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Training Load and Injury Part 1: The Devil Is in the Detail—Challenges to Applying the Current Research in the Training Load and Injury Field

The relationship between training (work)load and sports injury is a prominent topic in sports science and medicine research. The hypothesis of a link between training load and sports injury is not new.[5] Manipulating training load using new measures of exposure (training load–based metrics), assuming that changing load will cause the injury risk to reduce, has become common and recommended by international sports organizations.[8]

CLINICAL QUESTION

For many of us, the sole purpose of reading journal articles is to find information that will help us make better decisions in the clinic. If one reads something in *JOSPT* or another scientific journal that supports a relationship between training load and injury, should one accept the findings as true? In this article, we address why it is important for clinicians to critically evaluate the evidence behind conclusions in research (even when these recommendations are endorsed by international organizations), using the training load and injury field as an example.

BACKGROUND: This article sets the scene for a critique of the research underpinning 2 common clinical assumptions: (1) training workload is a key factor influencing sports injury risk, and (2) it can be manipulated to reduce injury risk. In this clinical commentary, we address why it is important for clinicians to critically evaluate the evidence behind research conclusions.

CLINICAL QUESTION: Has research been designed and conducted well enough to help clinicians answer the questions, "What is the relationship between training workload and sports injury risk?" and "Can the metrics based on training workload be used to decrease injury risk?"

KEY FINDINGS: In the past decade, many sports injury researchers have developed new measures of exposure, based on internal and external training workload, to study the relationship between training load and injury. Some of these metrics may have been embraced by researchers and clinicians because (1) they are apparently supported by the scientific literature, (2) they are simple to calculate and use (averages and their ratio), and (3) there is an apparent reasonable rationale/narrative to support using workload metrics. However, intentional or unintentional questionable research practices and overinterpretation of research results undermine the trustworthiness of research in the training load and sports injury field.

CLINICAL APPLICATION: Clinicians should always aim to critically examine the credibility of the evidence behind a research conclusion before implementing research findings in practice. Something that initially looks promising and inviting might not be as revolutionary or useful as one first anticipated. *J Orthop Sports Phys Ther 2020;50(10):574-576. Epub 1 Aug 2020. doi:10.2519/jospt.2020.9675*

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Most Popular Training Load Metrics

The acute load, chronic load, and their ratio (acute-chronic workload ratio [ACWR]) are measures of exposure embraced by the scientific community and used as prognostic factors for injury risk. These measures of exposure are training load–based metrics that have been developed from a liberal interpretation of Eric Banister's model,[6] proposed in the 1970s to model training load (impulse) and physical performance. The time frames for acute and chronic workload and for the ACWR were an approximation of the time decays derived from Banister's model.[6] The decays represented the time needed to dissipate the

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negative (fatigue) and positive (fitness) effects of training.

In the current-day reinterpretation of Banister's model, acute load represents a surrogate measure of fatigue, and chronic load a surrogate measure of fitness. The 2 components of Banister's equation have been substituted by the ratio of 2 averages (rolling or exponentially weighted moving averages): typically, 1 week for the acute workload and 4 weeks for the chronic workload.[4] Acute workload, chronic workload, and the ACWR are the metrics one is most likely to see reported in research examining the association between training load and injury.

Training Load Metrics: Make It as Simple as Possible, but Not Simpler

It is not surprising that new measures of exposure have gained popularity among clinicians and researchers. The metrics have been used in most studies and they are simple to calculate, easy to explain to athletes, and based on an apparently plausible rationale (do not train too much, too soon) that fits commonly accepted training principles. However, these metrics are also an excessive simplification of complex injury etiology and of the mechanical load and damage training load generates. One need only take a short wade into the training load and injury field to find copious and conflicting results regarding the relationship between training load and injury. It is difficult for clinicians to unravel the signal from the noise.[1]

Interpreting the Results Correctly and According to the Nature of the Study

Metrics such as ACWR are based on Banister's model of performance, but have been shoehorned into injury research by attributing to them a generic etiological role.[2] The associations between these measures of exposure and injuries are interpreted as supporting a causal link between load and injury (ie, training load causes injury). Yet, no studies have estimated any causal effects. Erroneous (causal) interpretation is not rare in sport medicine.[9]

Clinicians should always consider whether research results provide evidence of causal effects before deciding to change a prognostic factor (eg, training load) in an attempt to alter the likelihood of an (adverse) event. The interpretation should be coherent with the nature of the study (descriptive, predictive, or causal) and its limitations.

