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ARTICLE

Despite association, the acute:chronic work load ratio does not predict non-contact injury in elite footballers

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ABSTRACT

Purpose: To examine association and prediction of load-based markers (rate of perceived exertion) with non-contact injuries.

Materials and methods: Thirty-four elite Italian football players (age 26 ± 5 y, height 182 ± 5 cm, body mass 78 ± 4 kg) participated in a 3-seasons prospective study. Markers examined were: RPE, exposure, weekly load, week-to-week load change, cumulative 2, 3, 4 WL, acute:chronic 1:2 (acute:chronic2), 1:3 (acute:chronic3) and 1:4 (acute:chronic4) WL ratios. After checking multicollinearity between markers, a Generalized Estimating Equation analysis was used to examine association with a non-contact injury in the subsequent week. The associated markers were split into four groups based on 15th, 50th, 85th percentile to compare injury risk (IR) in different zones. Prediction was examined with receiver operating characteristic curve, area under the curve (AUC) and Youden index.

Results: IR increased when acute:chronic2 of 1.00–1.20, >1.20 were compared to <0.81 (odds ratio (OR), 90% confidence interval (CI): 1.6, 0.79–3.29; 2.2, 1.03–4.74). IR increased when comparing acute:chronic3 of 1.01–1.23, >1.23 vs. <0.80 (OR, 90% CI: 1.9, 0.9–3.8; 2.5, 1.2–5.4). IR increased when comparing acute:chronic4 of 0.78–1.02, 1.02–1.26, >1.26 vs. <0.78 (OR, 90% CI: 2.4, 1.4–3.9; 3.3, 1.6–6.6; 3.5, 1.7–7.4). The AUC ≤0.60 for all markers and Youden Index (close to 0) showed poor prediction.

Conclusion: Acute:chronic markers showed association however with poor prediction ability.

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KEYWORDS
Team sport; soccer; injury prevention; training load

Introduction

The relationship between training load and injury in athletes has recently received increased attention in research and practical settings. Indeed, the International Olympic Committee (IOC) recently released a consensus statement (Soligard et al. 2016) highlighting that the relative load (i.e., the rate of load application relative to what the athlete has been prepared for) is the most pertinent measure of load associated with injury in athletes. Referred to as the "acute: chronic ratio" (acute:chronic) (typically, acute = current week and chronic = rolling 4 week average), this measure has been suggested to reflect the ratio between fatigue (i.e., acute) and fitness (i.e., chronic) of the player and has been associated with injury in many sports (Malone, Owen, et al. 2016; Hulin et al. 2014, 2016a; Malone, Roe et al. 2016; Murray et al. 2016; Weiss et al. 2017). In general, it is suggested that injury likelihood is low when the acute: chronic ratio is within a range of 0.8–1.3, and more than double when the acute:chronic ratio exceeds 1.5 (Soligard et al. 2016). Additional load measures such as high acute weekly (Malone, Owen, et al. 2016), cumulated weekly (Malone, Owen, et al. 2016; Rogalski et al. 2013; Cross et al. 2016) and week-to-week changes (Cross et al. 2016) have also been associated with increased injury risk (IR), whilst high chronic loads have been reported to offer protective effects (Hulin et al. 2016a). However, a concomitant high acute:chonic ratio with high chronic load has been shown to increase the risk (Hulin et al. 2016b).

Whilst the understanding of the relationships between training load and IR in sports is increasing, some issues and limitations of other studies should be addressed. For example, studies on elite football players are lacking, with only one study in male senior (Malone, Owen, et al. 2016) and another in elite youth players (Bowen et al. 2017). It has also been suggested that different acute:chronic durations should be used to better fit the specificity of training/competitive patterns of football (e.g., 2 and 3 weekly chronic loads) (Buchheit 2017). In addition, there is a lack of a standard injury definition (Hulin 2017) with some studies investigating all injuries including "medical attention injuries" (i.e., injuries without any time loss) (Gabbett 2004), while others consider only time-loss injuries (Malone, Owen, et al. 2016; Malone, Roe et al. 2016; Hulin et al. 2016a, 2016b). Moreover, despite earlier recommendation (Gabbett 2010), only two studies have further classified time-loss injuries into contact and non-contact injury mechanisms (Rogalski et al. 2013; Bowen et al. 2017). While research has shown that non-contact injuries can be prevented (to a certain extent) with exercise-based programmes (Thorborg et al. 2017) in amateur football, there is still a lack of

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understanding on the relationship between load characteristics and non-contact injuries. Therefore, there is a need to further examine the relationships between load characteristics and non-contact injuries specifically in elite football players.

