Managing the Training Load in Adolescent Athletes

Andrew Murray

While historically adolescents were removed from their parents to prepare to become warriors, this process repeats itself in modern times but with the outcome being athletic performance. This review considers the process of developing athletes and managing load against the backdrop of differing approaches of conserving and maximizing the talent available. It acknowledges the typical training “dose” that adolescent athletes receive across a number of sports and the typical “response” when it is excessive or not managed appropriately. It also examines the best approaches to quantifying load and injury risk, acknowledging the relative strengths and weaknesses of subjective and objective approaches. Making evidence-based decisions is emphasized, while the appropriate monitoring techniques are determined by both the sporting context and individual situation. Ultimately a systematic approach to training-load monitoring is recommended for adolescent athletes to both maximize their athletic development and allow an opportunity for learning, reflection, and enhancement of performance knowledge of coaches and practitioners.

Keywords: youth, sport, stress, dose, response

Athlete Development: A Modern Phenomenon?

The 2007 film “300” portrayed the Spartan army in the battle of Thermopylae and mentioned the process of *agoge*, the rigorous education and training regimen mandated for all male Spartan citizens. The males were meant to compete in athletics and in battle. The training involved learning stealth, military training, pain tolerance, and social preparation. The process typically started at age 7 when the boy was separated from his mother and went through a process of training to become a soldier in the Spartan army. This process involved fighting, starvation and where necessary stealing and killing. The boys were taught to show no pain across the trials and no mercy to others—if they were successful in their training they returned to their families as a Spartan or otherwise they were outcast from society.

This process may have happened over 2300 years ago but now the process of athlete development moves along similar lines. Young athletes can be separated from their families as they enroll in academies or travel overseas for opportunities.1 Coaches and practitioners attempt to develop them as athletes, using the long-term athlete-development model and chasing 10,000 hours of deliberate practice. They “force” them to train and compete for their development and in some systems, they deal only with the champions who succeed in the system (perhaps in spite of). Despite this increased investment in youth academies, little is known about the physiological implications of putting adolescents through structured, intense training regimens.2

Developing Athletes With Sound Scientific Principles

The first consideration for every organization that is working with youth athletes is to consider if the objective/aim of the institution is about sport for all or sport for the elite. A recent consensus statement from the IOC mentions the need for development of healthy, capable, resilient young athletes “while attaining widespread and enjoyable participation for all levels of athletic achievement.”3(p983)

Many institutions and/or national systems that develop talents look to use a broad talent pool and are comfortable with a “survival of the fittest” approach. While this has seen overuse injuries in young people become more common1,2 there is evidence for a relationship between training load, (load can be defined as “the cumulative amount of stress placed on an individual from multiple sessions over a period of time, external workloads performed or the internal response to that workload”)6(p992) and injury and illness in young athletes.7

The Darwinian approach common in large talent pools such as China and Russia sees the “survivors” (those that are genetically predisposed to adapt to higher training loads)8 emerge from adolescence with fewer injuries and a greater training volume behind them.9 In countries where the talent pools are limited, the development of adolescent athletes should be directed to preserve the best talents (ie, minimize injury) and develop them to compete at the senior level. For this reason, managing training loads appropriately and understanding how to apply progressive overload to young cohorts can be a successful strategy to retain a large talent pool in countries with big populations and to preserve the limited talent pools when the population is small.

Training Young Athletes: Training Dose and Adaptations

Based on a perceived change in the focus in adolescent sport from participation to specialization, studies have developed guidelines on how to train youth athletes that caution against intense training in a single sport10; where intensity and specialization are encouraged.11 Guidelines have nowadays been provided to advise that young athletes should not spend more hours per week than their age playing sport. They should avoid specializing in one sport before adolescence and should have at least 1 day a week off from training.4 There is no specific information if this advice is aimed at the elite (by...
elite in this context we consider athletes training more than 14 h/wk) or recreational adolescent athlete. The reality of training volumes in terms of hours and age has been examined in elite youth track and field athletes. Looking at a sample of distance, track, jumps, throws, and multi-talent athletes the typical training volumes of 13- to 14-, 15- to 16-, and 17-year-old athletes was reported as 5.69 ± 2.53, 7.30 ± 3.3, and 8.92 ± 3.69 h/wk, respectively; all below the advice to train “less than your age.” These training exposures are similar to the ones reported in other youth athletic studies but significantly less than the training hours of elite youth athletes in gymnastics, tennis, and swimming. Young male gymnasts age 15 averaged 14.7 h/wk, but the range was from 8.5 to 20 hours. Male swimmers of the same age averaged a little over 13 h with a range from 3.5 h to 22.5 h). In no case for the elite populations reported in the literature does the “average” elite performer do more hours training than their age, but this particular oxymoron (average elite) reminds us that the exceptional performers at any age are not average and lie at the extremes.

