Citation for published version:

Williams, S, Trewartha, G, Cross, MJ, Kemp, SPT & Stokes, KA 2017, 'Monitoring what matters: A systematic process for selecting training load measures', *International Journal of Sports Physiology and Performance*, vol. 12, no. Suppl 2, pp. 101-106. <https://doi.org/10.1123/ijsp.2016-0337>

DOI:

[10.1123/ijsp.2016-0337](https://doi.org/10.1123/ijsp.2016-0337)

Publication date:

2017

Document Version

Peer reviewed version

[Link to publication](#)

University of Bath

Alternative formats

If you require this document in an alternative format, please contact:
openaccess@bath.ac.uk

General rights

Copyright and moral rights for the publications made accessible in the public portal are retained by the authors and/or other copyright owners and it is a condition of accessing publications that users recognise and abide by the legal requirements associated with these rights.

Take down policy

If you believe that this document breaches copyright please contact us providing details, and we will remove access to the work immediately and investigate your claim.

1 **Title:** Monitoring what matters: A systematic process for
2 selecting training load measures

3 **Submission Type:** Original report

4 **Authors:** Sean Williams¹, Grant Trewartha¹, Matthew J.
5 Cross², Simon P. T. Kemp², & Keith A. Stokes¹

6 **Affiliations:** ¹Department for Health, University of Bath, Bath,
7 UK. ²Rugby Football Union, Twickenham, UK

8 **Corresponding Author:**

9 Dr. Sean Williams

10 Department for Health

11 University of Bath

12 Bath (UK)

13 BA2 7AY

14 E: S.Williams@bath.ac.uk

15 T: 01225 383515

16 **Preferred Running Head:** Selecting training load measures
17 for injury risk monitoring

18 **Abstract Word Count:** 249

19 **Text-Only Word Count:** 2789

20 **Number of Tables:** 4

21 **Number of Figures:** 1

22

23

24

25

26

27

28

29

30

31

32 ABSTRACT

33 **Purpose:** Numerous derivative measures can be calculated
34 from the simple session-Rating of Perceived Exertion (sRPE)
35 tool for monitoring training loads (e.g., acute:chronic workload
36 and cumulative loads). The challenge from a practitioner's
37 perspective is to decide which measures they should calculate
38 and monitor in their athletes for injury prevention purposes.
39 The aim of the current study was to outline a systematic
40 process of data reduction and variable selection for such
41 training load measures. **Methods:** Training loads were
42 collected from 173 professional Rugby Union players during
43 the 2013/14 English Premiership season, using the sRPE
44 method, with injuries reported via an established surveillance
45 system. Ten derivative measures of sRPE training load were
46 identified from existing literature and subjected to principal-
47 component analysis. A representative measure from each
48 component was selected by identifying the variable that
49 explained the largest amount of variance in injury risk from
50 univariate generalised linear mixed-effects models. **Results:**
51 Three principal components were extracted, explaining 57%,
52 24%, and 9% of the variance, respectively. The training load
53 measures that were highly loaded on component one
54 represented measures of the 'cumulative load' placed on
55 players, component two was associated with measures of
56 'changes in load', and component three represented a measure
57 of 'acute load'. Four-week cumulative load, acute:chronic
58 workload and daily training load were selected as the
59 representative measures for each component. **Conclusions:** The
60 process outlined in the current study enables practitioners to
61 monitor the most parsimonious set of variables, whilst still
62 retaining the variation and distinct aspects of 'load' within the
63 data.

64

65 **Key Words:** rugby, injury, workload, RPE, team sports

66 INTRODUCTION

67 Training load monitoring is currently a prominent issue in elite
68 team sports settings, particularly as a tool to identify those
69 athletes at risk of injury, illness, and non-functional
70 overreaching.¹ The Session-Rating of Perceived Exertion
71 (sRPE) method developed by Foster² is amongst the most
72 commonly used measures for quantifying internal workloads in
73 elite team sports.³ This simple approach involves multiplying
74 the athlete's RPE for a given session (typically using a 1–10
75 scale) by the duration of the session (in minutes), to derive a
76 training load in arbitrary units (AU). One benefit of this
77 approach is that it can be used to quantify the various training
78 modalities undertaken by team sport athletes, including
79 resistance training⁴ and pitch-based conditioning and skills
80 sessions.⁵ In addition, the sRPE method has been shown to
81 relate favourably with objective load measures, including heart
82 rate,⁶ blood lactate,⁶ and match events (e.g., body impacts).^{7,8}
83 Thus, the sRPE method represents an inexpensive and highly
84 practical tool for the monitoring of training loads in this setting.