One controversial aspect of previous research that requires clarification is the supposition that significant associations between load and injury have prompted load and its derivatives to be deemed as "predictive" of injury (Hulin et al. 2016a, 2016b). However, as explained by Professor Roald Bahr (Bahr 2016), *associations* with injury and *predicting* injury are different terms and are analysis that should be used for different purposes (i.e., explanation and classification). Indeed, it has been shown that even strong associations may not predict injury (Pepe 2004). While associations such as odds ratio (OR) or relative risk can be useful to characterize the risk of a population, these statistical outcomes do not infer "prediction" (Pepe 2004). In order to determine the true use of a marker, it is important to assess not only an association but also the predictive validity and optimal cut-off value (Fawcett 2006). Predictive validity of a marker is typically assessed with receiver operating characteristic (ROC) curve (De Vet et al. 2011).

Utilising a simple, practical and valid measure of internal load derived from the rate of perceived exertion (RPE), the aim of the present study was to investigate (1) the association of internal perceived load with non-contact injury and (2) the ability of these measures to predict injury in elite football players. We hypothesised that there would be a significant association between various load measures and non-contact injury, though load measures would show inadequate level of predictive validity.

Methods

Participants

During three consecutive, competitive seasons (2013/14, 2014/15, 2015/16), 34 professional football players from the same SerieA team were prospectively followed (age: 26 ± 5 y; height: 182 ± 5 cm; body mass: 78 ± 4 kg). Only players competing at least 1 full season were included in the analysis, specifically, 12 players during three seasons, 10 during two seasons and 12 for one season. Each season was split into three distinct periods depending on the year and league start date: pre-season (early July to mid-end August), early and late in-season (mid-end August to end December and early January to mid-May, respectively, early and late in-season). Pre-season period lasted 38 ± 3 days, the in-season (i.e., competitive) periods were 128 ± 4 and 147 ± 7 days in early and late in-season, respectively. The study is in accordance with the spirit of the Helsinki Declaration. Approval for the study was obtained from the Club as player's data were routinely collected over the course of the season (Winter and Maughan 2009).

Quantification of internal load

Internal load was assessed using session-RPE method (Foster et al. 2001) and validated in football (Impellizzeri et al. 2004) whereby the intensity of the session is multiplied by the duration for each player for each training session or match. The intensity was determined using the Borg CR-10 scale modified by Foster et al. (2001) within 30 min after completion of the session/match and was collected by the same fitness coach throughout all seasons. The mean weekly RPE was calculated as indicator of the week intensity as well as the total exposure was calculated by summating the duration of each session. The weekly load (WL) corresponded to the sum of load for all training sessions and matches for each week. The absolute week-to-week change in load (W-WL) was calculated as the difference between current WL and previous WL. Cumulative loads were calculated for 2, 3 and 4 weeks. Chronic loads were calculated as rolling averages for 2, 3 and 4 weeks. An acute (WL) to chronic (rolling average of previous weeks) ratio was calculated for 2, 3 and 4 weeks (acute:chronic2, acute:chronic3, acute:chronic4, respectively).

Injury data collection

A non-contact injury was considered when a player was unable to take a full part in future football training or match due to physical complaints (Fuller et al. 2006) (all injuries diagnosed by the same club doctor). Injuries were recorded according to the classifications proposed by Fuller et al. (2006). Training exposure was considered as the duration (h) corresponding to team-based and individual physical activities. Injury incidence was calculated as all non-contact injuries per 1000 h of football activity (training + matches).

Statistical analysis

Data are presented as mean ± standard deviations (mean ± SD). Generally, in elite football teams, there are several differences in the training structure between pre- and in-season periods, including the organization, quality and quantity of training (e.g., general vs. specific, once vs. twice a day training session) and this results in different periodization and overall loads (Impellizzeri et al. 2005). Differences in load between pre- and in-season (early and late in-season, before and after Christmas break, respectively) have been examined in the present cohort with a one-way ANOVA. If WLs were different between periods ($P < 0.05$), only in-season data were considered in the analysis. Effect size (partial eta squared, η^2) was also calculated and values of 0.01, 0.06 and >0.15 were interpreted as small, medium and large, respectively. Pearson's moment of Correlation and variance inflation factors (VIF) were determined to detect multicollinearity between markers; if a VIF ≥ 10 was found, the variable was excluded from the analysis.

Determining association

A generalized estimating equations (GEE) analysis was used to determine the association between load measures and non-contact injury in the subsequent week (Williamson et al. 1996). To analyse longitudinal data with a binary outcome distribution (injury: yes/no), a logit link function was used and exchangeable working correlations matrix was chosen, based on lower quasi-likelihood under the independence model criterion. If GEE analysis was significant ($P < 0.05$), the variable was split in four groups based on 15th, 50th, 85th percentile to compare IR between zones of different load: extremely low

(<15th percentile), moderate low (>15–50th percentile), moderate high (from >50 to 85th percentile) and extremely high (>85th percentile). The percentage IR was calculated as a proportion of weeks with a subsequent injury for each group (Hopkins et al. 2007).

