Reflections on workload-injury associations in team sport: mistakes, regrets and implications for future research and practice

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Headline

It has been more than 7 years since the acute:chronic workload ratio was first associated with injury risk in cricket fast bowlers.[1] In that time, the commentary and feedback (positive and negative) on the concept of modelling workloads to identify associations with injury has been overwhelming. Naturally, receiving a large amount of criticism over a long period, the value of hindsight and using these methods in practice has helped me appraise my role in this area.

Aim

The goal of this article is to openly reflect on workload-injury research and acknowledge:

i) some areas that could have been conducted better.

ii) the limitations and uncertainty that should be considered when attempting to produce practical applications from monitoring workload in team sport.

Reflection 1: Inferences of prediction should be done very, very carefully or not at all

A recent publication explained my regret of certain terminology used in publications that demonstrated associations between field-based distance covered and injury in professional rugby league players.[2] Inferences such as "athlete workloads can predict injury"[3] and "the acute:chronic workload ratio predicts injury"[4] should not have been made. Secondly, these conclusions have contributed to the findings being sensationalised and miss- or over-interpreted. Player workloads alone will never, ever, be able to predict injury with accuracy because there are so many other factors that need to be considered.[5] Furthermore, there are many

different types of workload, some subjective and internal (i.e., session-RPE) and others objective and external (i.e., field-based accelerometer loads or distance covered). All of these measures have their inherent limitations, they should not be used interchangeably and the findings from one study are not always directly transferable to other cohorts or sports.

Despite whatever associations have been demonstrated between workload and injury risk, these studies have not demonstrated cause and effect; that is, in practice a change in *x* (workload) does not definitely result in a change in *y* (injury risk/rate).[6] These inferences of 'prediction' should be viewed in the context that workload is one of many variables (e.g. sleep, playing experience, strength, previous injury, training monotony, and more) that have been associated with injury.[5] When presented and interpreted with an open-mind that acknowledges the limitations and uncertainty of the research, these small associations *may* collectively help practitioners to demonstrate *good judgement*, rather than make exact predictions. Furthermore, the level and quality of evidence in the field of workload-injury research, does not demonstrate that any method of modelling workload can be considered 'gold standard'.[6,7] Although my opinion is that the concept of comparing acute and chronic workloads should not be completely dismissed, the value and apparent use of the acute:chronic workload ratio in the field has been overstated erroneously. Just like all measures of workload, the acute:chronic workload

ratio is not a causal prognostic factor, it is merely a reference metric for a practical setting.[6]

In the field, practitioners make 'predictions' (i.e. a forecast or an educated-guess) every day. These forecasts may consist of: i) how the periodisation of a microcycle might influence performance in the following match,[8] ii) which flight home may have the most positive influence on sleep and recovery[9] or iii) whether a particular training program may somewhat change the risk of a player sustaining an injury. These estimates (i.e. predictions/forecasts) are always multifactorial decisions, and workload-injury studies are indeed univariate investigations. As such, regardless of how perfect and accurate workload models are formulated, these studies will never provide a full-and-complete appraisal of injury risk – they are indeed one small piece in a gigantic puzzle. It is time to accept the lack of precision of injury prediction models – they will never work in our lifetime. Perhaps the conversation should be focused on how football departments can collaboratively demonstrate *good judgment* using the available evidence and their experience and expertise.

Reflection 2: 'Foxy thinkers' demonstrate superior judgement ability than 'hedgehogs'

Certain personality traits have been associated with greater judgement ability in the political sector.[10] Tetlock[10] classified political experts along the *hedgehog-fox* scale, which demonstrated that *foxes* had a significantly greater ability to forecast short- and long-term future political events than *hedgehogs*. The reference to hedgehogs and foxes was borrowed from Isaiah Berlin's essay that stated "*The fox knows many little things, but the hedgehog knows one big thing"*.[10,11]

Hedgehogs were defined as stubborn and confident. They believe in big ideas, are specialised in one or two areas and view counter-arguments with critical scepticism. Hedgehogs are reluctant to change their predictions or hedge their bets. They are more likely to get swept away in their own rhetoric than foxes.[10,11]

Foxes instead take multiple approaches toward a problem and believe in a plethora of little ideas. They are multidisciplinary, adaptable, self-critical, and tolerant of complexity or uncertainty. They are cautious in expressing their predictions and rely on observation rather than theory. They make more self-conscious efforts to integrate conflicting ideas into their final judgments.[10,11]