Questionable Research Practices: Key Barriers to Trustworthy Research Results

Questionable research or reporting practices (QRPs) are problems in research design, analysis, and reporting that impinge on the trustworthiness of the results.[3] Some QRPs can have very little effect on research results. Other QRPs can be fatal—obliterating the reader's trust in the results (**TABLE**).[7] Hypotheses with unsupported causality, causation that is claimed/assumed without proper designs or without discussing bias, and ignoring nonsignificant results and contradictory evidence are examples of QRPs that blight training load and injury studies.

Research involves specific steps (**FIGURE**). At each step, there are threats to reproducible science (ie, trustworthy research), such as *P* hacking and hypothesizing after the results are known. It is important to consider how far QRPs might have infiltrated the training load and injury research field and the implications for clinicians aiming to use research in their practice.

SUMMARY

In this article, we outlined why it is important to carefully assess the trustworthiness of research that one intends to use in practice. In part 2, we highlight various issues related to concepts and methods in the training load and injury research field. We focus on

TABLE List of Common Questionable Research Practices[a]

- Nonsignificance of results is not addressed
- Causation claimed without appropriate design or analysis
- Hypothesis contains unsupported causality
- Potential causal relationship is not justified
- Causation is claimed without discussing bias
- Inappropriate use of evidence
- Generalization to different population, setting, or location
- Secondary outcomes are overstated
- Clinical relevance of nonsignificant results
- Small effect size is overstated
- Precision of estimate not discussed or considered
- Outcome measure does not reflect objectives
- Supporting literature based on same underlying data
- Abstract does not reflect the main findings
- Title does not reflect the main findings
- Order of discussion differs from aim
- Objectives are phrased differently in discussion
- Generalization is not supported by sample
- Results section contains interpretation
- Conclusion does not reflect outcome measure
- Objectives are not reflected in the discussion
- Conclusions in abstract do not reflect main text
- Limitations are poorly discussed
- Supporting evidence is poorly documented
- Objective is not reflected by the conclusions
- Conclusions do not reflect findings in context
- Impact of limitations on results is not discussed
- Conclusions do not reflect findings
- Contradictory evidence is not mentioned
- Recommendations for practice are lacking or are not supported by findings
- Implications for practice are lacking or are not supported by findings

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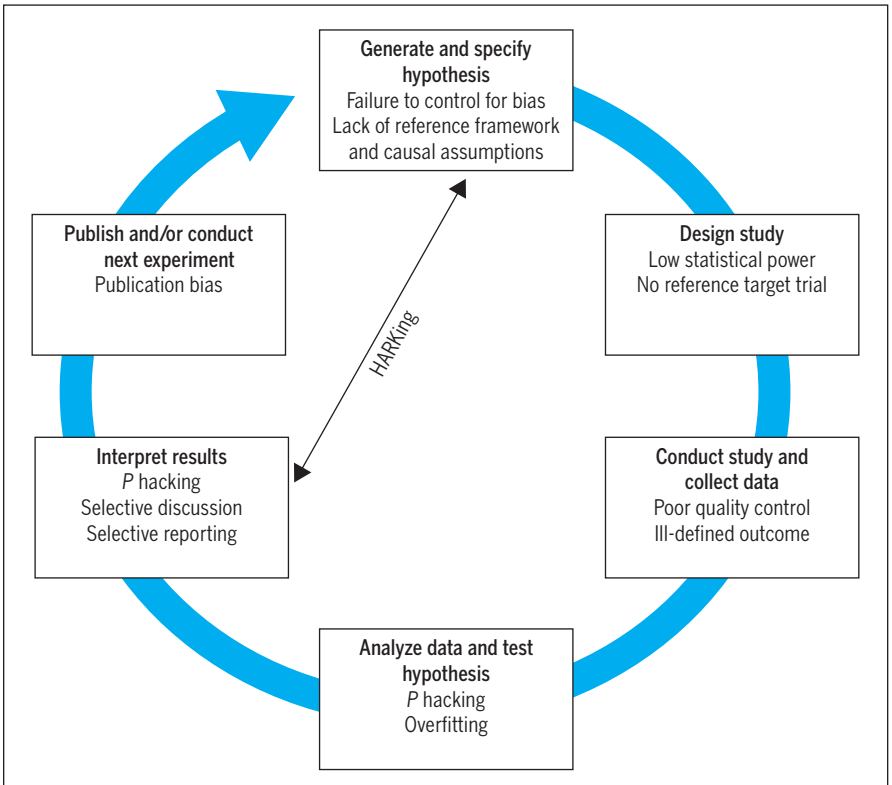