ORs and 90% confidence intervals (CIs) were calculated for comparison between risks in different load groups (MedCalc Software, Ostend, Belgium). Magnitude-based inferences were used to interpret change in percentage risk between groups (Hopkins et al. 2009). The smallest beneficial and harmful effect for a risk ratio was considered as an OR of <0.90 and >1.11, respectively. The effect was considered unclear if the chance of the true values of beneficial was >25% with the OR <66. If the effect was considered clear, thresholds for assigning qualitative terms of beneficial, trivial, harmful were as follows: <0.5%, most likely; 0.5–5%, very unlikely; 5–25%, unlikely; 25–75%, possible; 75–95%, likely; 95–99.5%, very likely; >99.5%, most likely (Hopkins 2007).

Determining prediction

Load variables that exhibited a significant association following GEE analysis were tested for predictive ability using ROC curve. The ROC curve examines the discriminant ability of a marker to classify players in two groups and plots the true positive rate (sensitivity) against the true negative rate (specificity) producing an area under the curve (AUC). An AUC of 1.00 (100%) represents perfect discriminant power, where 0.50 (50%) would represent no discriminatory power (Fawcett 2006; Crowcroft et al. 2016). An AUC >0.70 and the lower CI >0.50 was classified as a "good" benchmark (Menaspà et al. 2010). All ROC curve results were presented as AUC ± 90% CI.

To examine the predictive ability of the higher cut-off, sensitivity [true positive/(true positive + false negative)*100] and specificity [false positive/(false positive + true negative) *100] were calculated for each load-based marker using the 85th percentile as cut-off (Kent and Hancock 2016). In addition, the Youden Index (J) was calculated (J = sensitivity+specificity−1) from all ROC curve plots to determine the point where the sensitivity and specificity were optimised (i.e., high J) and considered the score at which a "cut-off" value from each load marker might be acceptable to discriminate a player at risk of injury. The maximum J index of 1 would suggest perfect discriminatory value, whilst a score of 0 would reflect no diagnostic value (Schisterman et al. 2005).

All analyses were performed using SPSS (Version 21. IBM Company, New York, USA) and Excel (Microsoft Excel 2011 for Mac, Microsoft Corporation, USA).

Results

A total of 90 (of which 72 occurred in-season and 18 classified as re-injuries) time-loss non-contact injuries were incurred during the three seasons. Non-contact injury incidences were 5.2/1000 h, 4.6/1000 h and 5.5/1000 h for pre-season, early in-season and late in-season (5.0/1000 h for all in-season periods). Injury occurrence, exposure and injury incidence per match and training are presented in Table 1. Details about type, location and re-injuries are presented in Appendix 1. WL was significantly different at different time points during the season (P < 0.0001, η^2 = 0.14). Pre-season showed high WL compared to early and late in-season periods (2082 ± 700 vs. 1528 ± 466 AU, P < 0.0001 and vs. 1526 ± 427 AU, P < 0.0001, respectively). Pre-season data were excluded from the analysis; therefore, 72 non-contact injuries were considered. Cumulative load of 2, 3 and 4 weeks showed substantial multi-collinearity (i.e., VIF >10) and therefore were excluded from the analysis.

Association

The results of the GEE analysis showed (Table 2) that week load and week-to-week load absolute change were significantly but

Table 1. Injury occurrence, exposure and injury incidence during all seasons (pre- and in-season) per training and match.

	2013/14		2014/15		2015/16	
	Pre-season	In-season	Pre-season	In-season	Pre-season	In-season
Non-contact injuries, training (n°)	7	17	6	7	5	15
Non-contact injuries, match (n°)		9		14		10
Exposure, training (h)	840	4146	1309	4309	1295	4134
Exposure, match (h)		494		592		593
Injury incidence, training (n°/1000 h)	8.3	4.1	4.6	1.6	3.9	3.6
Injury incidence, match (n°/1000 h)		18.2		23.7		16.9

Table 2. Association and prediction of different load markers. Odds ratios, 90% confidence intervals (90% CI) and P-level from the Generalized Estimating Equation analysis for load-based markers and binary outcome (injury: yes/no). Area Under the Curve (AUC) and 90% CI from the Receiving Operator Characteristic curve (ROC) analysis and the Youden Index (J).

