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1 **Title:**

2 More than a metric: How training load is used in elite sport for athlete management.

3  
4 **Abstract:**

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

19  
20 **Current training load climate**

21  
22 Athlete monitoring and training load management has long been a key responsibility for sport scientists  
23 [1]. Over the last decade, the emphasis on this topic in elite sport rose exponentially, largely stemming  
24 from the desire to achieve and maintain performance and mitigate injury risk. Load can be defined as  
25 “the cumulative amount of stress placed on an individual from multiple sessions and games over a  
26 period of time” [2]. This definition is specific to physical loads (the primary focus of this editorial),  
27 while we acknowledge other types of loads are also imperative to understand athlete performance (e.g.  
28 psychological and social load).

29  
30 Historically, athlete load management relied on coaches’ observations. As new technologies for  
31 measuring athlete training dose and response surfaced (e.g. heart rate monitoring, tracking systems),  
32 the desire to harness and embrace these technologies proliferated their use in sports science and  
33 medicine disciplines [1]. The pros and cons associated with many of these tools have been extensively  
34 outlined previously in the literature [3, 4]. Therefore, while we will not restate all these details within  
35 this editorial, it is prudent to understand that the most valuable tools are those which can provide  
36 accurate data to inform performance-related decisions, while minimizing athlete and practitioner  
37 burden.

38

39 Physical load can be subdivided into two components: External load (the external stressors applied to  
40 an athlete) and internal load (the corresponding internal psychophysiological response of the athlete)  
41 [5]. While internal load may determine the “functional outcome” of the training process [5], often it is  
42 logistically more difficult to capture, leading to the wider use of external metrics. Irrespective of how  
43 load is captured, it is crucial to critically appraise the reliability, validity and utility of the data being  
44 collected within one’s respective context. Depending on resources and context, this may be done  
45 through 1) existing independent validation, 2) partnering with universities or industry to perform new  
46 validation work, or 3) internal validation work, all of which may increase practitioners’ confidence with  
47 a given technology.

48

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

56

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

65

## 66 **Models for framing training load management**

67

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

73

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

85

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

103

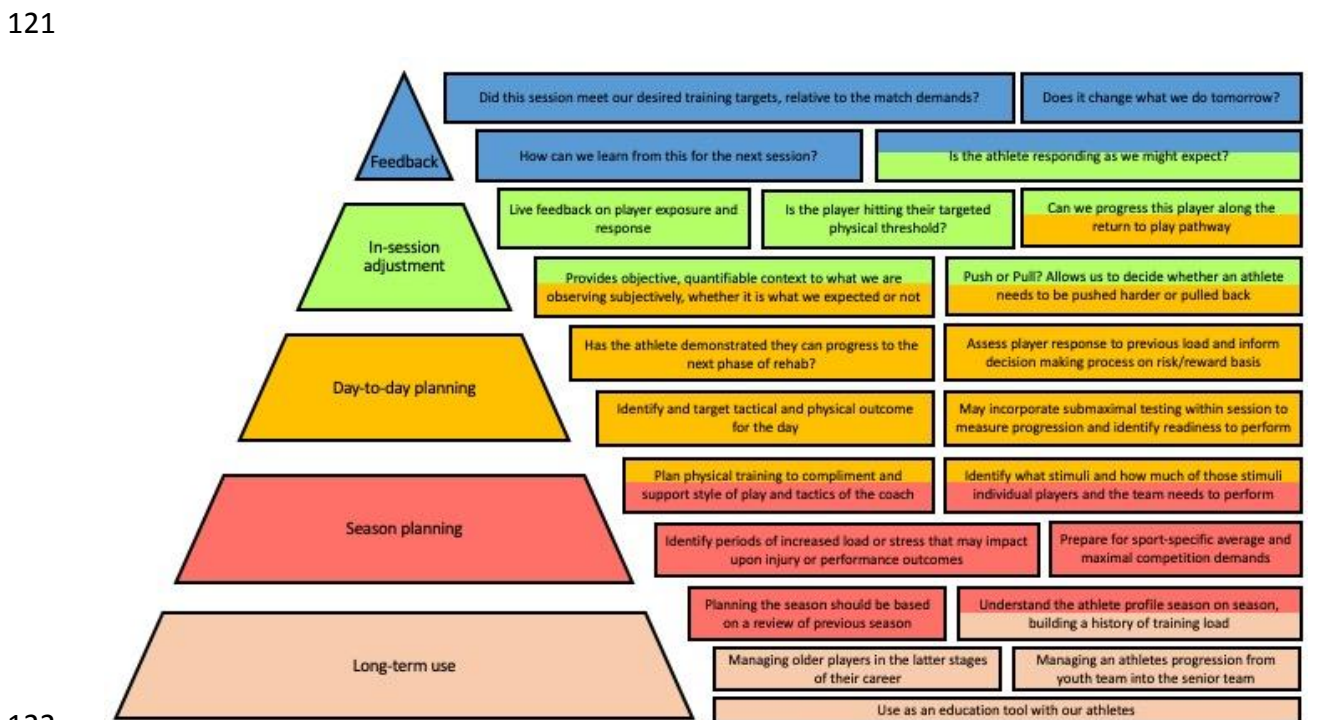
#### 104 **What can we use training load data for?**

