Training load and injury: speculation is not knowledge

Judd Kalkhoven questions the viability of currently available training load measures and metrics to provide useful estimates of injury risk.

Introduction

A primary goal of scientific research is to establish the causes of various phenomena. By determining causation, scientists aspire to develop and apply interventions that act on causal pathways to elicit a desirable outcome. Accordingly, strategies attempting to manipulate athletic injury outcomes should be founded on causal knowledge surrounding the mechanisms of injury (van Mechelen *et al.*, 1992).

Training load management strategies have been widely adopted to manage a number of important aspects relevant to athletic outcomes, such as athlete conditioning, fatigue, and injury risk, amongst others. Recently, the relationship between training load and injury has piqued the interests of research and applied sporting communities, with a multitude of research studies being published. However, the relationship between currently available training load measures (and metrics) and injury outcomes, as well as the capacity for us to use this data to assess injury risk, remains highly questionable. Notably, the widespread adoption of training load-based strategies for injury risk manipulation has taken place in the absence of a clear causal rationale, acting in contradiction of the popularised 'sequence of prevention' (van Mechelen *et al.*, 1992).

To move beyond generalised understandings of training and competition loads (within respective sports), coaches, athletes, practitioners, and other relevant personnel commonly turn to science in the hope of gaining both greater objectivity for facilitating nuanced decision making, and a competitive edge. It follows that, research into how best to manage athletic training loads is of high interest. While several technologies for assessing training load exist, and many of these deliver value in various ways, their capacity to provide an accurate and reliable, data-driven approach to injury risk mitigation remains improbable. To justify this claim, I will relate the data captured by currently available training load technologies to contemporary understandings of the causal mechanisms of tissue damage and injury. This will be followed by an exploration into psycho-physiological fatigue and its role in injury occurrence. Finally, I will end by providing some generalized comments and practical suggestions on the topic.

Injury causation

Injury occurs when either singular or repetitive forces are applied to a tissue that result in stresses and strains that exceed tissue strength and repairability (Kalkhoven *et al.*, 2020; Kalkhoven *et al.*, 2021). While physiological processes can contribute to both the formation of additional damage and tissue repair, it is clear from such mechanisms that mechanical loading (the forces experienced by specific biological tissues) is a fundamental contributor to athletic injury (Fig. 1). Such a mechanistic consideration is critical, especially for gradual onset injuries, whereby repetitive forces are the primary stimulus that results in the accumulation of tissue damage (Kalkhoven *et al.*, 2020; Kalkhoven *et al.*, 2021). Based on these causal understandings of injury, current training load measures and metrics should logically be critiqued based on their capacity to capture the mechanical loading and subsequent tissue damage experienced.

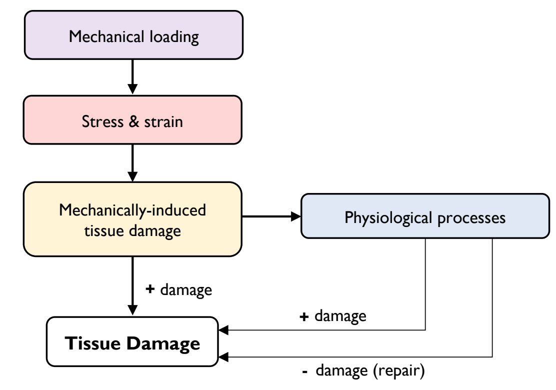

Figure 1. A simple conceptual figure highlighting contributions to tissue damage in athletes

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Theoretically, to capture the phenomenon of gradual onset injury with a high level of accuracy, two key components appear to need to be quantified, 1) the mechanical strength of the tissue in question, and 2) the mechanical loads and subsequent damage experienced. Unfortunately, quantifying these two components is not easy. Tissue strength is dependent upon a range of factors such as tissue morphology, mechanical properties, and architecture (Kalkhoven *et al.*, 2020), while estimating the forces experienced by specific tissues also holds numerous challenges, especially out in the field. Additionally, an added complexity exists whereby cumulative load is not an appropriate surrogate measure of tissue damage. This is because there is a non-linear relationship between load magnitude and damage, mandating that even when cumulative loads are identical, damage outcomes can vary dramatically depending on the loading pattern experienced. Such is the influence of this, a 10% reduction in stress is generally associated with a corresponding 100% increase, or more, in the number of load cycles to failure. It follows that, upon the accurate quantification of the mechanical loads experienced by specific tissues, a cumulative damage estimation method must be applied to estimate the damage outcome.