	Association			Prediction	
Marker	OR (90% CI)	P-level	Clinical inference	AUC (90% CI)	J
Duration (min)	1.00 (1.00–1.00)	0.08	Unclear		
RPE (AU)	1.37 (0.97–1.93)	0.13	Likely harmful	0.54 (0.48–0.59)	0.11
WL (AU)	1.00 (1.00–1.00)	0.02	Unclear	0.55 (0.50–0.59)	0.15
W-WL (AU)	1.00 (1.00–1.00)	0.04	Unclear	0.56 (0.51–0.62)	0.14
Acute:chronic2 (AU)	2.98 (1.87–4.75)	0.00	Most likely harmful	0.57 (0.52–0.63)	0.15
Acute:chronic3 (AU)	2.46 (1.43–4.24)	0.01	Very likely harmful	0.60 (0.54–0.65)	0.19
Acute:chronic4 (AU)	2.91 (1.58–5.36)	0.00	Most likely harmful	0.57 (0.52–0.63)	0.15

RPE: rate of perceived exertion; WL: week load; W-WL: week-to-week absolute difference in load; Acute:chronic2, Acute:chronic3, Acute:chronic4 WL ratios; OR: odds ratio; AUC: Area Under the Curve; J: Youden Index.

Table 3. Injury risk comparisons between different zones of load (<15th, 15–50th, 50–85th, >85th percentile).

Marker (AU)	Injury risk (%)	Load zones	Odds ratio (90% CI)	Qualitative term for clinical inference	Chances (%) the effect is beneficial/trivial/harmful
WL	1.4	<1086 (reference)			
	4.5	1086 to 1542	3.4 (1.42–8.28)	Very likely Harmful	1/1/98
	4.1	>1542 to 1985	3.1 (1.27–7.50)	Very likely Harmful	1/2/97
	3.1	>1985	2.3 (0.84–6.19)	Likely harmful	6/6/88
		1086 to 1542 (reference)			
		>1542 to 1985	0.9 (0.58–1.40)	Unclear	50/29/22
		>1985	0.7 (0.35–1.25)	Unclear	78/12/9
		>1542 to 1985 (reference)			
		>1985	0.7 (0.39–1.40)	Unclear	69/16/15
W-WL	2.7	<−572 (reference)			
	3.4	−572 to 1	1.2 (0.63–2.47)	Possibly harmful	22/17/61
	4.1	>1 to 614	1.5 (0.78–2.97)	Likely harmful	10/12/78
	4.5	>614	1.7 (0.78–3.51)	Likely harmful	9/10/81
		−572 to 1 (reference)			
		>1 to 614	1.2 (0.76–1.96)	Possibly harmful	14/23/63
		>614	1.3 (0.74–2.38)	Possibly harmful	14/17/69
		>1 to 614 (reference)			
		>614	1.1 (0.62–1.91)	Unclear	29/23/47
Acute:chronic2	2.4	<0.81 (reference)			
	3.5	0.81 to 1.00	1.5 (0.73–3.05)	Possibly harmful	12/13/75
	3.8	>1.00 to 1.20	1.6 (0.79–3.29	Likely harmful	9/11/81
	5.1	>1.20	2.2 (1.03–4.74)	Likely harmful	3/4/93
		0.81 to 1.00 (reference)			
		>1.00 to 1.20	1.1 (0.68–1.74)	Unclear	26/27/47
		>1.20	1.5 (0.85–2.58)	Likely harmful	7/13/80
		>1.00 to 1.20 (reference)			
		>1.20	1.4 (0.79–2.36)	Possibly harmful	11/16/73
Acute:chronic3	2.4	<0.80 (reference)			
	2.7	0.80 to1.01	1.1 (0.53–2.34)	Unclear	32/18/50
	4.4	>1.01 to 1.23	1.9 (0.94–3.81)	Likely harmful	4/7/89
	5.9	>1.23	2.5 (1.20–5.38)	Very likely harmful	1/2/96
		0.80 to1.01 (reference)			
		>1.01 to 1.23	1.7 (1.03–2.79)	Likely harmful	2/6/92
		>1.23	2.3 (1.29–4.01)	Very likely harmful	0/2/98
		>1.01 to 1.23 (reference)			
		>1.23	1.3 (0.80–2.24)	Possibly harmful	10/17/73
Acute:chronic4	1.4	<0.78 (reference)			
	3.3	0.78–1.02	2.4 (0.98–5.92)	Likely harmful	4/4/92
	4.5	>1.02–1.26	3.3 (1.37–8.02)	Very likely harmful	1/1/98
	4.9	>1.26	3.6 (1.41–9.31)	Very likely harmful	1/1/98
		0.78–1.02 (reference)			
		>1.02–1.26	1.4 (0.86–2.21)	Likely harmful	7/16/78
		>1.26	1.5 (0.85–2.68)	Likely harmful	7/12/81
		>1.02–1.26 (reference)			
		>1.26	1.1 (0.63–1.89)	Unclear	28/24/48

WL: week load; W-WL: week-to-week absolute change in week load; Acute:chronic2, Acute:chronic3, Acute:chronic4 WLs ratio.

unclearly associated with injuries whereas acute:chronic2, acute:chronic3, acute:chronic4 showed clear association with injuries ($P < 0.05$). Weekly duration and RPE showed no significant (unclear and clear, respectively) associations with injuries (Table 2). The IR, OR and 90% CI calculated for comparison between different load groups in each load marker (<15th, 15–50th, 50–85th, >85th percentile) and corresponding magnitude-based inferences are presented in Table 3.

