More than a Metric: How Training Load is Used in Elite Sport for Athlete Management

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ABSTRACT

Training load monitoring is a core aspect of modern-day sport science practice. Collecting, cleaning, analysing, interpreting, and disseminating load data is usually undertaken with a view to improve player performance and/or manage injury risk. To target these outcomes, practitioners attempt to optimise load at different stages throughout the training process, like adjusting individual sessions, planning day-to-day, periodising the season, and managing athletes with a long-term view. With greater investment in training load monitoring comes greater expectations, as stakeholders count on practitioners to transform data into informed, meaningful decisions. In this editorial we highlight how training load monitoring has many potential applications and cannot be simply reduced to one metric and/or calculation. With experience across a variety of sporting backgrounds, this editorial details the challenges and contextual factors that must be considered when interpreting such data. It further demonstrates the need for those working with athletes to develop strong communication channels with all stakeholders in the decision-making process. Importantly, this editorial highlights the complexity associated with using training load for managing injury risk and explores the potential for framing training load with a performance and training progression mindset.

Current Training Load Climate

Athlete monitoring and training load management has long been a key responsibility for sport scientists [1]. Over the last decade, the emphasis on this topic in elite sport has risen exponentially, largely stemming from the desire to achieve and maintain performance and mitigate injury risk. Load can be defined as "the cumulative amount of stress placed on an individual from multiple sessions and games over a period of time" [2]. This definition is specific to physical loads (the primary focus of this editorial), while we acknowledge other types of loads are also imperative to understanding athlete performance (e. g. psychological and social load).

Historically, athlete load management relied on coaches' observations. As new technologies for measuring athlete training dose and response surfaced (e. g. heart rate monitoring, tracking systems), the desire to harness and embrace these technologies proliferated their use in sports science and medicine disciplines [1]. The pros and cons associated with many of these tools have been extensively outlined previously in the literature [3, 4]. Therefore, while we will not restate all these details within this editorial, it is prudent to understand that the most valuable tools are those which can provide accurate data to inform performance-related decisions while minimising athlete and practitioner burden.

Physical load can be subdivided into two components: external load (the external stressors applied to an athlete) and internal load (the corresponding internal psychophysiological response of the athlete) [5]. Whereas internal load may determine the "functional outcome" of the training process [5], often it is logistically more difficult to capture, leading to the wider use of external metrics. Irrespective of how load is captured, it is crucial to critically appraise the reliability, validity, and utility of the data being collected within one's respective context. Depending on resources and context, this may be done through 1) existing independent validation, 2) partnering with universities or industry to perform new validation work, or 3) internal validation work, all of which may increase practitioners' confidence with a given technology.

With the exponential rise in available data, practitioners and researchers have had to search for simple and efficient ways of capturing, aggregating, and interpreting data. In some instances, certain metrics have been heavily relied upon, including high-speed running distances for capturing load and the acute:chronic workload ratio (ACWR) for aggregating data. While these metrics were openly welcomed by the sport science community as simple means to assess changes in injury risk and have since been widely adopted and proliferated in sports, the ACWR, in particular, has recently become the subject of much debate in the peer reviewed [6] and non-peer reviewed [7, 8] literature.

While early introductory research concentrated on the relationship between load parameters and injury, this may have led to the belief that these were the only measures of importance, however it has since been stated that these measures should only be a component of a wide variety of measures [9–11]. We agree that no single metric can clearly state the risk of injury or state of preparedness of an athlete and therefore review why load monitoring is far more than any individual metric, and how it can play a vital role in informing performance-related decisions. We outline the challenges and merits of investing time in this process. Pooling experience from multiple team and individual sports, we hope to describe when and why monitoring athletes adds value for the modern sports practitioner.