85 A number of derivative measures of internal training load can
86 be calculated from the daily sRPE values, and investigated with
87 respect to injury risk. For instance, cumulative loads can be
88 calculated by summing a player's sRPE load values over a
89 specified period (e.g., the preceding four weeks),^{9,10} whilst
90 changes in load can be assessed by analysing the week-to-week
91 change between the current and previous week's total.¹⁰ More
92 recently, the 'acute-chronic workload ratio' has been used to
93 determine if the comparison of acute (1-week data) to chronic
94 (average weekly load calculated over a rolling 4-week period)
95 load is associated with increased injury risk.^{11,12} A number of
96 additional derivative measures from the sRPE method have also
97 been reported in the literature, including training monotony,
98 training strain, and exponentially-weighted moving
99 averages^{2,6,13} (see Table 1). The challenge from a practitioner's
100 perspective is to decide which measures they should calculate
101 and monitor in their athletes. With respect to analysing the
102 association between training load measures and injury risk or
103 performance, many of the aforementioned variables are likely
104 to be highly correlated with one another, and so including
105 several of these measures within an analysis may not be
106 advisable for statistical reasons (i.e., multicollinearity).¹⁴ The
107 reduction of these factors to the most parsimonious set of
108 variables, which still convey the underlying dimensions of the
109 data, would be desirable for practitioners. In other words, the
110 ability to objectively identify and monitor the key training load

111 variables from the many derivative measures that can be
112 produced (Table 1), whilst still capturing the unique aspects of
113 'load', is likely to be beneficial for those involved in training
114 load monitoring. Indeed, the need to simplify practises in elite
115 sport and differentiate the signal from the noise in the measures
116 we monitor was emphasised in a recent editorial.¹⁵
117 Accordingly, the aim of the current study was to outline a
118 systematic process of data reduction and variable selection for
119 sRPE training load data, which practitioners in team sport
120 settings may use to optimise their athlete monitoring practices.

121 **METHODS**

122 **Subjects**

123 This was a prospective cohort study of professional Rugby
124 Union players registered in the first team squad of four teams
125 competing at the highest level of Rugby Union in England
126 (English Premiership). Training load data were collected for
127 173 players (team A = 43 players, team B = 41 players, team C
128 = 46 players and team D = 43 players) over one season
129 (2013/14). The study was approved by the Research Ethics
130 Approval Committee for Health at the University of Bath and
131 written informed consent was obtained from each participant.

132 **Methodology**

133 The intensity of all training sessions (i.e., including strength
134 and conditioning and other non-rugby sessions) was estimated
135 using the modified Borg CR-10 RPE (rating of perceived
136 exertion) scale,¹⁶ with ratings obtained from each individual
137 player within 30 minutes after the end of each training
138 session.¹⁷ Each club was briefed on the scale and were given
139 the same scale to use during the season. Each player had the
140 scale explained to them by their strength and conditioning
141 coach and players were asked to report their RPE for each
142 session confidentially to the strength and conditioning coach
143 without knowledge of other players' ratings. Session RPE in
144 arbitrary units (AU) for each player was then derived by
145 multiplying RPE by session duration (min).

146 From the daily training load values described above, a number
147 of derivative training load measures were calculated (Table 1).
148 The training load measures were identified from previous
149 investigations of the relationship between training load and
150 injury risk. Where multiple training sessions were undertaken
151 on a single day, the sRPE loads from those sessions were

(GLMM) were used to select the measure (variable) within each principal component that had the largest association with injury risk, and would therefore be selected as the representative measure for that component. The GLMM model was selected for its ability to account for repeated measurements within the data, and was implemented using the *lme4* package²³ with R (version 3.2.4, R Foundation for Statistical Computing, Vienna, Austria). Each training load measure was independently modelled as a fixed effects predictor variable, both by itself (linear model) and with a squared term included to investigate possible non-linear effects (non-linear model).^{11,24} Random effects were athlete identity nested within their team, and the residual. The models were offset for players' individual match exposure. The *MuMIn* package²⁵ was used to calculate a conditional R^2 value (R^2_{GLMM}) for each model, to determine which model explained the greatest amount of variance in injury risk. The R^2_{GLMM} statistic measures the variance explained by both fixed and random factors (i.e. the entire model).²⁵ The training load measure with the highest R^2 value within each component was selected as the representative measure for that component.

