per week, and (c) play no more hours of organized sports per week than the athlete's age (4,42,46,48,59,80,93).

In addition to monitoring the training load, it is also important to monitor how the athlete is coping with the stress of training. Subjective assessments can indicate both short-term and long-term changes in athlete well-being because of training. Monitoring athlete recovery and wellness is essential to guide and inform training and to detect any progression toward negative health outcomes and poor performance. The options for monitoring athlete wellness range from time-consuming and expensive objective fitness and fatigue markers (i.e., advanced jump testing, heart rate variability, cortisol, immune markers, etc.) to simple and feasible surveys. Specifically, assessments of mood disturbance (e.g., Profile of Mood States), perceived stress and recovery (e.g., Recovery-Stress Questionnaire), and stress symptoms (e.g., Daily Analysis of Life's Demands for Athletes) seem to be effective for monitoring athletes (107). These surveys have usual athlete compliance issues, so from a practical standpoint, single-item measures may help (38,127), but these have not been validated in young athletes. In practice, it is recommended to regularly use a simple, self-administered subjective measure (e.g., daily) to make immediate adjustments to training. This should be supplemented with a more detailed assessment (e.g., POMS or RESTQ-S) on a less frequent basis (e.g., weekly or monthly) to monitor long-term training effects.

Overall, it is important to collect a training diary capturing training frequency and duration, as well as a measure of intensity (e.g., Borg CR10 rating). Moreover, the overall load on youth athletes must be considered, including other sports, physical education, and academic commitments. It is also important to assess recovery and wellness alongside the training diary to understand an athlete's response to load, such as monitoring soreness on chronic training responses. Finally, practitioners should closely monitor and, where necessary, reduce training loads during growth spurts and in response to growth-related symptoms.

STRENGTH AND CONDITIONING PRESCRIPTION

As part of the overall training load imposed on the growing and maturing young athlete, considerations also need to be made regarding the design and delivery of the strength and conditioning program. First and foremost, the young athlete should be technically competent and confident in the breadth and depth of fundamental movement skills and basic levels of strength and be accustomed to a variety of physical fitness training methods to allow for the intensification of training load and volume during adolescence. However, clearly, not all athletes will possess the same levels of technical competency and/or training age or experience. Thus, it is important to consider the athletes' training age in each physical quality (i.e., movement competency) and/or training method (e.g., resistance training) separately because they may not have developed the skills and/or accumulated the same training history in all training methodologies to target the desired training adaptations (e.g., 2 years for strength training but no experience with plyometrics training). This should be part of a thorough needs analysis and fitness profiling, and the latter should consider both age- and maturity-related benchmarks (23,26).

The overall strength and conditioning program should be built on a flexible blueprint for holistic development of all physical qualities, such as the Youth Physical Development model (63). During the development phase, the approach presented in Table 1 (adapted from Pichardo et al. (91)) can be taken. Again, this assumes the athlete has been exposed to fundamental aspects of training during the foundation (9–11 years old) phase. Regardless of training age (and chronological and biological age), the training methods and associated exercises should be progressed logically in accordance with the technical ability of the individual

Table 1
A comprehensive summary of specific models of developing physical qualities in youth

Strength	Moderate-to-heavy free weight training with some eccentric-based training; core strength training	
Olympic lifting	Primary focus on technical reinforcement; secondary focus on performance outcomes	
Power	Increase strength while maintaining high velocity and rate of force development; intro to Olympic lifting and more intense plyometrics	
Plyometrics	Moderate-intensity plyometrics; multiple 2-foot hopping & jumping	Moderate- to high-intensity plyometrics; box jumps; hurdle jumps
Speed	Sprint technique + maximal sprints; emphasis on coordination pre-PHV; greater focus on strength, hypertrophy + plyos post-PHV	
Agility	Primary focus on COD speed development (40%); less focus on FMS (30%) but increased focus on reactive agility (30%)	
Aerobic	Mastery of sport-specific skill through deliberate practice and play; combination of small-sided games and HIIT	

Adapted and redrawn (with permission) from Pichardo et al. (91).

athlete and should follow basic principles of training, motor learning, and pedagogy. For example, adolescent athletes without experience in strength training should begin with bodyweight and light resistance training focusing on task mastery, incorporating ecological, constraints-based approaches to motor learning, and developing self-confidence and perceived competence. An example of the progressions for major resistance training movements is shown in Table 2.