Models for Framing Training Load Management

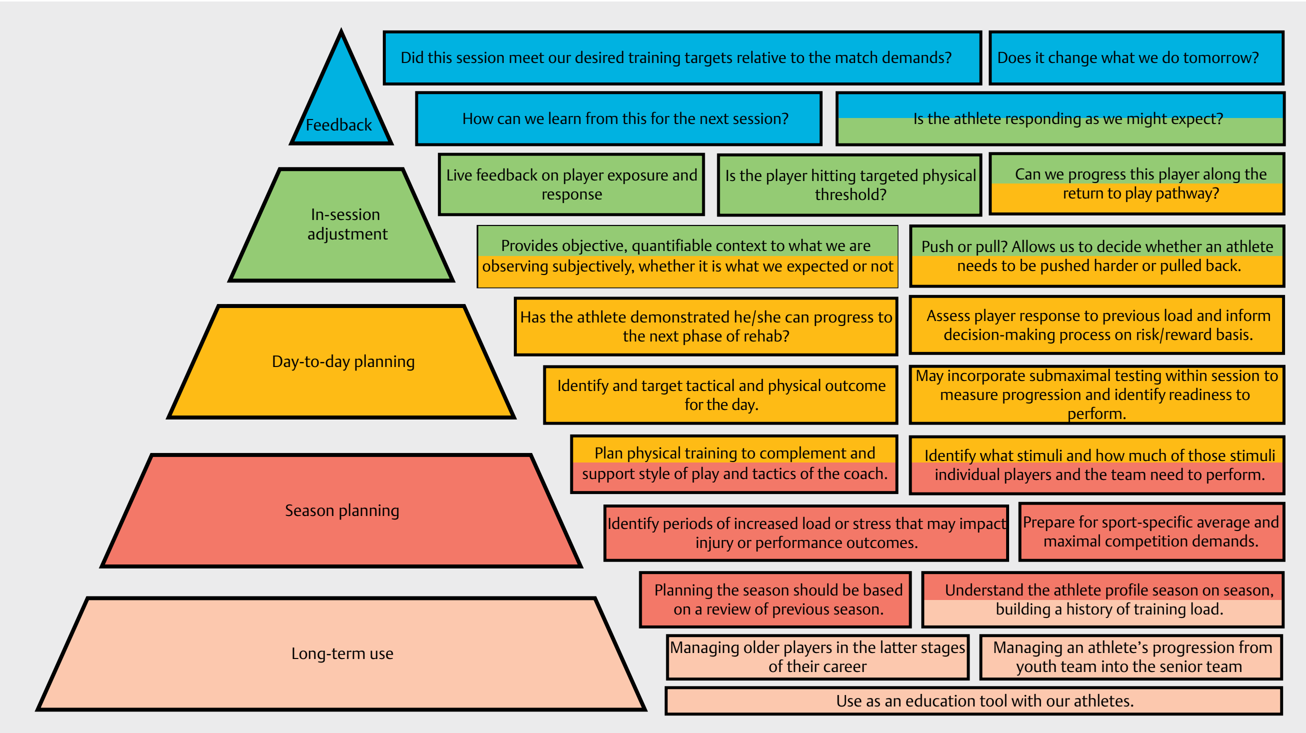
For sport science practitioners and researchers, it is important to build data collection practices on the foundation of clearly defined conceptual models linking the information to the desired outcome [12]. Two constructs which underpin athlete monitoring practice are performance and injury prevention. Although they are distinct constructs, performance and injury are closely linked, as injuries and subsequent training unavailability negatively affect team and individual athlete performance [13].

'Successful performance' looks very different across sports, so modelling how load relates to performance is challenging. However, in endurance sports where performance is closely linked with athletes' ability to maximise physical output, systems modelling has been used to good effect [14, 15]. It remains unknown whether these models apply in team sports where physical performance and team success may not be congruent. Although physical performance and team success may not always align, a recent framework for the training process demonstrated the link by which training monitoring can enable performance outcomes [5]. In this framework, using both external and internal load monitoring provides a link between the data being collected and the performance construct being evaluated. By identifying key physical determinants of performance, one can track athletes' individual fitness responses to a training dose through mechanisms like submaximal testing at periodic time points throughout the season to ensure physical qualities are optimised.