A large variety of training exposures are also due to the sport of choice for young athletes. In fact, while gymnastics and swimming can be considered early specialization sports, track and field is regarded as a late specialization sport with athletes peaking in their mid- to late 20s. This typically determines an earlier increase in training loads in these sports as compared with late specialization sports due to the early competitive rewards sought. For example in London 2012 the majority of female gymnasts were under 18 years of age while there were 24 swimmers under the age of 16. The downside of this approach in sports where early specialization is not necessary is the possible shortening of sporting careers. In track and field it has been shown that only 7% of the top-20-ranked athletes at U-15 level are still ranked in the top-20 in 4 wk or more, with chronic overuse injuries accounting for up to 40% of all injuries. The typical injury incidence is in a range of 1 to 10 injuries/1000 h, though based on athlete exposure this rate can be inflated in sports such as cross country running (10.9–15 injuries/1000 exposures). The differing definitions of injury rates highlight that the measurement of “injury” needs a clear definition and a common language as given in the AIS data dictionary:

Any recordable incident sustained while undertaking training or competition related to the athlete’s sport that results in an athlete being unable to participate in training or competition, as planned by coaching staff, for greater than 24 hours.

Recent work highlights these issues in longitudinal research and suggest that the management of load considering the accumulation over the last week (acute) and month (chronic) to measure the training stress balance and avoiding spikes in training of more than 10% might represent a successful training strategy to avoid injury. This concept has been mentioned previously in the adolescent literature as a guideline to avoid overuse injury. More recently a replacement for the term overuse with training load error has been proposed. Regardless of the nomenclature, measurement of load allows some form of quantification and assessment of how to recover from catastrophe and return to training.

Previous studies have shown links between training load and injury in adolescent populations. Cricket fast bowlers age 14.7 ± 1.4 years had 3.1 times the risk of an injury that affected availability when they had less than 3.5 days rest between bowling episodes. Soccer players age 16.5 ± 1.2 years showed higher risk of traumatic injury if they trained more or had higher monotony or strain. If they trained more they also had a higher risk of illness. Another study suggested that a history of training volume could have a protective benefit on groin injury in elite junior footballers age 15 to 17. In baseball, pitchers age 8 to 14 showed a U-shaped relationship where a moderate volume of pitches was protective from injury, a low volume made no difference and a high volume (>600 pitches in a season) gave a high risk of injury which increased with each additional pitch. Volleyball athletes age 16 to 18 showed an increased risk of jumper’s knee with each additional hour they trained in a week (odds ratio [OR] 1.72) or each additional set they played (OR 3.88), although another study in a similar group showed no difference in jump frequency between asymptomatic and symptomatic athletes. There may also be links between the types of sport and the injury risk. This is possibly related to the training types; that is, endurance sports will generally have longer durations at lower intensity while other sports may focus on higher intensity and lower duration.

Work in track and field athletes has shown that across a sample of 33 internationals (walkers, sprinters, endurance, jumpers, and throwers) there was a threshold of less than 20% modified training that was a key factor in determining the likelihood of success. Exceeding 20% modified training increases the risk of failure regardless of how it is reached. This 20% figure is remarkably similar to AFL data that showed in a team sport that if you are available for greater than 85% of training sessions then you should last the year. Modifying the training load of first year professionals in team sports has been suggested, but it is unclear if this is objectively done and there are no guidelines in the literature. While most data are currently drawn from adult athletes, the opportunity to train is extremely important for the adolescent athlete who is learning his craft and needs exposure to the volume of training.

Recently, at the elite level the effect of missed training days has been highlighted in a study analyzing self-reports of training and illness symptoms of elite Norwegian cross-country skiers (N = 37) over a 9-year period. The 16 athletes in the group who

Useful Approaches to Quantifying Training Load and Injury Risks

The catastrophic outcome of injury in an adolescent athlete can sometimes be identified not only in the interruption of competitive activities, but also as the end of access to physical activity and sport participation. For this reason, young athletes should be properly managed so as to try and reduce the possibility of injury. Within youth sport typically 20% of injuries are severe (no sport for 4 wk or more), with chronic overuse injuries accounting for up to 40% of all injuries. The typical injury incidence is in a range of 1 to 10 injuries/1000 h, though based on athlete exposure...
had won individual medals at the Olympics or World Championships reported an average of 14 d/y with symptoms of respiratory or gastrointestinal infection, compared with 22 d/y among the nonmedalists. Here we are not dealing with catastrophe but the shades of gray between—the accumulation of small periods of missed training can be just as devastating as long periods out to injury in a truly elite cohort of athletes. Equal consideration should be given to multiple single-day and -week absences as multiweek absences.