105

106 Athlete monitoring data can inform decisions related to 1) the load athletes need to be prepared for in  
107 competition 2) the load they are prescribed and 3) their subsequent response to that load. These span  
108 short-term decisions in the daily training environment through to long-term season planning. While the  
109 specific implementation will vary across environments, we describe five overarching levels for these

110 decisions spanning from long to short-term decisions, with several specific processes within each  
 111 (Figure 1).

112  
 113 To inform athlete management at any level, practitioners must establish whether the purpose of each  
 114 change is to prepare, maintain or adjust load in an optimal way. One must also consider what the  
 115 corresponding consequences of a change will be on injury risk or readiness to perform. While making  
 116 small adjustments in response to data in-session may have only acute changes for the athlete, larger  
 117 adaptations to season planning in response to historical trends or transition from one stage of a career  
 118 to another, may have longer lasting implications for the athlete. Individual athlete responses to stimuli  
 119 at any level of Figure 1 are likely to range widely and, therefore, both the external dose and internal  
 120 response should be measured accordingly.



122  
 123 Figure 1: Five overarching levels at which training load can inform athlete preparation and  
 124 management. 1) Feedback - represented by blue boxes 2) In-session adjustment– represented by green  
 125 boxes 3) Day-to-day planning represented by orange boxes 4) Season planning - represented by red  
 126 boxes 5) Long term use - represented by pink boxes. Training load uses which span more than one  
 127 category are represented by the split colour boxes.

128  
 129 **What we should not use training load for**

130  
 131 The ability to predict outcomes such as performance and injury has previously been described as the  
 132 “Quest for the Holy Grail” for Sport Science and Sport Medicine [22]. Unsurprisingly, injury prediction  
 133 has become a lucrative business, with bold marketing claims suggesting that certain technologies may  
 134 provide this ‘crystal ball’ to sports practitioners. Despite these claims, we are not currently in a position  
 135 to objectively and reliably predict injury outcomes. No single metric or collection of metrics should be

136 used as a definitive injury prediction tool. Rather, practitioners can gather the available evidence and  
137 use it alongside their experience to guide ongoing decision making by balancing risks and reward for  
138 each player. One danger is the potential for becoming risk averse in one's approach to managing  
139 athletes. The danger with framing athlete monitoring within the lens of injury risk reduction is that it  
140 may lead to a risk averse mentality in which one thinks they can protect the player by resting them.  
141 However, it is now clear that the decision to rest a player has potentially harmful consequences by  
142 restricting a players exposure to important moderators of injury risk such as exposure to high speed  
143 running [23, 24] and a well-developed chronic training exposure [11]. While it is an unwelcome truth,  
144 injury is inevitable in sport, a by-product of pushing players to their performance limits needed to be  
145 successful. Therefore, the approach of functional overreaching and strategic recovery periods to  
146 optimize performance presents a positive approach to monitoring, rather than reducing injuries alone.