Despite the poorer predictive ability of hedgehogs, they were more likely to be invited as 'expert guests' by television and media outlets than foxes.[10,11] In other words, non-negotiable, dramatic and bold predictions are more likely to provide attention and public intellectual status than cautious, multidisciplinary and adaptable predictions that are tolerant of complexity and integrate conflicting ideas.[11]

In practice, one hedgehog may view the acute:chronic workload ratio as utterly useless due to lack of predictive value and statistical artefacts in workload models. Whereas another hedgehog may (incorrectly) view the same ratio as having the almighty ability to predict injury with great accuracy. A fox however, may acknowledge that the acute:chronic workload ratio is not perfect and the statistical analysis in some studies is poor,[6,7,12] different injury definitions may result in dramatically different findings among studies,[7,13] and false correlations may be created between acute and chronic workloads when the 2 are coupled within chronic workload measures.[14] However, the fox may also acknowledge that workload has been associated with injury in scores of studies[15] and it is likely that measured in some fashion, workload is one of many *small* factors that may contribute to an injury event. As such, a fox may consider that monitoring workload in some way is one essential process in practice. Practitioners have the right to choose how they want to monitor workload. However, the limitations and uncertainty in their methods should be clearly acknowledged and communicated to all of the relevant stakeholders.[6]

The gold standard, best practice approach to modelling workloads is not currently known[6,7,12] and practitioners will have to use their experience and expertise in conjunction with an evidence-valued style to decide which methods suit their environment. These methods may or may not involve the use of the acute:chronic workload ratio, and evidence is available to support either decision.[5-7,12] Furthermore, a practitioner that is 'thinking foxy' would consider multiple approaches toward a problem, believe in a plethora of little ideas and be tolerant of the uncertainty in their methods; in my opinion this would involve considering multiple variables that have been associated with injury in team sports and perhaps even relying on some observation and experience rather than theory (Schematic 1).

Schematic 1. Illustrative representation of the fox and hedgehog personality types in reference to workload-injury relationships.

Reflection 3: The proactive approach is more important than the reactive approach

Recent findings have demonstrated a negative relationship (*r* -0.76 95% CI -0.51 to -0.87) between chronic workload and the acute:chronic workload ratio; higher chronic workloads are associated with lower acute:chronic workload ratios and vice versa.[6,14] As such, it may be suggested that these 2 variables are not distinct, i.e. they provide similar information and one may be used as a proxy for the other.[16] In my practical experience, aiming to gradually achieve higher chronic workloads (i.e. the *proactive* approach) is more productive than attempting to counteract increases in the acute:chronic workload ratio after they have been identified (i.e. the *reactive* approach). Higher chronic workloads *may* result in improvements in sub-maximal running performance and decreased injury risk compared with lower chronic workloads.[17] If indeed acute:chronic workload ratios >1.5 or >2.0 (for example) are associated with increased injury risk, there is no evidence that demonstrates an appropriate reaction that will mitigate this risk once the 'damage has been done'. As such, practitioners may choose to simply use chronic workload[1,4,17] and alter each micro-cycles training load based on week-to-week progressions rather

than attempting to react to changes in the acute:chronic workload ratio.

Practitioners have known for decades that higher workloads over a long period can result in positive physiological adaptions and improved physical performance.[18] Importantly, positive training adaptations may result in players developing resilience and a decreased risk of sustaining an injury.[19] When Gaelic football players are subjected to increases in session-RPE workload, players with greater aerobic capacity have a reduced risk of injury compared with players with lower aerobic capacity, regardless of whether increases in workload are measured via: i) absolute 7-day workload, ii) week-to-week change in workload or iii) acute:chronic workload ratio.[19] Furthermore, rugby league players with greater prolonged intermittent high-intensity running ability have a faster recovery of post-match lower-body neuromuscular power, despite completing greater internal and external match workloads than players with poorer intermittent high-intensity running ability.[20] Clearly, practitioners that are interested in influencing the likelihood of injury and physical performance will need to focus on proactively implementing periodised meso-cycles that will improve physical qualities.