Although minimising injury risk is desirable, injury is a complex and dynamic outcome which is influenced by several risk factors, often with no predictable pattern. This is best exemplified by a complex model of sports injury, which outlines a web of determinants that display a dynamic and open structure with inherent non-linearity due to recursive loops and interactions between risk factors [16]. Although its complex nature makes injury prediction extremely difficult, recognising and measuring known risk factors may help to determine periods when players may be at an increased risk of injury. One of the most widely recognised models of injury risk is that of Meeuwisse et al. [17], which demonstrates how these intrinsic and extrinsic risk factors not only influence risk but may also change over time. Therefore, while a single baseline intake for non-modifiable factors like age and sex may suffice, risk factors that change dynamically (e. g. strength) must be measured repeatedly, with a frequency that coincides with how often they change. Slowly changing risk factors, such as athlete strength, previous injury, and fitness levels can be measured at strategic phases throughout the season, like at the end of pre-season. Finally, some measures including load (which is a rapidly evolving risk factor) need to be updated daily. Windt and Gabbett [18] describe how loads expose athletes to potential injurious events, and alter athletes' injury risk profiles through positive and negative changes to modifiable risk factors. How loads causally relate to injury risk is an area of ongoing investigation and will likely develop as sport-, tissue- and load-specific models are developed [19–21].

What Can We Use Training Load Data For?

Athlete monitoring data can inform decisions related to 1) the load athletes need to be prepared for in competition, 2) the load they are prescribed, and 3) their subsequent response to that load. These span short-term decisions in the daily training environment through to long-term season planning. While the specific implementation will vary across environments, we describe five overarching levels for these decisions spanning from long- to short-term decisions, with several specific processes within each (▶ **Fig. 1**).



▶ **Fig. 1** Five overarching levels at which training load can inform athlete preparation and management. 1) Feedback, blue boxes; 2) in-session adjustment, green boxes; 3) day-to-day planning, orange boxes; 4) season planning, red boxes; 5) long-term use, pink boxes. Training load uses that span more than one category are represented by the split colour boxes.