RESULTS

A total of 8027 individual training weeks were observed during the study period, with 173 players providing 32 ± 8 training weeks each. Table 2 displays the mean values for each training load measure across the study period. For these 173 players, a total of 465 time-loss injuries (303 match, 162 training; 391 contact, 74 non-contact) were reported during the study period. Mean weekly training loads over the course of the season were 1706 ± 239 AU.

Both the Kaiser-Meyer-Olkin measure of sampling adequacy and Bartlett's test of sphericity indicated that the data were suitable for PCA, with values of 0.74 and $P < 0.001$, respectively. Three principal components were identified (Figure 1); component one explained 57% of the variance, component two explained an additional 24% of variance, and component three explained an additional 9% of total variance. Overall, the three components explained 90% of total variance. Table 3 displays the factor loadings after rotation. The training load measures that were highly loaded on component one represented measures of the 'cumulative load' placed on players, component two was associated with measures of 'changes in load', and component three represented a measure

278 4 week cumulative loads and the exponentially-weighted
279 moving average. Measures of ‘cumulative load’ have been
280 strongly associated with injury risk in elite Australian
281 footballers^{9,10} and Rugby Union.²⁴ It may be that these
282 cumulative load measures describe the accumulation of fatigue
283 within players, which may result in a reduction in the stress-
284 bearing capacity of tissue,²⁶ and thus an increased likelihood of
285 injury. Additionally, accumulated fatigue may alter
286 neuromuscular control responses, such that potentially
287 hazardous movement strategies are employed that increase the
288 likelihood of injury.²⁷ However, recent evidence suggests that
289 cumulative loads that are too low may also augment injury
290 risk,^{24,28} perhaps due to associated reductions in players’ fitness
291 levels.²⁹ As such, the cumulative loads accumulated by
292 collision sport athletes should be monitored, to aid the
293 management of these ‘fitness’ and ‘fatigue’ effects.

294 The second component identified by the PCA was highly
295 associated with the two training load measures that describe the
296 absolute and relative changes in a player’s load (week-to-week
297 change and acute:chronic workload, respectively). This
298 component described an additional 24% of total variance.
299 Substantial previous-to-current week changes in load were
300 found to significantly increase injury risk in elite Australian
301 footballers¹⁰ and Rugby Union players.²⁴ These results were
302 deemed to be especially pertinent to players returning from
303 injuries; a more conservative approach to the increase in week-
304 to-week training loads for previously injured players was
305 therefore advocated. Elsewhere, the acute:chronic workload
306 was found to be a greater predictor of injury than either acute or
307 chronic workload separately in elite Rugby League players.²⁸
308 Together, these findings suggest that sudden increases in load
309 should be avoided, and that loads should instead be
310 systematically increased relative to each player’s cumulative
311 load (as described by component one).²⁸

312 The third component identified by the PCA only contained one
313 highly-weighted factor, daily sRPE training load, which may be
314 considered a measure of ‘acute’ workload. This variable
315 described an additional 9% of total variance. The acute (or
316 recent) workloads undertaken by players are likely to reflect the
317 current level of fatigue in their system,³⁰ and so should be
318 monitored to ensure that workloads prescribed in the ensuing
319 period are appropriate with respect to the variables described in
320 components one and two (i.e., cumulative loads and changes in
321 load, respectively).