147

### 148 **Contextualising the data in your environment**

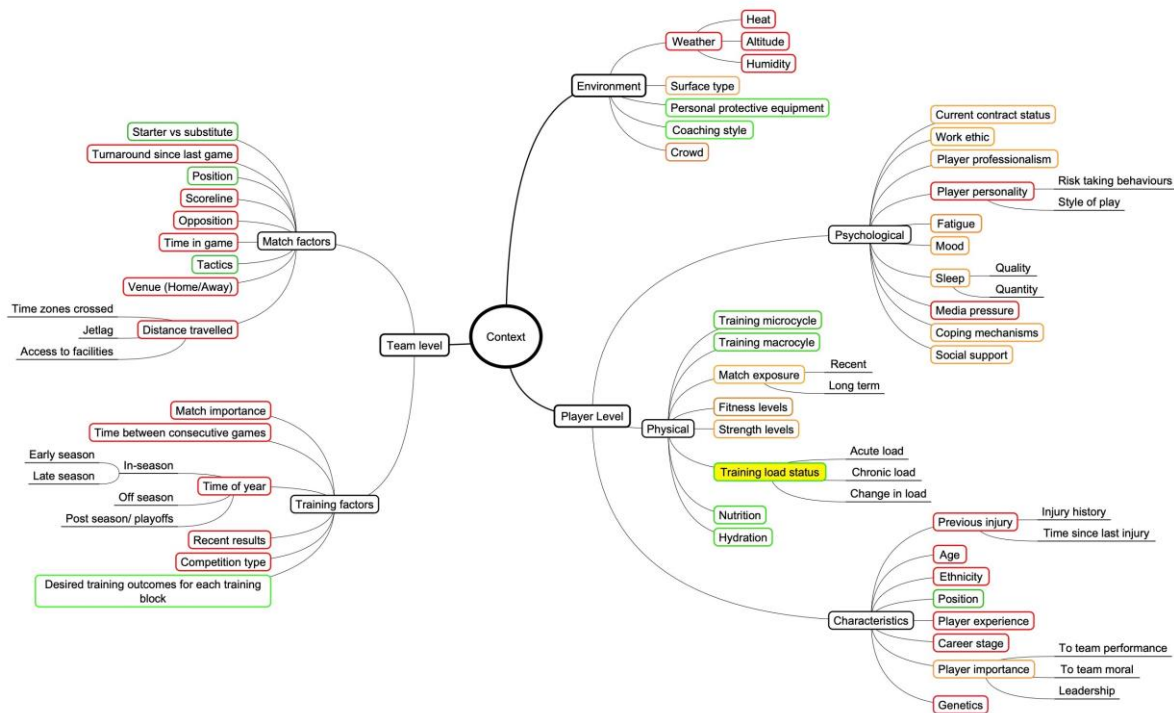
149

150 When interpreting athlete monitoring data, practitioners must weigh the potential positive and negative  
151 consequences of exposing an athlete to a training stimulus. Having collected, analysed and interpreted  
152 the data, practitioners are required to add context to support their subsequent recommendations. When  
153 making these training decisions, "Content is king, but context is God" [25]. Both performance and  
154 injury are highly complex, so the context applied by a practitioner when balancing the risks and rewards  
155 associated with each given training stimulus is vital [26]. Figure 2 provides just a sample of the  
156 contextual considerations that inform athlete management. While training load contributes as a portion  
157 to the picture, its modifiability makes it a desirable target for adjustment. Many of these are specific to  
158 match circumstances [27, 28] and are externally controlled (for example, venue and turnaround between  
159 games). Several refer to individual player characteristics and, therefore, depend on the practitioner's  
160 knowledge of each player to inform the decision-making process. In many cases, it is not possible to  
161 objectively capture all of this "context" regularly, so practitioners must depend on their relationships  
162 with the athletes through regular communication. As these relationships develop, conversations become  
163 one of the most powerful barometers for practitioners to gauge an athlete's load tolerance and how this  
164 changes in response to other stressors. Considering the athlete's career stage as one example, a youth  
165 player going through a developmental stage may require a more conservative loading strategy  
166 (especially during growth spurts), when compared with a first team player at the peak of his/her career.  
167 This simple example demonstrates the inability of training load to be "cookie cut", with each athlete  
168 needing individual attention to optimise their load.

169

170 Interdepartmental collaboration is pivotal for effective informed decision making. A challenge for sport  
171 scientists is distilling the most meaningful information to other key stakeholders, including the athletes

172 themselves. Central to this process is that the message and communication is delivered in appropriate  
 173 language and format which can be understood by non-experts in the area.



174  
 175 Figure 2: Contextual factors when managing athlete injury risk and readiness to perform. Boxes are  
 176 colour coded as to their degree of modifiability by the coaching/ conditioning staff as a group. Green  
 177 box indicates modifiable risk factor, orange indicates somewhat modifiable and red box indicates non-  
 178 modifiable. Training load is highlighted in a yellow box to demonstrate it is only part of the overall  
 179 picture.  
 180

181 **Challenges and complicating factors to the load monitoring process**

182  
 183 Aside from the contextual factors that need to be considered when adapting an athlete's training, there  