This consistent absence can be considered an absence of consistency in training and could potentially lead to underperformance. Within human resources there is a formula for dealing with absence that could be implemented in sport to quantify training consistency. The Bradford factor (BF) has thresholds of 45, 100, and 900. These relate to increasing levels of concern with the absence and, in the human resources world, escalate to concern, disciplinary action and dismissal. In the sport setting this approach could provide guidelines to reassess and modify an athletes’ program.

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BF = (\text{number of absences})^2 \times \text{total days of absence}
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We have analyzed the data of an adolescent sports academy to highlight the benefit of this approach (Figure 1). The top-10 young athletes (according to their BF) were analyzed over 7 months. The highest BF (3060 AU) was associated with a young athlete in his first year of the full-time program, the second-highest with an athlete in his second year, and the third with an athlete in his fourth year (2475 and 931 AU, respectively). This may reinforce what previous studies suggested: managing the transition into full-time training may be highly important to allow a progressive accumulation of training at a young age with limited risks, in particular as it is hypothesized that every time-loss event affects one’s ability to resume the preinjury training load.\(^{40}\)

Objectifying Decision Making

Athletes’ training and competition data can be used to quantify the risk associated with changes in load. The review of these data should drive decision making to create a safe and successful environment.\(^2\) All decisions pertaining to athletes should increasingly be based on evidence—be that about performance, training load or injury. It is commonplace in elite sport to use a data management system to underpin decisions and to measure the impact coaches and service providers have on performance. Indeed, quantification and monitoring of both the dose (training load) and response (performance) is imperative to maximize the likelihood of optimal athletic preparation.

Coaches and practitioners attempt to modify and control the dose to maximize the positive influences and minimize the negative effects. This modification occurs on the basis of information they obtain through various feedback methods on the response. Any data collected should assist the decision-making process to ultimately provide meaningful information that informs the decision or training outcome and becomes knowledge on which to base future decisions. The transition of data into knowledge can provide a deeper level of understanding.\(^{41}\) Putting data in context transforms numbers and evidence to information. Summarizing information in meaningful outcomes can inform and affect a performance plan. It should be the case that performance discussions account for the data and do not rely solely on the opinion of influential members of the group. Which markers are important to each sport needs to be balanced alongside what is practical to be monitored and ultimately how they will be stored and acted on to influence performance.

Figure 2 shows output from of heart-rate data from an adolescent endurance athlete—the highlighted area is a training camp (period of intensified training). This figure highlights a number of
metrics that are tracked from session type to time spent in specific heart-rate zones, load calculations, and subsequent calculations of load and its derivatives such as monotony, strain, and training-stress balance (TSB) are also presented. In this example we see an athlete with high monotony and strain values across this period of intensified training, which is to be expected from the design. We do not however see an elevation of the TSB to a level that would cause concern as suggested in the literature (>1.25).

The use of objective data with youth athletes is fundamental for appropriate training load monitoring and reliance on simple methods like session RPE may be of limited application. The main source of concern stems from the ability of young people to be able to reliably assess the perceived exertion, as well as potential language and cultural issues with anchoring scales when translated from the original constructs. This means that objectively, depending on the sport, you can measure a number of factors such as volume, loads, jumps, or pitch counts without relying too much only on the perception of load.

The collection of data can initially be wide as we decide what to measure and then narrow over time as we attempt to ask questions that can create a collective series of statements to form a definite proposition. Having the data is important, as it can reflect differences in coaching approaches and potential impact on athletes. Coaches have an enormous influence on young athletes, not only with regards to the emotional elements of developing youngsters but also in the loading paradigms used.

Changing a coach at a young age can also represent a change in the risks of injury for young athletes due to the differences in coaching philosophies, experience, planning, and perceived needs for high workloads. As the literature is limited with regards longitudinal studies of youth training loads, it is difficult for coaches to develop appropriate training programs for youngsters. There is a risk of adult-type prescriptions being applied. Different coaching styles not only refer to teaching aspects but are also reflected in differences in the training dose. As we monitor closely training loads in our academy we routinely analyze not only year-on-year approaches but also coaching styles in terms of training prescription. Figure 3 shows an individual endurance athletes’ average volume of training performed and the velocity in track sessions as an acute (7-d), chronic (28-d) load and the balance between the 2. The dashed line shows the break between seasons.