Because there is an increased risk of injury during the adolescent growth spurt (54,74,130) and some individuals will experience "adolescent awkwardness" (87,95), training modifications may be warranted (47,51,87). More specifically, this may include allocating training groups by maturity (bio-banding), which could aid in program design and implementation and injury prevention (22). More specifically, high-intensity lower-body plyometrics and acceleration/deceleration activities may be reduced, and incorporating some fundamental movement patterns may be important for those who experience some loss of motor coordination during the growth spurt (i.e., adolescent awkwardness) (52,133). Some aspects of the strength and conditioning program can be efficiently and effectively incorporated directly within technical-tactical sessions using models such as RAMP (49) or RAMPAGE (122) that contain segments addressing multiple physical qualities during the warmup for the main sport training session. For example, fundamental movement skills, mobility, and physical qualities such as speed, change of direction, and plyometrics can be incorporated into a relatively short-duration warm-up period (78).

It is also possible to incorporate some aspects of strength or neuromuscular training into the warm-up. In youth sports, clear and consistent evidence suggests that neuromuscular training programs can reduce injury risk. The most commonly used injury prevention program for young athletes is the FIFA 11+ prevention program, which includes running, strength, plyometrics, and balance exercises (121). On average, the FIFA 11+ prevention program demonstrated a 39% reduction in academy football injuries (121). Moreover, in a multinational cluster randomized controlled trial assessing the FIFA 11+ kids, a total of 3,895 players were tracked, and 292,749 hours of football exposure (1,103). Results indicated that the overall injury rate in the intervention group was reduced by 48% compared with the control group (103). Furthermore, there is evidence for the effectiveness of neuromuscular training strategies in a variety of other sports (13,28). Despite the evidence to support their implementation in youth sport, the player, parent, and coach knowledge on implementing these injury prevention programs is limited (85,86,126). Moreover, programs such as these do not negate the need for long-term strength and conditioning programs that enable practitioners to safely progress young athletes beyond a constrained warm-up protocol.

Practitioners should also consider how strategies such as the activity ladder promoted by Rathleff et al. (96) could be used to mitigate soreness in adolescent populations. This strategy involved training load management while also implementing a progressive strengthening protocol (96). It should be noted that research in this area is limited, but a randomized controlled superiority trial has been registered, which aims to compare self-management, including exercises, education, and activity modification, to usual care for adolescents with Osgood-Schlatter (58). There is, however, compelling evidence that the implementation of an iterative sequence of prevention in a youth soccer academy can effectively reduce the occurrence of injuries during the growth spurt phase (52).

Table 2
Exercise progression for resistance training movements

Movement	Beginner	Novice	Intermediate	Standard
Squat	Supported or assisted squat	Bodyweight squat	Goblet squat	Barbell back squat
Hinge	Wall hip hinge	Band-resisted standing hip hinge	DB hip hinge	Barbell RDL
Horizontal push	Eccentric to kneeling/modified push-up	Push-up	DB bench press	Barbell bench press
Horizontal pull	TRX row	Inverted row	Single arm DB row	Barbell bent-over row
Vertical push	Half kneeling landmine shoulder press	Standing press	DB push press	Barbell push press
Vertical pull	Isometric hangs or bent arm hangs	Band-assisted pull-up	Jump up to eccentric pull-up	Body weight pull-up

Nutrition for the adolescent athlete. During the adolescent growth spurt, sufficient energy is required to not only sustain resting and activity energy expenditure (i.e., training) but also to synthesize new tissues (i.e., growth) (123). Increases in training load (including strength and conditioning) and marked changes in body composition during adolescence result in elite youth athletes displaying energy expenditures that are comparable with or exceed their adult counterparts (40,115). Athletes should focus on the consumption of optimal totality of energy and carbohydrate intake within the appropriate timing of training and competition to facilitate adaptation and help recovery and regeneration. Optimal protein intake will support recovery and growth with focus on micronutrients iron, calcium, and supplementation of vitamin D between winter months (i.e., October and March in the northern hemisphere).