Prediction

The ROC curve (Figure 1), the values AUC (90% CI) and the *J* for each load marker (Table 2) showed poor predictive ability of injury (AUC: 0.55–0.60). When using the 85th percentile as cut-off, each marker showed poor sensitivity (Table 4). Given the decrease of IR in the higher group of the WL compared to intermediate groups (i.e., 3.1% vs. 4.5%, 4.1%, respectively in 4th, 2th, 3th group), a further analysis was performed to examine the high frequency of non-contact injuries group

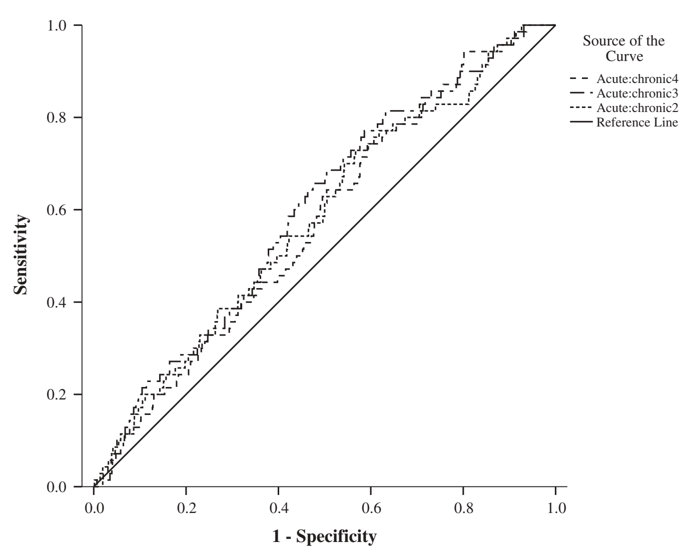

Figure 1. Receiving operating characteristic (ROC) curves for the acute:chronic2, acute:chronic3, acute:chronic4 WL ratios markers.

Table 4. Sensitivity and specificity for each marker when the load is extremely high (i.e., >85th percentile).

Variables (AU)	True positive	False positive	False negative	True negative	Sensitivity (%)	Specificity (%)
WL	9	284	63	1597	12.5	84.9
WL 2nd vs. other	31	653	41	1229	43.1	65.3
W-WTL	13	279	59	1593	18.1	85.1
Acute:chronic2	15	277	57	1596	20.8	85.2
Acute:chronic3	17	273	55	1588	23.6	85.3
Acute:chronic4	14	274	56	1576	20.0	85.2

True positive: the players with injury with marker >85th percentile; False positive: the players without injury with marker >85th percentile; False negative: the players with injury with marker <85th percentile; True negative: the players without injury with marker <85th percentile. Sensitivity and Specificity.

compared to the other (i.e., WL between >1086 and 1542 vs. other groups), and sensitivity and specificity were 43.1% and 65.3%, respectively.

Discussion

In accordance with our hypotheses, the main and novel findings of this study were that various load markers were clearly associated with the occurrence of non-contact injury in elite footballers; however, they showed poor predictive ability to detect individuals that will go on to incur a non-contact injury.

Evidence for implementing a global load monitoring strategy

The results of the present study support the IOC consensus statement (Soligard et al. 2016), which highlights the association of load and IR. However, despite being significantly associated ($P < 0.05$) with non-contact injury, the absolute loads in the current study (i.e., weekly acute load and week-to-week absolute change) did not exhibit an increased risk of injury (OR 1, unclear clinical inference). Despite RPE (i.e., intensity) showing no significant association ($P > 0.05$) with non-contact injury using traditional statistical analyses, magnitude-based inference statistics highlighted a likely harmful effect (Table 2). As recommended by the IOC, it may be the rate of load application that is a more pertinent measure associated with injury. The acute:chronic ratios of 2, 3 and 4 weeks investigated in the current study all showed a significant association with non-contact injury coupled with an increased risk (OR 3.0, 2.5 and 2.9, respectively). These results support the findings in other sports that the acute:chronic ratio offers some explanation into non-contact injury occurrence with rapid increases in relative load (Soligard et al. 2016). Unfortunately, our results showed similar association with IR in acute:chronic 2, 3, 4 ratios; therefore, further work is needed not only to validate our findings but also to identify the optimal combination of acute and chronic durations. Recently, a protective effect of a traditional acute:chronic4 between 1.00 and 1.25 has been found in elite football players (Malone, Owen, et al. 2016). However, the present study investigated OR between different load groups (i.e., based on percentiles) for all acute:chronic ratios and it was found that IR increased (OR >1) as the acute:chronic values increased (Table 3). Collectively, these results show that there was no protective effect of load in the present cohort.

