Mathematical coupling causes spurious correlation within the conventional acute-to-chronic workload ratio calculations

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INTRODUCTION

The monitoring of training workloads is now a much-researched topic in team sports.[1] Within this topic, researchers and practitioners are particularly interested in the impact of relatively short (acute) periods of higher training workloads normalised for the prior and longer-term (chronic) workloads. In recent years, a well-established approach for normalising this acute 'spike' to chronic load has been by calculating the "acute:chronic workload ratio" (ACWR). Both this index and chronic workload itself have been reported to be independent predictors of training-related injuries.[2] It has also been reported, particularly in team sports competitors, that there are associations between acute spikes in training workloads (relative to chronic workloads) and time-loss injuries.[1]

The ACWR is usually calculated as the simple ratio of recent (i.e. one-week) to longer term (i.e. four-week) training workloads.[1] While it is important for the numerator and denominator of any ratio to be correlated only through biological mechanisms,[3] one aspect of the ACWR calculation is that the acute workload also constitutes a substantial part of the chronic workload.[4] This "*mathematical coupling*" between two variables,[5] also referred to as "*relating a part to the whole*",[6] is unusual and raises the possibility that research inferences and athlete monitoring might be compromised by resulting spurious correlations.[3] A spurious correlation is one which exists between two variables irrespective of any true biological/physiological association between those variables.[3 5]

MATHEMATICAL COUPLING IN THE ACWR CALCULATION

Irrespective of different data smoothing approaches over a 28-day period,[7] the conventional calculation of the ACWR is ultimately:

$$ACWR = \frac{A}{0.25 \cdot (W1 + W2 + W3 + A)}$$

where A is the 7-day acute workload and hypothetical W1, W2 and W3 are the preceding 7-day workloads, respectively.[1 4] Given the conceptual definition of acute and chronic workload variables[4] we hypothesised that "mathematical coupling" might exist, leading to a spurious correlation between acute and chronic workload estimates.[3]

To test our hypothesis with adequate statistical precision, we generated data to simulate four 7-day periods of high-speed distance data reported in a recent study involving elite Australian footballers[2] for a hypothetical squad of 1000 players (Supplementary file). Each of the four sets of data was randomly generated and was completely independent from the other datasets. The most recent 7-day period was designated as the acute period (A), while the 28-day period defining chronic workload was calculated as a conventional rolling average. The mean±SD high-speed distance for W1, W2 and W3 and A were 2021±889 m, 1977±880 m, 1968±860 m and 2035 ±901 m, respectively. None of the preceding 7-day datasets were found to be substantially correlated with A ($r < 0.06$). However, as demonstrated in Figure 1, there was a moderate-to-large, positive correlation between the calculated chronic and acute workload data; $r = 0.52$ (95%CI: 0.47 to 0.56). If A was not included in the calculation of C, then the correlation between A and C was, as expected, close to zero; $r = 0.01$ (95%CI: -0.05 to 0.07).

Figure 1 about here

The moderate-to-large but spurious (false) correlation between the acute and chronic workload variables substantiated the presence of mathematical coupling, since the acute workload represents a term in the calculation of the denominator in the ACWR.[3] Any functions that are designed to quantify the association between acute and chronic workload variables must be mathematically distinct from each other and not naturally associated if any

true physiological explanations or likelihood of injury are attempted to be researched.[3] Accordingly, the mathematical coupling issues we observed could also affect the chronic workload variance and, crucially, its physiological range of measurements.[3] In our simulated data, the SD for chronic high-speed distance (with the acute data period included) was ± 439 m (data range: 654 to 3469 m). Nevertheless, following removal of the acute period data from the calculation of the chronic period distance, the SD was a higher ± 499 m (data range: 541 to 3553 m). Furthermore, the formulation of rolling averages might also influence the observed SD.[8] Therefore, and as expected, inclusion of the acute data in the calculation artifactually reduced the between-athlete variability in chronic workload.

The mathematical coupling issue can also alter the ACWR itself. For example, with an acute distance of 2375 m, the chronic distance can be calculated conventionally to be 1639 m. But this value without mathematical coupling should really be 1393 m. The respective ACWRs are 1.45 with the acute period included in the chronic calculation vs 1.71 when the acute data are not included in the chronic calculation. Therefore, the traditional mathematical definition of the chronic workload term in the ACWR protocol also appears to limit a valid and unbiased interpretation of the observed ACWR estimates.

CONCLUSIONS

Collectively, our findings have demonstrated that the numerator and denominator in the ACWR are mathematically coupled and, therefore, spuriously correlated. The simplest solution is not to include acute workload periods in the calculation of chronic workload if the workload-injury aetiological relationship, grounded on the magnitude of the ACWR, is to be interpreted accurately.