Despite the increase in sports science and medicine support in elite youth sport (104,108,134), many young athletes do not have access to a full-time nutritionist (15). Until recently, nutritional guidelines for young athletes were based on those of their adult counterparts. Additional energy requirements associated with growth and maturation (40) and those associated with training, competition, and physical activity (116) underline the need for answers to the questions of many parents and guardians about how to feed their child athlete as they experience the adolescent growth spurt.

As young athletes navigate through adolescence between the ages of 12–18 years, they experience increases in stature (~25 cm), body mass (~30 kg), and fat-free mass (~23 kg) with an associated rise in resting metabolic rate ~400 $\text{kcal}\cdot\text{d}^{-1}$ (40). When considering the level of organized sport and physical activity (i.e., walking or PE) (53) young people partake in each day (53), it is not surprising that the daily energy expenditure of adolescents increases by ~750 $\text{kcal}\cdot\text{d}^{-1}$ from pre- to post-adolescent growth spurt (40). Indeed, around the time of PHV, young soccer players exhibit mean daily energy expenditures as high as 3,380 $\pm$ 517 $\text{kcal}\cdot\text{d}^{-1}$ (116). Despite such high daily energy expenditures, young athletes often fail to consume optimal energy and carbohydrate intake both pre- and post-training (115) and, on occasion, through the entire training week, irrespective of age (40). The consequence is an "energy problem" where athletes, coaches, parents, and guardians struggle to bridge the gap between high energy expenditures with sufficient high-quality food and fluid intake. Failure of young athletes to achieve optimal food and fluids has been attributed to a lack of time, nutritional understanding, and a lack of food and drink provision (15,16). Failure to achieve optimal energy and carbohydrate intake presents a risk of low energy availability and RED-S, especially in females (readers are directed to Loucks et al. (64) and Mountjoy et al. (77)).

Facilitating increased food and fluid intake of young athletes (i.e., opportunity) and enhancing knowledge of athletes and stakeholders (i.e., capability) provides the potential to change behavior (5,19) and improve the health and performance of young athletes during such a vital phase of technical, tactical, physical and psychosocial development. To this end, to support the adolescent growth spurt, it is important to increase energy, carbohydrate, and protein consumption throughout the day. For example, nutritional intake guidelines for academy soccer players of 6, 2, and 1 $\text{g}\cdot\text{kg}^{-1}$ for carbohydrate, protein, and fat, respectively (40), should translate to young athletes experiencing growth and maturation across a variety of sports. Importantly, during periods of training, extra snacks become essential in mid-afternoon and presleep to support fueling and recovery, assuming that sessions are often after school. Regularly following a plan such as this will not only support growth and maturation but also a young athlete's health, wellbeing, and sports performance.

Sleep and the adolescent athlete. The hypothalamus not only triggers puberty (100) but also affects sleep-wake cycles that underpin the shift to the evening chronotype ("biological schedule") of many adolescents (37). This natural biological phenomenon, coupled with the increased training demands and academic requirements, can easily compromise the rest and recovery of the adolescent athlete. Indeed, a large proportion of adolescents across the world do not meet the recommended amount of sleep of 8–10 hours per night (33). It has been reported that the average duration of sleep among adolescent athletes is ~6.3 hours (71). Besides the biological shift to the evening chronotype, other factors can also explain sleep deprivation, such as screen time and social media use (111), anxiety (117), and potentially evening training or competition combined with academic responsibilities (homework) plus an early wake time for either training and/or schooling. Poor sleep health has negative implications for cognitive/academic performance, overall well-being, optimal athletic performance, recovery, and injury and illness risk within adolescent athletes (119) and should be acknowledged as a key contributor to the overall development of young athletes.

Several recommendations can be made to improve sleep habits (particularly adolescents), including education, monitoring, and scheduling; however, the latter may hinge upon logistics. Sleep education can be incorporated by stand-alone sessions, combined with nutrition education, and/or incorporated within training sessions. Topics should include the recommended amount of sleep, effects of sleep on performance, health, and recovery; napping; and good sleep habits (i.e., avoiding stimulants and social media close to bedtime, bedtime routine, sleep environment, etc.). Meta-analytical data indicated that school-based sleep education programs produced longer sleep time and better mood among students, but the improvements were not maintained at follow-up (18). This latter point lends to the importance of ongoing education on the importance of sleep, which can be accomplished by consistent messaging by all those involved in a young athlete's development. This might include posting and sharing infographics (see https://www.nsca.com/education/articles/infographics/case-study-sleep-and-injury-in-elite-soccer/) in common spaces and by text messages, etc.