Each individual box highlights a different coach leading the program. The first was a coach who favored low-volume, high-intensity workouts. The second from a coach favoring progressions in volume before speed. The final coach with a moderate approach using both volume and speed to get a desired result. Of course we also see differences in the phase of the season but this raises more questions about what is important to monitor and hence manipulate across the year. The current literature does not provide useful guidelines on how to use this information to suggest appropriate training loads for young athletes. In adults it seems there is consensus with a 7- and 28-day moving average balance of 0.8 to 1.3 across a number of sports. For adolescents this level may be different and it may also be linked to the training experience (in terms of years of full-time training). The periods to use in this equation may also differ. There may also be different latent periods for injury to occur following an inappropriate training load for the age and training experience of the athlete.

Within the limits of what is ethically sound in young athletes, some use of biomarkers could be implemented. Recent research has highlighted the individuality of responses in a number of blood markers during an intense training camp. The authors identified

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Figure 3 — Training imposed on 1 athlete highlighting a change in coaching approach. The top graph shows the volume of sessions (sum of distance covered in m) and the bottom the average velocity (m/s; intensity) of the session. Each data point is representative of a training day: the acute (7-d rolling average), chronic (28-d rolling average), and training-stress balance (TSB: acute:chronic) are shown for each day across the period. The 3 different coaches and their approaches are highlighted by the 3 different-color boxes: the first low volume and high intensity (left), the second progressions in volume before speed (center), and the third manipulation of volume and intensity (right). The end of 1 season and start of the next is shown by the dashed vertical line.
differing levels of responses in specific markers dependent on the type of training across a 7-day period. For creatine kinase (CK) in endurance athletes they reported an increase of 54 units, while the strength and high intensity interval training groups determined acute CK increases 10 to 15 times larger.

In our experience, despite the fact that adolescent athletes are reported to present CK responses to training lower than the adult counterparts, we sometimes observe marked signs of muscle damage in our cohorts. The example in Figure 4 shows an increase in CK of approximately 1000 units in just 5 days. This supports our view that each athlete is an individual and needs to be treated as such and only evidence collected routinely can help drive meaningful changes in a training program.

While measures of external loads can be easier to collect and are potentially more reliable, they only provide limited information about the implications of the training dose to the athlete. Efforts should be made to quantify aspects of internal load measures across all modalities of training where appropriate and within what is reasonably expected and ethically viable. Young cohorts should also be assessed with regards to external stresses contributing to the overall stress experienced by young athletes. There is the accumulation of the daily schedule of training and life across the week, which sees an accumulation of fatigue toward the end of the week in athletes enrolled in sporting academies and/or structured training. There are also periods of high stress in life in general (e.g., family and academic commitments). There comes a point that there may be a need to draw the line with a “Goldilocks” type approach to find the right training. The decision about what the correct amount of load is should ultimately come from the team supporting the individual, in conjunction with the athlete and be based on the available evidence.

Cautionary notes should be made about any cultural or language differences that may influence perception of what is stressful, understanding of the implications and consequences, and acceptance of the need to communicate with the coach or coaching staff if there is a feeling of exhaustion/need to withdraw from training. While internal load measures such as RPE were commonly used in adult athletes this does not mean that all adolescents understand and use the scale appropriately. Ultimately communication between coach and practitioner is key to serve the needs of the athlete.

**Summary**

The management of training load in young athletes is fundamental to guarantee a long sporting career and/or engagement in sporting activities. For this reason, various monitoring approaches should be implemented which ideally limit the exposure to invasive measures. The choice of monitoring techniques and methods should be

![Figure 4](image_url) — Individual morning monitoring responses to an intensified training period in an endurance athlete from the day before travel and throughout. Hydration scores measured via urine (mOsm; bars), creatine kinase via blood (CK; black line; U/L), and urea via blood (mg/dL; gray line). The SD is shown via error bars for the blood measures.
determined by what is important to the sporting context and the individual situation and take into account social/behavioral norms (in particular when psychometric tools are implemented). These data then need to be gathered to have a holistic approach to the quantification of the training dose and communicated to the coaching staff with the view of delivering not only appropriate training corrections but also capture learning for future cases (ie, turning these data into knowledge). Without a systematic approach to training load monitoring in young athletes there is no opportunity for learning and reflection and training prescriptions may continue to be adapted versions of adult programs. Adolescent athletes are on a journey to adulthood and their development should be seen always as a long term project. Future research efforts should therefore focus on defining appropriate training doses and risk thresholds for young athletes to make sure that modern coaching approaches are employed to develop resilient athletes and reduce the risk of burnout.

References

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