Personally, the acute:chronic workload ratio is by no means the most useful tool for monitoring workload in athletes. Indeed, practitioners may prescribe meso-cycles that improve athletic development and then choose to vary the subsequent weeks training with traditional periodisation strategies, which allow for variation in the volume and intensity of training within and between each microcycle.[21] This can be done without using any form of acute:chronic workload ratio. That being said, I still uses this ratio as a simple reference metric together with other factors in practice, and I whole-heartedly acknowledge that there are many limitations and plenty of ambiguity in workload-injury relationships, regardless of whichever way you choose to measure workload.

Reflection 4: Exponentially weighted workloads are more valuable than rolling averages

Another important consideration in the measurement of workload is the use of either *rolling average* or *exponentially weighted moving average* workloads. The advantage of the latter model is a decreased weighting for older workload values or vice versa for more recent values.[22] When considering the acute:chronic workload ratio and injury risk, the exponentially weighted moving average method is superior than the rolling average.[23,24] *Exponentially weighted moving average chronic workload* is also a more useful method of monitoring workload for physical performance reasons than *rolling average chronic workload*. For example, Figure 1 highlights a 3 week training block (weeks 6, 7 and 8) following an unmonitored Christmas-break (XMAS 1, XMAS 2). In this example, players may be expected to have developed some positive physiological adaptations following weeks 6 and 7.[25] However, because the rolling average method considers all training weeks to be equal, chronic workload at the end of 'Week 7' is still considered to be in a zone associated with poorer sub-maximal running ability.[17] Whereas, the exponentially weighted moving average chronic workload following 'Week 7' is now in an area that has been associated with improvements in sub-maximal running ability. As such, given the stronger (yet still uncertain) associations that exponentially weighted moving average workloads have with injury risk and the potential greater practical value to performance monitoring, this method of monitoring workload might be considered more useful in practice than rolling average workloads.

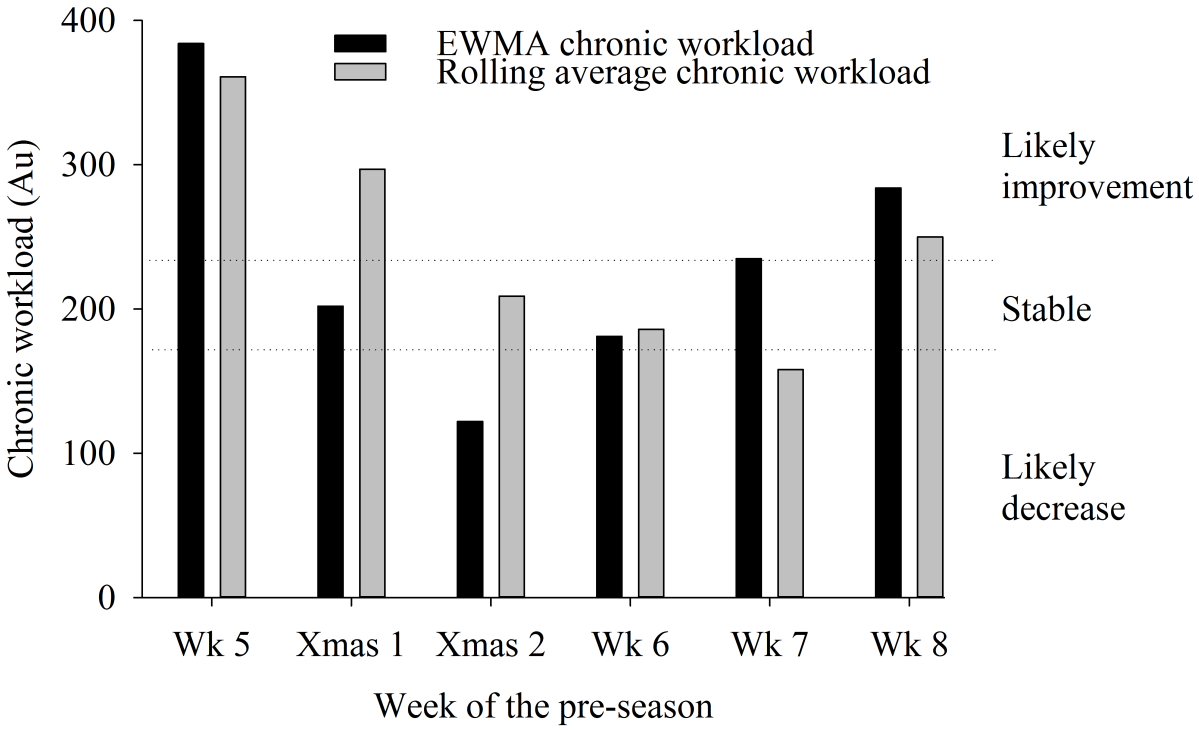

Figure 1. Example data demonstrating differences in *exponentially weighted moving average* (EWMA) and *rolling average* chronic workload following a period of unmonitored training.