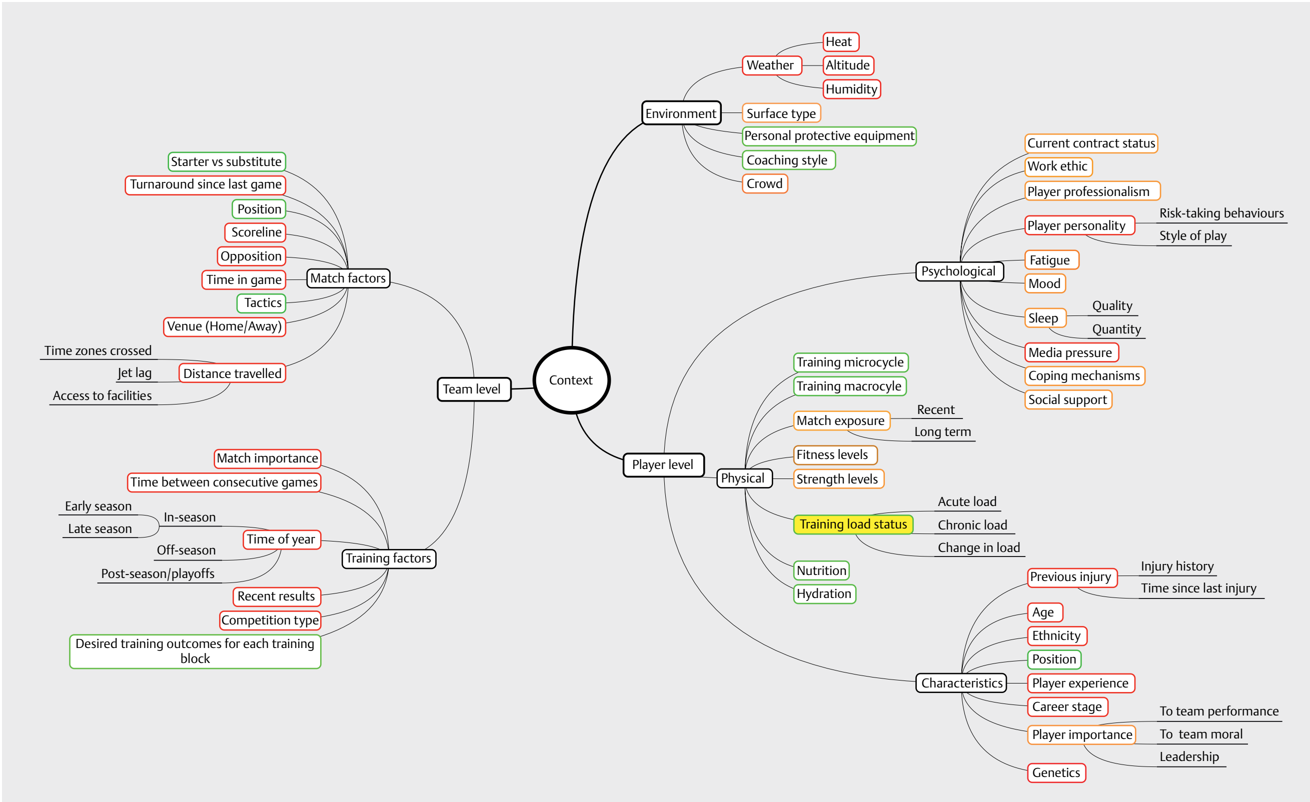
To inform athlete management at any level, practitioners must establish whether the purpose of each change is to prepare, maintain, or adjust load in an optimal way. One must also consider what the corresponding consequences of a change will be on injury risk or readiness to perform. Although making small adjustments in response to data in-session may have only acute changes for the athlete, larger adaptations to season planning in response to historical trends or transition from one stage of a career to another may have longer lasting implications for the athlete. Individual athlete responses to stimuli at any level of ▶ **Fig. 1** are likely to range widely and, therefore, both the external dose and internal response should be measured accordingly.

What We Should not Use Training Load For

The ability to predict outcomes such as performance and injury has previously been described as the "Quest for the Holy Grail" for sport science and sport medicine [22]. Unsurprisingly, injury prediction has become a lucrative business, with bold marketing claims suggesting that certain technologies may provide this 'crystal ball' to sports practitioners. Despite these claims, we are not currently in a position to objectively and reliably predict injury outcomes. No single metric or collection of metrics should be used as a definitive injury prediction tool. Rather, practitioners can gather the available evidence and use it alongside their experience to guide ongoing decision-making by balancing risks and reward for each player. One danger is the potential to become risk-averse in one's approach to managing athletes. The danger with framing athlete monitoring within the lens of injury risk reduction is that it may lead to a risk-averse mentality in which one thinks they can protect the player by resting them. However, it is now clear that the decision to rest a player has potentially harmful consequences by restricting a player's exposure to important moderators of injury risk such as high speed running [23, 24] and a well-developed chronic training exposure [11]. While it is an unwelcome truth, injury is inevitable in sport, a by-product of pushing players to their performance limits needed to be successful. Therefore, the approach of functional overreaching and strategic recovery periods to optimise performance presents a positive approach to monitoring rather than reducing injuries alone.