FIGURE. Potential threats to the scientific process. Abbreviation: HARKing, hypothesizing after the results are known. Adapted with permission from Munafò et al[7] under the Creative Commons Attribution 4.0 International (CC BY 4.0) license (http://creativecommons.org/licenses/by/4.0/).

decisions researchers can make about hypotheses, study designs, and conducting, analyzing, and reporting research,[10] and how those decisions can impact the trustworthiness of research results.

We aim to raise potential challenges to applying the current research in the training load and injury field, and identify some biases, to improve future research. We hope our commentary encourages clinicians to be careful when applying research in practice.

STUDY DETAILS

AUTHOR CONTRIBUTIONS: All authors contributed substantially to the conception of the work (in full or some sections), interpretation of published data, drafting the work or revising it critically for important intellectual content, and giving final approval of the version to be submitted and published.

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REFERENCES

1. Ardern CL, Dupont G, Impellizzeri FM, et al. Unravelling confusion in sports medicine and sports science practice: a systematic approach to using the best of research and practice-based evidence to make a quality decision. *Br J Sports Med*. 2019;53:50-56. https://doi.org/10.1136/bjsports-2016-097239
2. Gabbett TJ, Hulin BT, Blanch P, Whiteley R. High training workloads alone do not cause sports injuries: how you get there is the real issue. *Br J Sports Med*. 2016;50:444-445. https://doi.org/10.1136/bjsports-2015-095567
3. Gerrits RG, Jansen T, Mulyanto J, van den Berg MJ, Klazinga NS, Kringos DS. Occurrence and nature of questionable research practices in the reporting of messages and conclusions in international scientific Health Services Research publications: a structured assessment of publications authored by researchers in the Netherlands. *BMJ Open*. 2019;9:e027903. https://doi.org/10.1136/bmjopen-2018-027903
4. Hulin BT, Gabbett TJ, Blanch P, Chapman P, Bailey D, Orchard JW. Spikes in acute workload are associated with increased injury risk in elite cricket fast bowlers. *Br J Sports Med*. 2014;48:708-712. https://doi.org/10.1136/bjsports-2013-092524
5. Kibler WB, Chandler TJ, Stracener ES. Musculoskeletal adaptations and injuries due to overtraining. *Exerc Sport Sci Rev*. 1992;20:99-126.
6. Morton RH, Fitz-Clarke JR, Banister EW. Modeling human performance in running. *J Appl Physiol (1985)*. 1990;69:1171-1177. https://doi.org/10.1152/jappl.1990.69.3.1171
7. Munafò M, Nosek B, Bishop D, et al. A manifesto for reproducible science. *Nat Hum Behav*. 2017;1:art 0021. https://doi.org/10.1038/s41562-016-0021
8. Soligard T, Schwellnus M, Alonso JM, et al. How much is too much? (Part 1) International Olympic Committee consensus statement on load in sport and risk of injury. *Br J Sports Med*. 2016;50:1030-1041. https://doi.org/10.1136/bjsports-2016-096581
9. Stovitz SD, Verhagen E, Shrier I. Distinguishing between causal and non-causal associations: implications for sports medicine clinicians. *Br J Sports Med*. 2019;53:398-399. https://doi.org/10.1136/bjsports-2017-098520
10. Wicherts JM, Veldkamp CL, Augusteijn HE, Bakker M, van Aert RC, van Assen MA. Degrees of freedom in planning, running, analyzing, and reporting psychological studies: a checklist to avoid *p*-hacking. *Front Psychol*. 2016;7:1832. https://doi.org/10.3389/fpsyg.2016.01832