But, can we predict when a player will get injured?

While the findings of significant association with non-contact injury provides the practitioner with evidence to implement a load monitoring preventative strategy, such information does not imply an ability to predict individual players who will incur the injury (i.e., diagnostic accuracy). The poor diagnostic characteristics of load variables in the present study (Table 2) show that load monitoring cannot be confidently used as a tool to predict injury in individual players. In the present sample, ROC curve analysis revealed AUC ≤0.60 for WL, week-to-week change as well as acute:chronic2, 3 and 4 (Table 2), which is lower than the AUC >0.70 which has to be reported to establish some predictive ability (Crowcroft et al. 2016). In addition, the Youden Index, which assesses the balance between sensitivity and specificity to quantify cut-off values (Crowcroft et al. 2016), also showed poor discriminatory value (J = 0.14–0.19, Table 2). A J of 1 suggests a perfect discriminatory value and J of 0 reflects no diagnostic value (Schisterman et al. 2005); unfortunately, our results were close to 0. While, to our knowledge (Schisterman et al. 2005), this is the first study to use a predictive analysis for load variables as predictors of injury occurrence in elite athletes, it is in line with other studies showing poor diagnostic ability of subjective monitoring variables used to identify performance change (Crowcroft et al. 2016; Saw et al. 2016). In addition, mathematical coupling has been found between numerator and denominator in the acute:chronic ratio (i.e., acute is a part of the chronic load) providing spurious correlations and therefore limiting inferences (Lolli et al. 2017).

What if the acute:chronic ratio is really high?

In the present study, we investigated the sensitivity (i.e., the ability of this load measure to correctly identify a player incurring non-contact injury) of very high acute:chronic ratios (>85th percentile versus ≤85th percentile). With the acute:chronic2, 3 and 4, we found 21%, 24% and 20% sensitivity, respectively. To put this into perspective, in absolute number of non-contact injuries, acute:chronic2 identified 15 true positives and 277 false positives, acute:chronic3: 17 true positives and 273 false positives and acute:chronic4: 14 true positives and 274 false positives (Table 4). Given these findings, even with very high acute:chronic ratios (considering the present sample), it seems unlikely to predict injury. It is important to highlight that the value of acute:chronic4 > 85th percentile in the present study is lower compared to that reported in the

IOC consensus (1.26 vs. 1.50 AU, respectively) and this may explain the difference in results (Soligard et al. 2016).

Limitations and future directions

There are some limitations to the current study. First, the cohort used in this study belong to one team and limits generalization of the findings. Future studies should include more teams over multiple seasons. Second, we did not account for potential confounding variables such as previous injury, multiple injuries in the same player, fitness or age. Future studies would benefit from methods and analyses that account for these confounders. In addition, the present study examined only internal load while other studies examined external loads (i.e., running loads); future studies should examine both internal and external measures together. The strengths of this study include a longitudinal period studied over three seasons and statistical analyses accounting for repeated measures in addition to investigating predictive ability.

Conclusion

The findings of the present study support the association between session-RPE derived training and match load measures, especially relative measures of acute:chronic2, 3 and 4 with non-contact injury. However, while significantly associated, this should not be confused with ability to predict injury at an individual player level. Overall, our findings provide justification for the implementation of a team-wide monitoring strategy of internal load in elite footballers; however, caution should be taken when making decisions at the individual player level.

Practical implications

The load markers based on internal perceived load (session-RPE) as acute:chronic ratios (e.g., 1:4 weeks, 1:3 weeks and 1:2 weeks) are significantly associated with non-contact injury in elite football players. While internal perceived load markers are associated with non-contact injury occurrence, such markers have poor predictive validity to identify individual players who will go on to incur such an injury.

Disclosure statement

No potential conflict of interest was reported by the authors.

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References

Bahr R. 2016. Why screening tests to predict injury do not work—and probably never will…: a critical review. Br J Sports Med. 50(13):776–780.

Bowen L, Gross AS, Gimpel M, Li F-X. 2017. Accumulated workloads and the acute: chronicworkload ratio relate to injury risk in elite youth football players. Br J Sports Med. 51(5):452–459.