An initial screening of current sleep practices using a tool such as the 15-item Paediatric Sleep Practices Questionnaire (PSPQ) can provide information on sleep timing, sleep routines and consistency, technology use before bedtime, and sleep environment (72), which allows for comprehensive sleep education. The routine daily or weekly monitoring of sleep duration and quality is often easily implemented as part of a subjective recovery and wellness survey commonly administered to young athletes, whereas some adolescent athletes may use wearable technology; however, the accuracy of both has been questioned (89). Finally, those involved in a young athlete's development should try avoiding early training sessions if possible and be mindful of the impact of heightened academic pressures on sleep behaviors.

Psychology. Adolescence represents a period of profound changes in psychology and behavior, influenced by hormonal fluctuations, brain development, and a myriad of social and cultural factors (98,118). The physical and functional changes that accompany puberty also have important implications for psychosocial and behavioral development.

The onset and completion of the pubertal growth spurts coincide with the stages of early (10–14 years) and middle (15–18) adolescence. Driven by hormonal changes, early adolescence is associated with rapid and intense changes in emotional reactivity and sensitivity, and increased self-awareness, self-consciousness, and peer comparison (8). It is also a stage where children experience an increased desire for independence and to establish a self-identity, exploring new behaviors and responsibilities and separating emotionally from their parents (90). Coaches can capitalize on these desires by listening to and respecting their opinions and promoting the "athlete voice" in decision-making processes, and in the design and implementation of their training, goals, and strategies. Adolescent athletes can also be given more opportunities to take on positions of responsibility, such as monitoring their learning and development, leading drills or warm-ups, giving team talks, or mentoring younger athletes.

As athletes transition from early to middle adolescence, they become increasingly independent and more capable of engaging in abstract and sophisticated thought. They also become more capable of considering multiple perspectives and engaging in complex reasoning (35,41). Recognizing these improvements, athletes should be given more challenging tasks and learning opportunities to help encourage more sophisticated skills such as planning, critical thinking, and self-reflection (20,81). Moreover, coaches can help develop young athletes' interest and understanding of training adaptation and injury risk or recovery processes to increase their buy-in to the training process.

In middle-adolescence, young athletes have more capacity to self-reflect, analyze their thoughts and feelings, and establish their moral compass. Although emotional intensity remains high, the peer group remains an important sense of influence and validation; athletes are now more capable of regulating their emotional states, controlling their