This applied feature aims to address issues and areas that are often common in the real world, but are seldom covered by the usual learning mediums (university courses, journals, books, etc.). Please contact the editor if you have any ideas for future issues: **editor@bases.org.uk**

Perhaps the challenge of capturing the phenomena of tissue damage and gradual onset injury is best illustrated by Matijevich *et al.,* (2020) who utilised multiple wearable sensors, in combination with biomechanics and machine learning, to provide a rigorous approach to estimating tibial bone damage when running. Notably, this approach yielded an impressive 18% error when estimating damage. However, when using vertical average loading rate (VALR), an impact metric commonly derived from current wearables, damage estimation errors were as high as 104%. A key message here is that the capacity of current measures and metrics, such as those derived from global positioning systems (GPS) or inertial measurement units (IMUs), to capture the phenomena of tissue damage and gradual onset injury, is unviable. While IMUs provide valuable contributions to multi-sensor setups (Matijevich *et al.*, 2020), the accelerations of body segments and correlates of ground reaction force impact peaks or loading rates that are commonly derived from such technologies, are not equivalent to the forces experienced by specific tissues (e.g., bones, muscles, tendons). Accordingly, to provide more accurate estimates of tissue damage and injury risk, multi-sensor setups (such as that adopted by Matijevich *et al.*, 2020) permitting targeted estimates of tissue-level forces appear to be the most likely solution.

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What about fatigue?

Shifting away from mechanical loads, an alternative factor of interest is that of psycho-physiological fatigue. Fatigue is often touted as a key causal factor for the occurrence of injury, presenting as a core component in theories underpinning the training load-injury relationship. However, the contributions of fatigue to injury are not immediately clear. While questions such as "What exactly is fatigue?" (which requires an entire book to address!), and "do any of the available training load metrics actually capture fatigue?", must be asked, I will leave these questions for the reader to contemplate. Instead, keeping with the theme of causation, a question I would rather address is "What is the causal role of fatigue in injury occurrence?". While it is reasonable to consider that fatigue is related to injury in some way, and evidence does exist to support a role for fatigue in certain injury types (such as muscle injury), the relevance of fatigue to injury appears to vary depending on the injury type in question. For example, anterior cruciate ligament (ACL) injury is one such injury type whereby fatigue appears to have minimal contribution, and interestingly, may even be protective. While this might seem surprising, such outcomes can potentially be explained by fatigue induced reductions in athletic outputs (and related forces), along with changes to biomechanical functioning, altering the loading experienced by certain tissues.

Of additional interest, it should be noted that many muscular injuries also appear to occur in the absence of fatigue. For example, it is not atypical for sprinters or powerlifters to strain muscles early on in a competition. Although fatigue is a complex phenomenon that can present both acutely and chronically, and therefore its contributions to these types of injuries cannot be ruled out entirely, it appears that fatigue may have minimal contribution to the occurrence of many injuries. There remains a need to better establish the causal role of fatigue to many injury types. Accordingly, fatigue should likely be considered as merely a single risk factor, albeit a potentially important one, that may only be relevant to certain injuries.

Speculation is not knowledge

Currently, the training load-injury relationship is founded on a large number of weak and unsupported assumptions regarding injury causality and the perceived capabilities of currently available training load monitoring technologies. These points serve to highlight that manipulating training loads on the basis of managing injury risk involves a large amount of speculation. While repetitive mechanical loads play a critical role in gradual onset injury occurrence, and potentially the occurrence of some traumatic injuries whereby prior tissue damage acts as a precursor to tissue failure, the capacity of currently available measures and metrics to quantify these pathways, assess tissue damage, and facilitate nuanced decision-making regarding injury risk mitigation, remains highly questionable. Further innovation is required to permit more accurate and reliable assessments of injury risk, which may, in turn, better guide the manipulation of training loads.

Embrace uncertainty

Currently, athletes, coaches and associated practitioners have no choice but to embrace the uncertainty that accompanies the pursuit of sporting excellence and that is inherent in the training process. Such statements are not permitting the reckless prescription of training and rehabilitation procedures, whereby principles of progressive overload, tissue adaptation, and recovery must be respected. Rather, it serves to highlight that the currently obtained training load data is poorly reflective of the causal pathways to injury, and accordingly, should not be expected to permit an accurate, data-driven approach to injury risk mitigation and decision-making.

Summary

Despite the shortcomings of training load data discussed in this article, it is noteworthy that the currently available technologies do hold some value. Tools assessing training load still assist practitioners with the monitoring of athletes, providing generalized insights into training and competition outputs, and facilitating practitioner assessments regarding whether an athlete is doing what is prescribed and how they are coping. Of course, the way the currently available training load monitoring tools are utilised is at the discretion of each practitioner and athlete, who, based on their respective sports, must determine what information they do and do not find valuable. However, the capabilities and relevance of current technologies and accompanying data should be carefully considered when selecting training load variables of interest. The evident limitations when attempting to quantify injury risk from current training load data imply that extreme caution must be exercised when considering causal relationships with injury, and when utilising such information for decision making. ■

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