Buchheit M. 2017. Applying the acute: chronicworkload ratio in elite football: worth the effort? Br J Sports Med. 51(18):1325–1327.

Cross MJ, Williams S, Trewartha G, Kemp SPT, Stokes KA. 2016. The influence of in-season training loads on injury risk in professional Rugby Union. Int J Sports Physiol Perform. 11(3):350–355.

Crowcroft S, McCleave E, Slattery K, Coutts AJ. 2016. Assessing the measurement sensitivity and diagnostic characteristics of athlete monitoring tools in national swimmers. Int J Sports Physiol Perform. 12(Suppl 2):1–21.

De Vet H, Terwee CB, Mokkink L, Knol D. 2011. Measurement in medicine: a practical guide (Practical Guides to Biostatistics and Epidemiology). Cambridge: Cambridge University Press; p. 167-168. doi:10.1017/CBO9780511996214.

Fawcett T. 2006. An introduction to ROC analysis. Pattern Recognit Lett. 27 (8):861–874.

Foster C, Florhaug JA, Franklin J, Gottschall L, Hrovatin LA, Parker S, Doleshal P, Dodge C. 2001. A new approach to monitoring exercise training. J Strength Cond Res. 15(1):109–115.

Fuller CW, Ekstrand J, Junge A, Andersen TE, Bahr R, Dvorak J, Hagglund M, McCrory P, Meeuwisse WH. 2006. Consensus statement on injury definitions and data collection procedures in studies of football (soccer) injuries. Br J Sports Med. 40(3):193–201.

Gabbett TJ. 2004. Reductions in pre-season training loads reduce training injury rates in rugby league players. Br J Sports Med. 38(6):743–749.

Gabbett TJ. 2010. The development and application of an injury prediction model for noncontact, soft-tissue injuries in elite collision sport athletes. J Strength Cond Res. 24(10):2593–2603.

Hopkins WG. 2007. A spreadsheet for deriving a confidence interval, mechanistic inference and clinical inference from a P value. Sportscience. 11:16–20.

Hopkins WG, Marshall SW, Batterham AM, Hanin J. 2009. Progressive statistics for studies in sports medicine and exercise science. Med Sci Sports Exerc. 41(1):3–13.

Hopkins WG, Marshall SW, Quarrie KL, Hume PA. 2007. Risk factors and risk statistics for sports injuries. Clin J Sport Med. 17(3):208–210.

Hulin BT. 2017. The never-ending search for the perfect acute: chronicworkload ratio: what role injury definition? Br J Sports Med. 51(13):991–992.

Hulin BT, Gabbett TJ, Blanch P, Chapman P, Bailey D, Orchard JW. 2014. Spikes in acute workload are associated with increased injury risk in elite cricket fast bowlers. Br J Sports Med. 48(8):708–712.

Hulin BT, Gabbett TJ, Caputi P, Lawson DW, Sampson JA. 2016a. Low chronic workload and the acute: chronicworkload ratio are more predictive of injury than between-match recovery time: a two-season prospective cohort study in elite rugby league players. Br J Sports Med. 50(16):1008–1012.

Hulin BT, Gabbett TJ, Lawson DW, Caputi P, Sampson JA. 2016b. The acute: chronicworkload ratio predicts injury: high chronic workload may decrease injury risk in elite rugby league players. Br J Sports Med. 50 (4):231–236.

Impellizzeri FM, Rampinini E, Coutts AJ, Sassi A, Marcora SM. 2004. Use of RPE-based training load in soccer. Med Sci Sports Exerc. 36(6):1042–1047.

Impellizzeri FM, Rampinini E, Marcora SM. 2005. Physiological assessment of aerobic training in soccer. J Sports Sci. 23(6):583–592.

Kent P, Hancock MJ. 2016. Interpretation of dichotomous outcomes: sensitivity, specificity, likelihood ratios, and pre-test and post-test probability. J Physiother. 62(4):231–233.

Lolli L, Batterham AM, Hawkins R, Kelly DM, Strudwick AJ, Thorpe R, Gregson W, Atkinson G. 2017. Mathematical coupling causes spurious correlation within the conventional acute-to-chronic workload ratio calculations. Br J Sports Med.

Malone S, Owen A, Newton M, Mendes B, Collins KD, Gabbett TJ. 2016. The acute: chonicworkload ratio in relation to injury risk in professional soccer. J Sci Med Sport. 20(6):561–565.

Malone S, Roe M, Doran DA, Gabbett TJ, Collins K. 2016. High chronic training loads and exposure to bouts of maximal velocity running reduce injury risk in elite Gaelic football. J Sci Med Sport. 20 (3):250–254.

