

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

3

4 Lorenzo Lolli¹, Alan M Batterham¹, Richard Hawkins², David M Kelly^{2,3}, Anthony J
5 Strudwick², Robin Thorpe^{2,3}, Warren Gregson³, Greg Atkinson¹

6

7 ¹ Health and Social Care Institute, Teesside University, Middlesbrough, UK

8 ² Medicine and Science Department, Manchester United Football Club, UK

9 ³ Football Exchange, Research Institute for Sport and Exercise Sciences, Liverpool John

10 Moores University, Liverpool, UK

11

12

13

14 **Correspondence:**

15 Lorenzo Lolli

16 Health and Social Care Institute

17 School of Health and Social Care

18 Constantine Building

19 Teesside University

20 Middlesbrough, TS1 3BA, United Kingdom

21 e-mail: L.Lolli@tees.ac.uk

22 Telephone: +44 (0) 1642 342934

23 INTRODUCTION

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

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

42

43 MATHEMATICAL COUPLING IN THE ACWR CALCULATION

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

46

$$47 \quad ACWR = \frac{A}{0.25 \cdot (W1 + W2 + W3 + A)}$$

48 where A is the 7-day acute workload and hypothetical W1, W2 and W3 are the preceding 7-
49 day workloads, respectively.^{1,4} Given the conceptual definition of acute and chronic workload
50 variables⁴ we hypothesised that “mathematical coupling” might exist, leading to a spurious
51 correlation between acute and chronic workload estimates.³

52 To test our hypothesis with adequate statistical precision, we generated data to
53 simulate four 7-day periods of high-speed distance data reported in a recent study involving
54 elite Australian footballers² for a hypothetical squad of 1000 players (Supplementary file).
55 Each of the four sets of data was randomly generated and was completely independent from
56 the other datasets. The most recent 7-day period was designated as the acute period (A),
57 while the 28-day period defining chronic workload was calculated as a conventional rolling
58 average. The mean±SD high-speed distance for W1, W2 and W3 and A were 2021±889 m,
59 1977±880 m, 1968±860 m and 2035 ±901 m, respectively. None of the preceding 7-day
60 datasets were found to be substantially correlated with A ($r < 0.06$). However, as
61 demonstrated in Figure 1, there was a moderate-to-large, positive correlation between the
62 calculated chronic and acute workload data; $r = 0.52$ (95%CI: 0.47 to 0.56). If A was not
63 included in the calculation of C, then the correlation between A and C was, as expected, close
64 to zero; $r = 0.01$ (95%CI: -0.05 to 0.07).

65

66 *Figure 1 about here*

67

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

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

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

89

90 **CONCLUSIONS**

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

96

97

98 **Contributors**

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

101

102 **Competing interests**

103 None declared

104

105 **Provenance and peer review**

106

107 **REFERENCES**

- 108 1. Windt J, Gabbett TJ. How do training and competition workloads relate to injury? The workload-injury
109 aetiology model. *Br J Sports Med* 2017;51(5):428-435. doi: 10.1136/bjsports-2016-096040
- 110 2. Murray NB, Gabbett TJ, Townshend AD, et al. Individual and combined effects of acute and chronic running
111 loads on injury risk in elite Australian footballers. *Scand J Med Sci Sports* 2016 doi:
112 10.1111/sms.12719
- 113 3. Pearson K. Mathematical contributions to the theory of evolution. On a form of spurious correlation which
114 may arise when indices are used in the measurement of organs. *Proc R Soc Lond* 1896;60:489-98. doi:
115 10.1098/rspl.1896.0076
- 116 4. Blanch P, Gabbett TJ. Has the athlete trained enough to return to play safely? The acute: chronic workload
117 ratio permits clinicians to quantify a player's risk of subsequent injury. *Br J Sports Med*
118 2016;50(8):471-75. doi: 10.1136/bjsports-2015-095445
- 119 5. Tu YK, Gilthorpe MS. Revisiting the relation between change and initial value: a review and evaluation. *Stat*
120 *Med* 2007;26(2):443-57. doi: 10.1002/sim.2538
- 121 6. Altman DG. Practical statistics for medical research: London: Chapman and Hall 1991:282.
- 122 7. Williams S, West S, Cross MJ, et al. Better way to determine the acute:chronic workload ratio? *Br J Sports*
123 *Med* 2016 doi: 10.1136/bjsports-2016-096589
- 124 8. Menaspa P. Building evidence with flawed data? The importance of analysing valid data. *Br J Sports Med*
125 2017 doi: 10.1136/bjsports-2016-097029

126

127

FIGURE LEGENDS

128

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

135

136

137