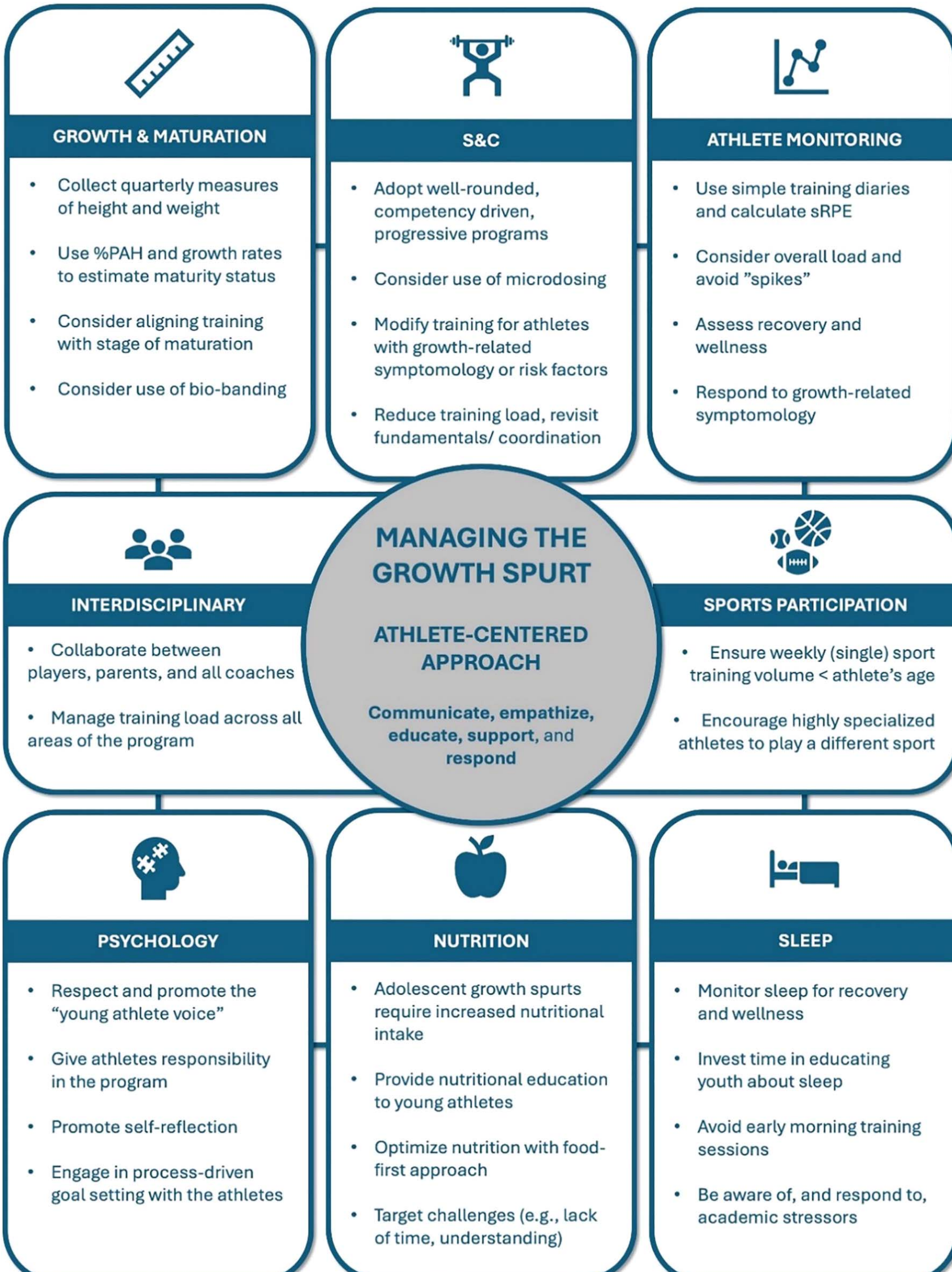

Figure 4. Summary of recommendations for training during the adolescent growth spurt.

Table 3 Player profile	
Name	**Alex ramirez**
Age	13.6 y
Position	Central midfielder
Training age	4 y
Height (percentage of predicted adult height)	165.1 cm (89.4%)
Maturity status	Circa-PHV
Current growth rate	8.3 cm/y

impulses, and resisting social pressures. By recognizing and praising efforts towards more independent thinking and more mature behaviors and thoughts, coaches can encourage feelings of confidence and self-determination and reinforce a belief that young athletes can use their own initiative to handle situations or challenges in a mature manner. Most athletes will also experience a heightened interest in sexual and romantic interest during middle-adolescence and may begin to establish new priorities above and beyond sport. Such changes are completely natural and should not be considered as a negative distraction to sport that should be suppressed. In summary, practitioners should create environments that support the adolescent athlete's growing need for independence while still providing the guidance, support, and structure they need to develop into successful, healthy, and well-rounded individuals (6).

How athletes perceive the physical and functional changes that accompany puberty is more important than the changes themselves (24). Children's perceptions of the physical self and feelings of physical self-worth are important drivers of motivated behavior in sport and exercise and generally decline with advancing maturity, especially in girls (83). Children who perceive themselves as more competent in sports, in better physical condition, stronger, and more attractive participate more in sports, exercise, and physical activity (24). As a coach, it is important to encourage athletes to perceive the changes that occur during puberty as a natural, positive, and attractive consequence of becoming an adult and not as a barrier to participation in sport and exercise.