Contextualising the Data in your Environment

When interpreting athlete monitoring data, practitioners must weigh the potential positive and negative consequences of exposing an athlete to a training stimulus. Having collected, analysed, and interpreted the data, practitioners are required to add context to support their subsequent recommendations. When making these training decisions, "Content is king, but context is God" [25]. Both performance and injury are highly complex, so the context applied by a practitioner when balancing the risks and rewards associated with each given training stimulus is vital [26]. ▶ **Fig. 2** provides just a sample of the contextual considerations that inform athlete management. While training load contributes as a portion



▶ **Fig. 2** Contextual factors when managing athlete injury risk and readiness to perform. Boxes are colour-coded as to their degree of modifiability by the coaching/conditioning staff as a group. Green box indicates modifiable risk factor, orange indicates somewhat modifiable, and red box indicates non-modifiable. Training load is highlighted in a yellow box to demonstrate it is only part of the overall picture.

of the picture, its modifiability makes it a desirable target for adjustment. Many of these are specific to match circumstances [27, 28] and are externally controlled (for example, venue and turnaround between games). Several refer to individual player characteristics and, therefore, depend on the practitioner's knowledge of each player to inform the decision-making process. In many cases, it is not possible to objectively capture the entire context regularly, so practitioners must depend on their relationships with the athletes through regular communication. As these relationships develop, conversations become one of the most powerful barometers for practitioners to gauge an athlete's load tolerance and how this changes in response to other stressors. Considering the athlete's career stage as one example, a youth player going through a developmental stage may require a more conservative loading strategy (especially during growth spurts), when compared with a first team player at the peak of his/her career. This simple example demonstrates the inability of training load to be "cookie-cut", with each athlete needing individual attention to optimise their load.

Interdepartmental collaboration is pivotal for effective informed decision-making. A challenge for sport scientists is distilling the most meaningful information to other key stakeholders, including the athletes themselves. Central to this process is that the message and communication is delivered in appropriate language and format which can be understood by non-experts in the area.

Challenges and Complicating Factors to the Load Monitoring Process

Aside from the contextual factors that need to be considered when adapting an athlete's training, there are several challenges for practitioners to overcome. These can be broadly classified into issues with data, monitoring restrictions, buy-in, working in lower participation sports, and managing expectations.

Given the amount of data available to inform the decision-making process, a number of data-related issues are apparent in athlete monitoring. First and foremost, building trust in the data being collected is essential. Where feasible, the use of psychometric principles should be used to understand each technology's limitations and its associated validity and reliability [12, 29]. Included in this is recognising the amount of error associated with a measure, to ensure that changes in that measure represent true change and not simply error in collection.

From a logistical perspective, data collection procedures are often hampered by available resources. For example, large squad sizes (e. g. ~90 players during an NFL preseason) make regular individual measurements difficult. Given that external load measures can be collected with less effort from players (just wearing the device), such external measures are often collected more frequently than internal load measures that place a larger burden on the athletes (e. g. wellness surveys, RPE). Furthermore, in sports where players are based remotely or move in and out of teams (e. g. national teams, farm teams), capturing load and aggregating the data can be difficult if there are sporadic periods of absenteeism, which leads to problems in maintaining normal monitoring practices [30]. Missing data may also occur when league rules ban wearable technology use during matches, or mandate alternative technologies during competition.

Athlete and coach 'buy-in' is one of the greatest challenges to athlete management. With respect to training load specifically, this is a major challenge in sports where tradition stigmatises athlete monitoring, with coaches adopting the tried and tested methods of observation. This may be especially prevalent in lower participation sports where little research evidence exists. These environments may learn from similar sports to support the need for investment in the practice of athlete monitoring. Taking the research and practice from other sporting environments and critically appraising the merits of this in the context of one's own sport is an essential skill for sport scientists and should be included in formal training and continued professional development.

Using technology in sport has become so commonplace that in many environments it is culturally accepted and expected of sport science staff. Sport scientists may be required to provide accurate, consistent and actionable insights daily. However, providing these insights becomes more challenging based on all the potential confounders, contextual factors, and considerations associated with using load data. The lack of clear links between this data and either injury or performance has arguably led to a negative perception of training load management. From a causal perspective, another challenge is not knowing whether a decision influences an outcome – if a player is pulled from training due to a negative response to previous load, that player will not get injured. However, one will never know what would have happened if they had played. Conversely, should the athlete play and he/she gets injured, the blame may be attributed to the practitioner for not picking up on the warning signs. This encourages risk-averse behaviour and may be limiting athletes' ability to train and play.