To select one training load measure to represent each component, it is recommended that the univariate associations between each measure and injury risk be compared (e.g., using generalised linear mixed-effects models). Both linear and non-linear relationships between these load measures and injury risk should be explored, as a number of recent studies have reported non-linear associations.^{11,24} Using this approach in the current study, 4-week cumulative load was selected as the measure representing component one (cumulative load), acute:chronic workload was selected as the measure representing component two (changes in load), whilst daily training load was the only variable highly correlated with component three (acute load) and so was automatically selected as the representative variable for this component. The specific variables chosen are likely to be unique to the current dataset, but the process outlined here may be used to select and monitor the most pertinent variables in other settings. In the current study, this process resulted in the selection of three training load measures (4-week cumulative load, acute:chronic workload, and daily training load) for further analysis and monitoring, from an initial group of ten possible measures, and would thus simplify the load monitoring analysis process, whilst still capturing the unique components of 'load' in this cohort. In addition, the process outlined here could also be applied to select the most pertinent variables for other training load measures (e.g., GPS and accelerometer data) for both injury risk and performance monitoring.

Practical Applications

- For those collecting sRPE data in elite collision sport athletes, a measure of cumulative load, change in load, and acute load should be monitored for injury risk management purposes.
- In other sports settings, the data reduction and variable selection procedures outlined in the current study may be similarly applied to extract key measures for the specific environment, in order to optimise the training load monitoring process.

Conclusions

The current study has outlined a systematic process of data reduction and variable selection that may be used to simplify the analysis of training load measures in team sport settings. Three principal components were identified in this elite rugby union dataset to monitor injury risk, representing measures of cumulative loads, changes in loads, and acute loads. Selecting

366 one measure to represent each of these components enables
367 practitioners to monitor the most parsimonious set of variables,
368 whilst still retaining the variation and unique components
369 within the data.

370 **Acknowledgements**

371 The authors would like to acknowledge with considerable
372 gratitude all club medical and strength and conditioning staff
373 for the recording of injury and exposure data throughout the
374 study period.

375

References

1. Halson S. Monitoring Training Load to Understand Fatigue in Athletes. *Sports Med.* 2014;44(2):139-147.
2. Foster C. Monitoring training in athletes with reference to overtraining syndrome. *Med. Sci. Sports Exerc.* 1998;30(7):1164-1168.
3. Akenhead R, Nassis G. Training load and player monitoring in high-level football: Current practice and perceptions. *International Journal of Sports Physiology and Performance.* 2015;In Press.
4. Sweet TW, Foster C, McGuigan MR, Brice G. Quantitation of resistance training using the session rating of perceived exertion method. *J. Strength Cond. Res.* 2004;18(4):796-802.
5. Clarke N, Farthing JP, Norris SR, Arnold BE, Lanovaz JL. Quantification of training load in Canadian Football: Application of Session-RPE in collision-based team sports. *The Journal of Strength & Conditioning Research.* 2013;27(8):2198-2205.
6. Gabbett TJ. The development and application of an injury prediction model for noncontact, soft-tissue injuries in elite collision sport athletes. *J. Strength Cond. Res.* 2010;24(10):2593-2603.
7. Lovell TW, Sirotic AC, Impellizzeri FM, Coutts AJ. Factors affecting perception of effort (session rating of perceived exertion) during rugby league training. *International Journal of Sports Physiology & Performance.* 2013;8(1):62-69.
8. Webborn N. Lifetime injury prevention: The sport profile model. *Br. J. Sports Med.* 2012;46(3):193-197.
9. Colby M, Dawson B, Heasman J, Rogalski B, Gabbett TJ. Accelerometer and GPS-derived running loads and injury risk in elite Australian footballers. *The Journal of Strength & Conditioning Research.* 2014;28(8):2244-2252.
10. Rogalski B, Dawson B, Heasman J, Gabbett TJ. Training and game loads and injury risk in elite Australian footballers. *J. Sci. Med. Sport.* 2013;16(6):499-503.
11. 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(8):708-712.
12. Hulin BT, Gabbett TJ, Lawson DW, Caputi P, Sampson JA. The acute:chronic workload ratio predicts injury: high chronic workload may decrease injury risk in elite rugby league players. *Br. J. Sports Med.* 2015.
13. Kara SD. *Injuries in professional rugby union: A study of five year of injury data with training loads and travel*