Menaspà P, Sassi A, Impellizzeri FM. 2010. Aerobic fitness variables do not predict the professional career of young cyclists. Med Sci Sports Exerc. 42(4):805–812.

Murray NB, Gabbett TJ, Townshend AD, Hulin BT, McLellan CP. 2016. Individual and combined effects of acute and chronic running loads on injury risk in elite Australian footballers. Scand J Med Sci Sports. 27(9):990–998.
Pepe MS. 2004. Limitations of the odds ratio in gauging the performance of a diagnostic, prognostic, or screening marker. Am J Epidemiol. 159(9):882–890.
Rogalski B, Dawson B, Heasman J, Gabbett TJ. 2013. Training and game loads and injury risk in elite Australian footballers. J Sci Med Sport. 16(6):499–503.
Saw AE, Main LC, Gastin PB. 2016. Monitoring the athlete training response: subjective self-reported measures trump commonly used objective measures: a systematic review. Br J Sports Med. 50(5):281–291.
Schisterman EF, Perkins NJ, Liu A, Bondell H. 2005. Optimal cut-point and its corresponding Youden Index to discriminate individuals using pooled blood samples. Epidemiology. 16(1):73–81.
Soligard T, Schwellnus M, Alonso J-M, Bahr R, Clarsen B, Dijkstra HP, Gabbett T, Gleeson M, Hägglund M, Hutchinson MR, et al. 2016. How much is too much? (Part 1) International Olympic Committee consensus statement on load in sport and risk of injury. Br J Sports Med. 50(17):1030–1041.
Thorborg K, Krommes KK, Esteve E, Clausen MB, Bartels EM, Rathleff MS. 2017. Effect of specific exercise-based football injury prevention programmes on the overall injury rate in football: a systematic review and meta-analysis of the FIFA 11 and 11+ programmes. Br J Sports Med. 51(7):562–571. eng.
Weiss KJ, Allen SV, McGuigan MR, Whatman CS. 2017. The relationship between training load and injury in men's professional Basketball players. Int J Sports Physiol Perform. 12(9):1238-1242. doi:10.1123/ijspp.2016-0726.
Williamson DS, Bangdiwala SI, Marshall SW, Waller AE. 1996. Repeated measures analysis of binary outcomes: applications to injury research. Accid Anal Prev. 28(5):571–579.
Winter EM, Maughan RJ. 2009. Requirements for ethics approvals. J Sports Sci. 27(10):985.

Appendix 1. Details of re-injuries during pre- and in-season periods*

Season	Location	Type of injury	Event (Training/match)
2013/14			
Pre-season	Thigh (H)	Muscle strain	Training
	Thigh (Q)	Muscle strain	Training
	Knee	Sprain	Training (Friendly match)
	Thigh (Ad)	Muscle strain	Training (Friendly match)
	Thigh (H)	Muscle strain	Training (Friendly match)
	Thigh (H)	Muscle strain	Training (Friendly match)
In-season	Knee	Lesion of meniscus	Training
	Hip	Muscle tear	Training
2014/15			
Pre-season	Lower back	Muscle strain	Training
	Lower leg	Muscle strain	Training
	Lower leg	Muscle strain	Training
	Thigh (H)	Muscle strain	Training (Friendly match)
	Thigh (Ad)	Muscle strain	Training
	Lower leg	Muscle strain	Training
In-season	Knee	Ligament injury	Match
	Thigh (H)	Muscle tear	Match
	Thigh	Muscle strain	Match
	Thigh (Q)	Muscle strain	Match
2015/16			
Pre-season	Thigh (Q)	Muscle tear	Training (Friendly match)
	Knee (PT)	Tendinosis	Training
	Lower leg	Muscle strain	Training
	Foot	Other injuries	Training
	Thigh (H)	Muscle strain	Training (Friendly match)
In-season	Knee (CL)	Ligament injury	Training
	Thigh (H)	Muscle strain	Match
	Lower leg/Achilles tendon	Tendinosis	Training
	Thigh (H)	Muscle strain	Match
	Thigh (H)	Muscle tear	Match
	Knee (PT)	Tendinosis	Training
	Knee (PT)	Tendinosis	Training
	Groin	Muscle strain	Training
	Thigh	Muscle strain	Training
	Thigh (H)	Muscle tear	Match
	Thigh (H)	Muscle tear	Match
	Knee	Other bone injuries	Match

H: hamstring; Q: quadriceps; Ad: adductor; PT: patellar tendon; CL: collateral ligament.
*Fuller CW, Ekstrand J, Junge A, Andersen TE, Bahr R, Dvorak J, Hagglund M, McCrory P, Meeuwisse WH. 2006. Consensus statement on injury definitions and data collection procedures in studies of football (soccer) injuries. Br J Sports Med. 40(3):193–201.