In "Seeing What Others Don't: The Remarkable Ways We Gain Insights" [31], Gary Klein outlines four common guidelines for decision support systems. These are:

1. The system should allow people to do their jobs better;
2. It should clearly display critical cues, the items of information that users rely on to do their jobs;
3. Filter out irrelevant data so the operators are not overwhelmed with meaningless messages;
4. The system should monitor progress toward their goals.

Such guidelines could theoretically underpin a discussion about athlete monitoring systems. Klein outlines several challenges associated with these guidelines, but sport scientists can clearly use these principles as a framework for their work. While these guidelines best work when there is structure and order in the system, as is the case in elite sport, the outcomes are inherently disorderly and complex. Therefore, these guidelines should be re-visited regularly to ensure they are still appropriate for the monitoring outcomes. Having a set of guidelines to frame athlete monitoring processes will help to mitigate some of the challenges described within this section and ensure realistic and achievable expectations.

What Next for Training Load Monitoring?

Training load monitoring is evolving rapidly and as technology improves it is important that we embrace new insights afforded by such data, while still providing concise and actionable feedback to key decision makers. Despite the progress made in recent years, a number of improvements are still required. In a recent paper, Kalkhoven et al. [21] outlined the need for greater consideration for tissue specificity when considering injury risk, especially in the cases of stress, strain, and overuse injuries. They provide a conceptual model for athletic injury consisting of causal contextual factors, force application and distribution, structural load application, and tissue-specific stress and strain. Although this demonstrates the complexity of understanding injury risk, it is again important to frame athlete monitoring in the context of the type of injuries practitioners are trying to prevent.

In practice, there are several improvements which could be made to the current methods of data collection and analysis [32, 33]. These range from new technology becoming available to improvements in data analysis and interpretation. Our ability to measure some aspects of external load remains limited, highly time-consuming, and often unreliable. Examples of this include the high levels of isometric external load in scrummaging by forwards in rugby, by linemen in American football, and in basketball when jostling for possession. In handball or volleyball, capturing arm swings or throws and the associated loads on the shoulder remains difficult but important. Furthermore, some sports do not allow wearable technology use during competition, meaning a significant portion of the external load experienced by the athlete cannot be captured. Therefore the idea of 'invisible monitoring', whereby loads may be evaluated while minimising athlete and practitioner burden, carries high potential. Examples of more 'invisible monitoring' include equipment with inbuilt instrumentation such as mouthguards or smart garments, or optical tracking solutions that do not require athletes to wear additional equipment or technology [34]. Finally, new technologies may bring previously 'siloed' data streams together. For example, linking physical tracking data to event data provides valuable context compared to the physical data alone [35].

Conclusion

Athlete monitoring is a vital tool in the modern-day sport scientists' toolbox. While recent framing may have overemphasised a medicalised rationale for athlete monitoring, workloads can inform decision-making in diverse ways: from historical reviews of match and training demands, through daily real-time decision support, to proactive future planning. This informed decision-making process must consider the limitations with any data collected and its psychometric properties – including its theoretical relevance, validity, reliability, and sensitivity.

Ultimately, athletes play sport to perform, not avoid injury, so re-calibrating their focus from "predicting" injury and towards maximising performance may help sport scientists' improve player and coach buy-in. Currently, athlete monitoring stands between art and science, with practitioners working to contextualise load-related data within the decision-making process. Both injury and performance are multifactorial and cannot be explained by any risk factor in isolation. It has been said that "prediction of the path of a hurricane is an imperfect science, but useful enough to guide critical decisions and give estimates" [36]. In this vein, while training load management is highly complex and imperfect, it is an important piece of the puzzle to help guide decisions for maximising player performance, welfare, and team success.

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Conflict of interest statement

The authors have no conflicts of interest to report. This editorial meets the ethical standards of the journal as per Harris et al. [37].

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