- as co-variables, Auckland University of Technology, Auckland, New Zealand; 2013.
14. Hair JF, Black WC, Babin BJ, Anderson RE. *Multivariate data analysis - A global perspective*. New Jersey, USA: Pearson; 2009.
 15. Coutts AJ. In the age of technology, Occam's razor still applies. *IJSPP*. 2014;9(5):2014-0353.
 16. Foster C, Florhaug JA, Franklin J, et al. A new approach to monitoring exercise training. *The Journal of Strength & Conditioning Research*. 2001;15(1):109-115.
 17. Kraft JA, Green JM, Thompson KR. Session ratings of perceived exertion responses during resistance training bouts equated for total work but differing in work rate. *The Journal of Strength & Conditioning Research*. 2014;28(2):540-545.
 18. Fuller CW, Molloy MG, Bagate C, et al. Consensus statement on injury definitions and data collection procedures for studies of injuries in rugby union. *British journal of sports medicine*. 2007;41(5):328-331.
 19. Federolf P, Reid R, Gilgien M, Haugen P, Smith G. The application of principal component analysis to quantify technique in sports. *Scand. J. Med. Sci. Sports*. 2014;24(3):491-499.
 20. Colyer S, Stokes K, Bilzon JL, Cardinale M, Salo A. Physical predictors of elite skeleton start performance. *International Journal of Sports Physiology and Performance*. 2016;Epub ahead of print.
 21. Weaving D, Marshall P, Earle K, Nevill A, Abt G. Combining internal-and external-training-load measures in professional Rugby League. *IJSPP*. 2014;9(6):905-912.
 22. Kaiser HF. An index of factorial simplicity. *Psychometrika*. 1974;39(1):31-36.
 23. Bates D, Maechler M, Dai B. The lme4 package. 2008; <http://cran.r-project.org/web/packages/lme4/lme4.pdf>. Accessed 01 August 2014, 2014.
 24. Cross M, Williams S, Trewartha G, Kemp S, Stokes K. The influence of in-season training loads on injury risk in professional Rugby Union. *International Journal of Sports Physiology and Performance*. 2016;11:350-355.
 25. Barton K. MuMIn: Multi-Model Inference. R package version 1.15.6. 2016; <https://CRAN.R-project.org/package=MuMIn>.
 26. Kumar S. Theories of musculoskeletal injury causation. *Ergonomics*. 2001;44(1):17-47.
 27. McLean SG, Felin RE, Suedekum N, Calabrese G, Passerallo A, Joy S. Impact of fatigue on gender-based high-risk landing strategies. *Med. Sci. Sports Exerc*. 2007;39(3):502.

- 476 28. Hulin BT, Gabbett TJ, Lawson DW, Caputi P, Sampson
477 JA. The acute: chronic workload ratio predicts injury:
478 high chronic workload may decrease injury risk in elite
479 rugby league players. *Br. J. Sports Med.* 2015;bjsports-
480 2015-094817.
- 481 29. Gabbett TJ, Ullah S, Finch CF. Identifying risk factors
482 for contact injury in professional rugby league players -
483 Application of a frailty model for recurrent injury. *J.*
484 *Sci. Med. Sport.* 2012;15(6):496-504.
- 485 30. Banister E, Calvert T, Savage M, Bach T. A systems
486 model of training for athletic performance. *Aust J*
487 *Sports Med.* 1975;7(3):57-61.
- 488 31. Gabbett TJ, Domrow N. Relationships between training
489 load, injury, and fitness in sub-elite collision sport
490 athletes. *J. Sports Sci.* 2007;25(13):1507-1519.
- 491 32. Gabbett TJ, Jenkins DG. Relationship between training
492 load and injury in professional rugby league players. *J.*
493 *Sci. Med. Sport.* 2011;14(3):204-209.
- 494 33. Gabbett TJ, Ullah S, Jenkins D, Abernethy B. Skill
495 qualities as risk factors for contact injury in professional
496 rugby league players. *J. Sports Sci.* 2012;30(13):1421-
497 1427.
- 498 34. Holt CC. Forecasting seasonals and trends by
499 exponentially weighted moving averages. *International*
500 *Journal of Forecasting.* 2004;20(1):5-10.

501

502

503 **Table and Figure Captions**

504

505 **Table 1.** Summary of training load measures investigated
506 within the current study, including their calculation and use in
507 existing literature.