Coaches should be especially sensitive around the subject of growth, focusing on how the body functions rather than size or shape. Girls who mature in advance of their same-age peers are more likely to hold fewer positive perceptions of the physical self, which, in turn, predicts less engagement in physical activity (114). Higher perceptions of peer acceptance do, however, seem to mitigate such risks, highlighting the importance of the peer group during adolescence (92). Boys who mature early generally hold more positive perceptions of the physical self than their later maturing peers, although this does not seem to affect engagement in physical activity (113). That said, early-developing boys need to be reminded that the physical and functional advantages they experience during adolescence are temporary and that further work and effort will be required to guarantee future success. Conversely, later maturing youth need to be reassured that their growth spurt will come and that continued involvement in sport will lay the foundations for future success at the adult level.

SUMMARY OF RECOMMENDATIONS FOR TRAINING DURING THE ADOLESCENT GROWTH SPURT

Overall, there are several evidence-based recommendations for training during the adolescent growth spurt (Figure 3), and those working in youth sport should seek to implement these as part of a holistic approach to athlete development. Managing the program of an adolescent athlete experiencing a growth spurt will inevitably involve manipulating several factors in line with the unique needs of the individual. The themes identified in Figure 4 will likely need to be manipulated to different degrees at different stages for each young athlete, something of a "dimmer switch" effect, and practitioners should avoid adopting a "one size fits all" approach.

CASE EXAMPLE: DEVELOPMENT OF A YOUTH ACADEMY SOCCER PLAYER DURING A GROWTH SPURT

Table 4 summarizes that many disciplines (e.g., strength and conditioning prescription, training load, nutrition, psychology) can be altered within the development program of young athletes. However, it should be noted that not all young athletes experiencing the growth spurt will need interventions in all these disciplines simultaneously or to the same extent. Indeed, managing the growth spurt for adolescent athletes will always be individual and context-specific, and there are many nuances for practitioners to consider. There should also be routine "check-in" reflections on the program, whereby subjective observations from practitioners across multiple disciplines (e.g., technical coaches, strength and conditioning coaches, physiotherapists) should be considered in tandem with objective data. The following case example (Tables 3 and 4) is provided to highlight how an interdisciplinary approach was taken to manage a young athlete's development program through a phase of rapid growth during the adolescent growth spurt.

Background. Alex was a promising academy footballer and had been identified as one of the top prospects in his age group. At the age of 13 years, Alex had recently started experiencing a significant growth spurt over the past 3–4 months. This rapid change in his body had brought about challenges in

Table 4
A case example highlighting how an interdisciplinary approach could be taken to manage a young athlete's development program through a phase of rapid growth during the adolescent growth spurt

Discipline	Information
Strength and conditioning: *Strength*	Objective: To maintain strength and coordination during rapid physical changes • Moderate-to-heavy free weight training and lumbo-pelvic strength training; 2 × 45-min sessions per week • Alex had a high-level of movement competency and his program included the following exercises: Goblet squat, barbell RDL, short lever Copenhagen, DB bench press, single-arm DB row, body weight pull-up, side plank, and front plank
Strength and conditioning: *Flexibility and mobility*	Objective: To maintain flexibility during rapid physical changes • Focus on dynamic stretching and mobility exercises to maintain joint mobility and flexibility as Alex grows; this included hip mobility, quadriceps, hamstring, calf and groin stretches, and dynamic warm-up routines as part of his sessions • 4 × 5-min session per week
Strength and conditioning: *Speed*	Objective: To develop physical adaptation and maintain movement competency during rapid physical changes • 2 × 15-min session per week, 1 session focused on acceleration and 1 session focused on maximal velocity • Exposure to sprint technique + maximal sprinting • Emphasis on coordination during the growth spurt
Strength and conditioning: *change of direction and agility*	Objective: To develop physical adaptation and maintain movement competency during rapid physical changes • Reduced volume for decelerations • 1 × 15-min session per week • Primary focus on COD speed development; with a secondary focus on reactive agility
Strength and conditioning: *aerobic*	Objective: To maintain aerobic fitness during the period of rapid physical changes • Training is a combination of drills including the speed, change of direct, and technical drills listed • Aerobic fitness is deliberately developed through a combination of small-sided games • 3 × 90-min soccer training sessions and 1 × 80-min match; consideration for reducing overall training load (see below)
Technical and tactical	Objective: To refine and adapt technical skills to Alex's changing physique • *Ball striking*—Technical sessions will focus on different ball striking techniques, ensuring that Alex maintains proper form even as his body changes • *Receiving skills*—Because coordination may be temporarily compromised, Alex will focus on ball control drills with both feet and body contact with other players • *Team sessions*—Alex will engage in team sessions that require decision-making • Tactical sessions will include match analysis and positioning drills to ensure Alex continues to develop his game understanding and can compensate for any temporary physical limitations