 184 are several challenges for practitioners to overcome. These can be broadly classified into issues with  
 185 data, monitoring restrictions, buy-in, working in lower participation sports and managing expectations.  
 186

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

193  
 194 From a logistical perspective, data collection procedures are often hampered by available resources. For  
 195 example, large squad sizes (e.g. ~90 players during an NFL preseason) make regular individual

196 measurements difficult. Given that external load measures can be collected with less effort from players  
197 (just wearing the device), such external measures are often collected more frequently than internal load  
198 measures that place a larger burden on the athletes (e.g. wellness surveys, RPE). Furthermore, in sports  
199 where players are based remotely or move in and out of teams (e.g. national teams, farm teams),  
200 capturing load and aggregating the data can be difficult if there are sporadic periods of absenteeism,  
201 which leads to problems in maintaining normal monitoring practices [30]. Missing data may also occur  
202 when league rules ban wearable technology use during matches, or mandate alternative technologies  
203 during competition.

204  
205 Athlete and coach ‘buy-in’ is one of the greatest challenges to athlete management. With respect to  
206 training load specifically, this is a major challenge in sports where tradition stigmatises athlete  
207 monitoring, with coaches adopting the tried and tested methods of observation. This may be especially  
208 prevalent in lower participation sports where little research evidence exists. These environments may  
209 learn from similar sports to support the need for investment in the practice of athlete monitoring. Taking  
210 the research and practice from other sporting environments and critically appraising the merits of this  
211 in the context of one’s own sport is an essential skill for sport scientists and should be included in formal  
212 training and continued professional development.

213  
214 Using technology in sport has become so commonplace that in many environments it is culturally  
215 accepted and expected of sport science staff. Sport scientists may be required to provide accurate,  
216 consistent and actionable insights daily. However, providing these insights becomes more challenging  
217 based on all the potential confounders, contextual factors and considerations associated with using load  
218 data. The lack of clear links between this data and either injury or performance has arguably led to a  
219 negative perception of training load management. From a causal perspective, another challenge is not  
220 knowing whether a decision influences an outcome – if a player is pulled from training due to a negative  
221 response to previous load, that player will not get injured. However, one will never know what would  
222 have happened if they had played. Conversely, should the athlete play and he/she gets injured, it is  
223 likely that blame may be attributed to the practitioner for not picking up on the warning signs. This  
224 encourages risk averse behaviour and may be limiting athletes’ ability to train and play.