508 **Figure 1.** Scree plot for Principal Component Analysis,
509 displaying the presence of three principal components.

510 **Table 2.** Descriptive data for internal sRPE training load
511 measures for each team over the study period.

512 **Table 3.** Data reduction procedure; rotated component matrix
513 of the training load measures.

514 **Table 4.** Variable selection procedure; univariate relationships
515 between training load measures and injury risk. *, variable
516 explaining the largest amount of variation in injury risk, and
517 therefore selected as the representative measure for this
518 component.

519

520

521 **Table and Figures**

522 Table 1.

Training load measure	Calculation	Supporting literature
Daily training load	Session RPE x session duration [minutes].	Foster ²
1,2,3,4 -weekly cumulative loads	Sum of previous (7, 14, 21, 28) days' training load values	Gabbett et al. ^{6,29,31-33} Rogalski et al. ¹⁰ Colby et al. ⁹
Week-to-week change	Absolute difference between current and previous week's training load totals	Rogalski et al. ¹⁰ Cross et al. ²⁴
Training monotony	A measure of the day-to-day consistency of a player's training load within a given week: daily mean/standard deviation	Foster ²
Training strain	Weekly training load x training monotony	Foster ²
Acute:chronic workload	Calculated by expressing a player's acute workload [1-week load] as a percentage of their chronic workload [four-week rolling average]	Hulin et al. ^{11,12}
Exponentially-weighted moving average	$f x$ (previous day's training load) + $(1-f) x$ (cumulative load up to that point), where f is a decay factor with value between 0 and 1. An f value of 0.1 was adopted for the calculation of the exponentially-weighted moving average of training load, based upon a previous study using a comparable population ¹³ . The resulting cumulative load is effectively smoothed with a time constant of 10 d.	Holt ³⁴ ; Kara ¹³

523

524

525

526

527

528

Table 2.

sRPE Training Load Measure	Team A	Team B	Team C	Team D	Mean $\pm$ Between Team SD
Daily training load [AU]	218	293	226	244	245 $\pm$ 33
1-week cumulative load [AU]	1528	2048	1556	1692	1706 $\pm$ 239
Two-week cumulative load [AU]	2259	3479	2644	2677	2765 $\pm$ 513
Three-week cumulative load [AU]	3047	4757	3529	3682	3754 $\pm$ 721
Four-week cumulative load [AU]	3891	6030	3892	4262	4518 $\pm$ 1022
Week-to-week change [AU]	4	-17	-5	-63	-34 $\pm$ 30
Training monotony [AU]	0.81	0.67	0.98	0.85	0.83 $\pm$ 0.13
Training strain [AU]	1256	1439	1511	1329	1384 $\pm$ 113
Acute:chronic workload [%]	87	127	112	95	103 $\pm$ 18
Exponentially-weighted moving average [AU]	240	251	166	209	188 $\pm$ 38

Table 3.

Training load measure	Component		
	1 [Cumulative]	2 [Changes in load]	3 [Acute]
Daily training load	0.15	0.14	0.98
1-week cumulative load	0.84	0.47	-0.21
2-week cumulative load	0.95	-0.02	0.14
3-week cumulative load	0.94	-0.22	0.12
4-week cumulative load	0.88	-0.34	0.12
Week-to-week change	0.08	0.88	-0.16
Training monotony	0.68	0.47	-0.16
Training strain	0.79	0.50	-0.21
Acute:chronic workload	-0.19	0.86	0.00
Exponentially-weighted moving average	0.98	-0.01	-0.08

Note, factor loadings >.70 appear in bold.

Table 4.

Training load measure	Conditional R^2_{GLMM}	
	Linear model	Non-linear model
<i>Component 1</i>		
1-week cumulative	37.48%	38.15%
2-week cumulative	38.01%	38.97%
3-week cumulative	38.88%	38.70%
4-week cumulative*	41.51%	42.67%
Exponentially-weighted moving average	38.47%	38.86%
Training strain	38.63%	38.94%
<i>Component 2</i>		
Week-to-week change	41.20%	41.22%
Acute:chronic workload*	42.12%	42.15%
<i>Component 3</i>		
Daily training load*	36.97%	36.77%