Table 4
(continued)

	• Important for coaching staff to understand potential challenges and limitations during the growth spurt
Load monitoring	Objective: The strength and conditioning coach will continue to collect training information (frequency, duration, and intensity [Borg CR10 rating]) to calculate sRPE as the athlete matures. In addition to this, growth-related soreness and symptoms will be monitored • If Alex becomes symptomatic the S&C coach and technical coach will reduce training loads during growth spurts and in response to growth-related symptoms • Until such time, Alex's schedule will be individualized based upon his recovery, wellness, and other commitments (other sports, physical education, and academic commitments)
Psychology	Objective: To provide mental and emotional support during a potentially challenging developmental phase • Alex will be given input into his program and asked for feedback on his training goals, confidence, and how he feels he is progressing • The psychologist will continue to monitor his mental and emotional well-being, creating interventions and informing the multidisciplinary team where necessary
Nutrition	Objective: To support healthy growth and optimize performance through tailored nutrition • *Caloric intake:* Given Alex's rapid growth, his caloric intake will be adjusted to ensure he is consuming enough energy to support his development • *Pre- and post-training nutrition:* Alex will be advised to consume a balanced meal or snack before training sessions, such as whole-grain toast with peanut butter or a fruit smoothie. Post-training nutrition will focus on recovery, with an emphasis on protein (30 g serving) and carbohydrates (1.5–2.0 g/kg), such as a grilled chicken sandwich or yoghurt with granola • *Protein:* Adequate protein intake is essential for tissue synthesis and recovery. Alex will be guided to include high-quality protein sources such as chicken, fish, eggs, and legumes in his meals, particularly after training sessions • *Hydration:* Alex will be educated on the importance of staying hydrated and will be encouraged to drink water regularly throughout the day and during training • *Vitamins and minerals:* Focus on calcium and vitamin D for bone health, along with a balanced diet with fruits and vegetables

The above case example (Tables 3 and 4) is provided to highlight how an interdisciplinary approach was taken to manage a young athlete's development program through a phase of rapid growth during the adolescent growth spurt.

coordination, balance, perceived athletic competence and confidence, and performance, which required an individualized holistic training program to facilitate his continued development. The holistic program was closely monitored by an interdisciplinary team, including the strength and conditioning coach, technical coach, psychologist, physiotherapist, and nutritionist. Regular assessments were conducted to evaluate Alex's progress, with continued adjustments to the program as necessary. This included periodic physical testing, video analysis, psychological consultations, and nutrition meetings. Regular meetings were held with Alex's parents to inform them of his progress and to help identify potential barriers and facilitators to his development. As part of this meeting, information was also obtained on Alex's general activity patterns at home and school.

WHERE NEXT? A CALL TO ACTION

Most of the available research in the area of growth, maturation, training load and injury risk has been conducted on young male athletes. Although there seems to be a clear and very plausible link between the adolescent growth spurt and injuries in adolescent females, this area remains largely under-researched in the academic literature and should be a priority for youth sports injury research, particularly considering the greater prevalence and rise in anterior cruciate ligament injuries in adolescent females (3,10,129). Future research should also consider the effects of maturity on training load to build on how maturity could mediate or moderate the dose–response relationship (106). Finally, further studies are required to understand the interaction between growth-related injury, soreness, and training load. These studies could help to identify the longitudinal associations between increased training load and increased soreness. Moreover, studies should investigate how strategies such as the activity ladder promoted by Rathleff et al. (96) could be used to mitigate soreness in adolescent populations, which could lead to a deeper understanding of the dose (training load) and response (soreness).

Conflicts of Interest and Source of Funding: The authors report no conflicts of interest and no source of funding.

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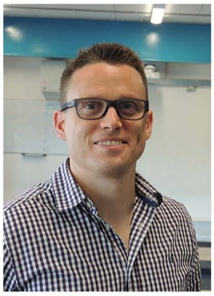

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