Contributors

LL and GA developed the article concept. All authors contributed to write, provide feedback, and revise the manuscript.

Competing interests

None declared

Provenance and peer review

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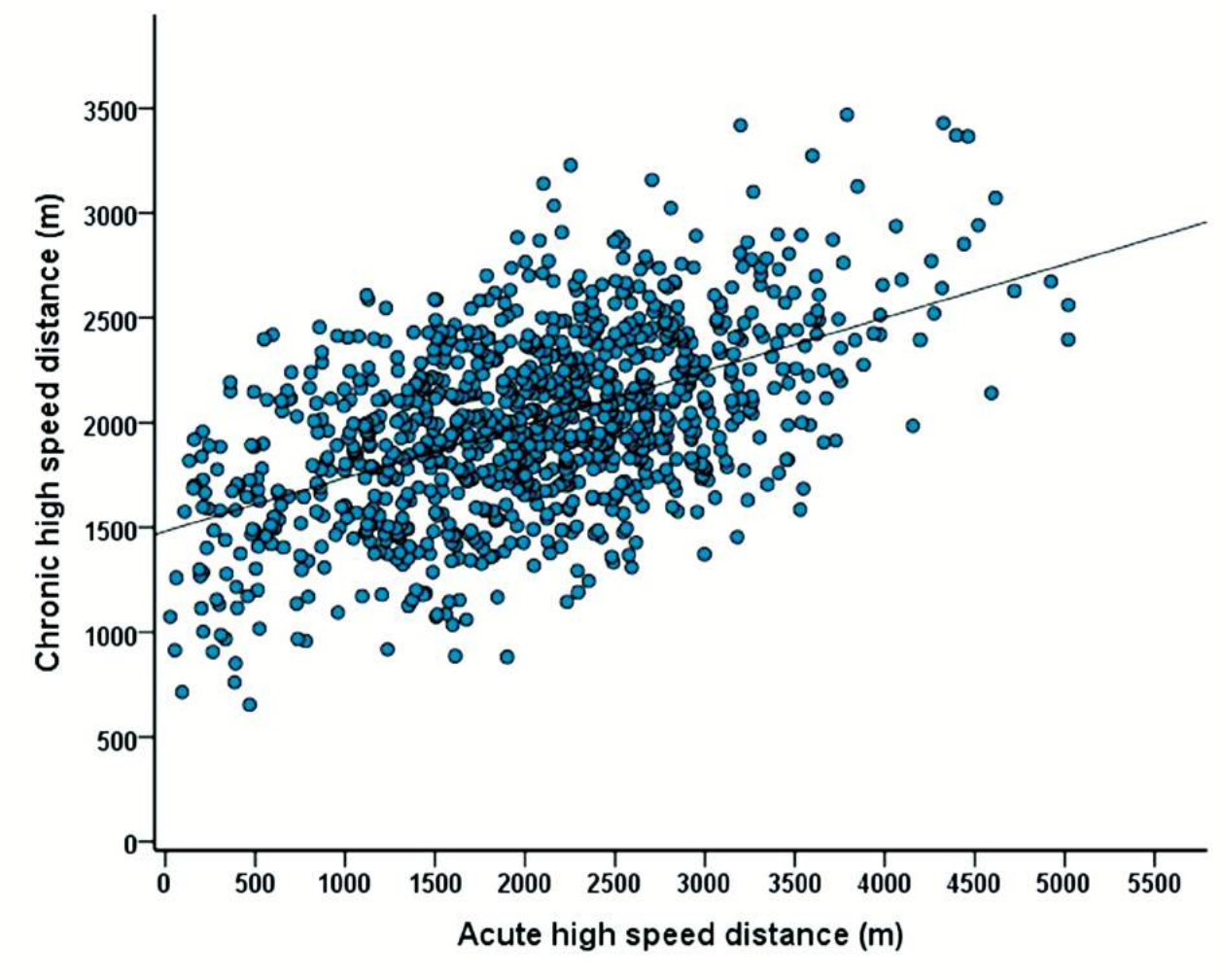
FIGURE LEGENDS

Figure 1. The spurious correlation between the simulated acute phase data and the chronic phase data. Although the four weeks of data were uncorrelated with each other, this correlation is explained by the fact that the acute phase data is part of the calculation of the chronic phase data leading to mathematical coupling. This spurious correlation will be present irrespective of any true physiological association between acute and chronic workloads, leading to biased inferences.


Chronic high speed distance (m)
3500
3000
2500
2000
1500
1000
500
0
0
500
1000
1500
2000
2500
3000
3500
4000
4500
5000
5500
Acute high speed distance (m)