225  
226 In “Seeing What Others Don’t: The Remarkable Ways We Gain Insights”[31], Gary Klein outlines four  
227 common guidelines for decision support systems. These are:

- 228  
229
- 230 1. The system should allow people to do their jobs better
  - 231 2. It should clearly display critical cues, the items of information that users rely on to do their  
232 jobs
  - 233 3. Filter out irrelevant data so the operators are not overwhelmed with meaningless messages



233 4. The system should monitor progress toward their goals

234  
235 Such guidelines could theoretically underpin a discussion about athlete monitoring systems. Klein  
236 outlines several challenges associated with these guidelines, but sport scientists can clearly use these  
237 principles as a framework for their work. While these guidelines best work when there is structure and  
238 order in the system, as is the case in elite sport, the outcomes are inherently disorderly and complex.  
239 Therefore, these guidelines should be re-visited regularly to ensure they are still appropriate for the  
240 monitoring outcomes. Having a set of guidelines to frame athlete monitoring processes will help to  
241 mitigate some of the challenges described within this section and ensure realistic and achievable  
242 expectations.

243  
244 **What next for training load monitoring?**

245  
246 Training load monitoring is evolving rapidly and as technology improves it is important that we  
247 embrace new insights afforded by such data, while still providing concise and actionable feedback to  
248 key decision makers. Despite the progress made in recent years, a number of improvements are still  
249 required. In a recent paper, Kalkhoven et al [21] outlined the need for greater consideration for tissue  
250 specificity when considering injury risk, especially in the cases of stress, strain and overuse injuries.  
251 They provide a conceptual model for athletic injury consisting of causal contextual factors, force  
252 application and distribution, structural load application and tissue specific stress and strain. While this  
253 demonstrates the complexity of understanding injury risk, it is again important to frame athlete  
254 monitoring in the context of the type of injuries practitioners are trying to prevent.

255  
256 In practice, there are several improvements which could be made to the current methods of data  
257 collection and analysis [32, 33]. These range from new technology becoming available, to  
258 improvements in data analysis and interpretation. Our ability to measure some aspects of external load  
259 remains limited, highly time consuming and often unreliable. Examples of this include the high levels  
260 of isometric external load in scrummaging by forwards in rugby, by linemen in American football and  
261 in basketball when jostling for possession. In handball or volleyball, capturing arm swings or throws  
262 and the associated loads on the shoulder remains difficult but important. Furthermore, some sports do  
263 not allow wearable technology use during competition, meaning a significant portion of the external  
264 load experienced by the athlete cannot be captured. Therefore, the idea of ‘invisible monitoring’  
265 whereby loads may be evaluated while minimizing athlete and practitioner burden carries high  
266 potential. Examples of more ‘invisible monitoring’ include equipment with inbuilt instrumentation such  
267 as mouthguards or smart garments, or optical tracking solutions that do not require athletes to wear  
268 additional equipment or technology [34]. Finally, new technologies may bring previously ‘siloes’ data

269 streams together. For example, linking physical tracking data to event data provides valuable context  
270 compared to the physical data alone [35].

271

## 272 **Conclusion**

273

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

280

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

290

## 291 **Conflict of Interest Statement**

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

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### **Figure Captions:**

Figure 1: Five overarching levels at which training load can inform athlete preparation and management. 1) Feedback - represented by blue boxes 2) In-session adjustment– represented by green boxes 3) Day-to-day planning represented by orange boxes 4) Season planning - represented by red boxes 5) Long term use - represented by pink boxes. Training load uses which span more than one category are represented by the split colour boxes.

Figure 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.