Reflection 5: Applied research in sport is lacking methodological and statistical quality and is not always transferable between environments

There are plenty of studies that have investigated the influence of different workloads on injury in team and individual sports. These studies are typically retrospective observations rather than the randomised control trials that would usually be needed to apply interventions in clinical settings.[6] Furthermore, the majority of these studies have not used all of the statistical tools available to researchers[6,7,12] and stronger evidence, coming from all-encompassing methodologically studies is needed before recommendations that are made with certainty can ever be provided.[6,7]

Methods of quantifying workload and defining injury also differ between studies and sports. As such and not surprisingly, workload-injury associations also differ between studies and sports. Practitioners should consider these limiting factors and uncertainty when implementing all applied research findings in practice.

Conclusion

There are many practical applications that can be generated from previous workload-injury studies. For example, cricket fast bowlers with higher 4-week average bowling workloads (~180 deliveries per week) have a reduced risk of injury compared with <90 deliveries,[1] and rugby league players with higher 28-day average field-based accelerometer loads (~250 arbitrary units) were associated with likely improved sub-maximal running performance and lower risk of non-contact lower limb soft tissue injury compared with players with lower 28-day average field-based accelerometer loads (~165 arbitrary units).[17] However, these studies do not demonstrate cause and effect or that injuries will certainly occur when programs go outside these ranges. Injuries may indeed occur due to factors other than workload; practitioners need to collectively consider multiple variables and

approaches to training programming and monitoring. This should consist of strong collaborative partnerships among physiotherapists, sport scientists, coaches, dieticians, psychologists, and players. These collaborations may help practitioners demonstrate greater judgement ability by 'thinking foxy', which consists of being multidisciplinary, adaptable, self-critical, tolerant of complexity or uncertainty and making self-conscious efforts to integrate conflicting ideas into their judgments.

Practitioners should consider that the language and terminology used in some publications has contributed to the findings being sensationalised and miss- or over-interpreted. Player workloads alone will never, ever, be able to predict injury with accuracy because there are many other factors that need to be considered.[5] Inferences of 'prediction' whether made in peer-reviewed publications or in practice, should be viewed in the context that workload is one of many variables (e.g., sleep, playing experience, strength, previous injury, etc.) that have been associated with injury.[5] When presented and interpreted with an open-mind that acknowledges the limitations and uncertainty of the research, these small associations *may* collectively help practitioners to demonstrate *good judgement*, rather than make exact predictions.

A proactive approach to implementing and monitoring workload is more important and useful in practice than attempting to react to 'red flags' or sudden increases in workload. For example, the negative relationship between chronic workload and the acute:chronic workload ratio suggests that these 2 variables may provide similar information.[6,14] As such, gradually achieving higher chronic workloads may: i) reduce the likelihood of a sudden increase in acute workload relative to chronic workload, and ii) improve physical qualities, which may in turn improve performance and reduce the likelihood of injury. However, practitioners will need to use their own experience in their current sport and cohort to decide which methods of monitoring workload are relevant to them and the uncertainty in those methods should be communicated to all of the relevant stakeholders.

Practical Applications

- Inferences such as "athlete workloads can predict injury" and "the acute:chronic workload ratio predicts injury" should not have been made in previous publications
- These inferences have contributed to the findings being sensationalised and miss- or over-interpreted
- An open-mind that acknowledges the limitations and uncertainty of most research, may help practitioners to demonstrate good judgement, rather than make exact predictions
- Decision making and judgements should consider multiple approaches toward a problem, believe in a plethora of little ideas, be tolerant of uncertainty in methods, make self-conscious efforts to integrate conflicting ideas and rely on observation and experience together with theory
- Aiming to gradually achieve higher chronic workloads (i.e. the *proactive* approach) is more productive than attempting to counteract increases in workload after they have been identified (i.e. the *reactive* approach)

Acknowledgement

I would like to express my gratitude and appreciation to colleagues and reviewers that have provided feedback on previous versions of this manuscript.

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