Timothy J.H. Lathlean, Stuart V. Newstead, Paul B. Gastin

Elite Junior Australian Football Players With Impaired Wellness Are at Increased Injury Risk at High Loads

Sports Health: A Multidisciplinary Approach, 2022; 2-9

Published version available via DOI: http://dx.doi.org/10.1177/19417381221087245

INTRODUCTION

Subjective and objective measures [eg, session rating of perceived exertion (sRPE) and player tracking data] of training load have been used to help identify relationships with injury across team sports.[13,18,27,28,35] These can be defined according to external load (physical work prescribed in the training plan) and internal load (the psychophysiological response to external load).[22] The majority of the research has focused on relationships between training load and injury in the absence of conceptual frameworks [eg, linking mechanical loading (stress and strain) with tissue damage as precursors to injury[43] or aligning individual and contextual factors with both external and internal load, training effects over the acute and chronic periods and sport performance outcomes[24]]. Most studies to date have evaluated the load and injury relationship according to linear methods, despite empirical research demonstrating evidence of nonlinear (ie, U-[8] or J-curve[4]) relationships. A recent paper examining statistical methods for analyzing nonlinear relationships between load and injury in elite youth handball players[3] found evidence to support a nonlinear relationship between load (sRPE), using several analytical approaches. Although previous load and injury studies have identified linear and nonlinear relationships, none of these have adjusted for potential variables that could confound the load-injury relationship[26] such as responses to training and competition.[25]

How players respond or cope with training and competition is important, as this can affect their readiness for subsequent activities or predisposition and progression towards negative health outcomes such as injury. Further, an athlete's psychological readiness to perform has been linked with their subsequent performance.[20,37] Athlete self-reports have been used to identify players at risk of negative health,[39] including in elite junior team sport.[1,12,32] Customized athlete self-report measures are useful in monitoring the athlete response to training and competition.[10,41] Although these have received critique in their psychometric qualities (eg, content validity) and alignment with COSMIN guidelines,[25] they are reported as noninvasive, easy to administer, and sensitive to changes in load in competition.[41] Further, subjective measures (eg, self-reported stress, vigor, fatigue, and/or physical recovery) are as more responsive to short- and long-term training periods than those considered objective in nature (eg, inflammatory or muscle damage markers such creatine kinase)[41].

Various models have identified whether physical (fatigue and soreness)[26,42] or psychological (stress, mood, and sleep)[23,32] wellness factors are linked with injury.[21] Our research to date has highlighted a significant U-curve relationship between load and injury[31] as well as evidence of linear relationships between wellness and injury.[32] Such univariate associations between wellness and injury in team sport may not reflect the complex patterns of injury.[35] Therefore, analytical techniques such as synergistic modeling (moderation, mediation, mediating moderation) can help to establish these relationships from an ecological or systems perspective. Moderating (interaction) variables act as "dimmer switches," modifying the effect of a given variable on an outcome, eg, aerobic fitness protecting against spikes in load.[46] Mediating variables act to amplify or enhance certain relationships between other variables, eg, fatigue amplifying the effect of load on injury (akin to a "domino effect"); moderated mediation can occur when a variable acts to mediate a certain relationship while also directly moderating the strength of that relationship.[46] In the present study, wellness may act with both a "domino" and "dimmer switch" effect on the relationship between load and injury. Our research aims to clarify the relationships among load, wellness, and injury (represented diagrammatically in Figure 1). The specific aim was to investigate the relationships between measures of training load, player wellness, and injury in elite junior Australian football players using synergistic modeling to assess the direct effect as well as the moderation (interaction) and mediation (indirect effect), with key contributing load and wellness measures.

METHODS

Participants

In total, 562 players from 9 of the 12 under-18 state league clubs (mean age: 17.7 years, range 16-18 years; mean height: 188.4 cm, range 176.7-202.7 cm) provided informed consent and were subsequently granted access to an online monitoring tool of their club's choice (Athletic Logic, Google Forms, DropBox, or club-designed) to report their training and match loads, subjective wellness and identifiable injuries. Of these 562 players, 280 contributed load, wellness, and injury information, which could be subsequently analyzed, modeled, and reported from this research. All investigations conformed to the Code of Ethics of the World Medical Association (Declaration of Helsinki) and were approved by the Monash University Human Research Ethics Committee (MUHREC), with consent obtained from all participants.

Instrumentation

Training and match loads were assessed using the sRPE method using standard protocols.[13,14,22] From these sRPE ratings, several absolute and relative load measures were then calculated.[29] Players were asked to report wellness variables (sleep quality, fatigue, soreness, stress, and mood) 3 times a week according to a linear 5-point Likert scale, in accordance with previous literature[33] and consistent with recent studies in elite junior team sport.[37] Players were requested to enter their wellness and self-report injury information in the morning before training. If players were not able to do this, clubs set up suitable facilities for players to enter their data (eg, tablet, laptop), before commencing training. Practitioners, with practicum student support, were also asked to report injury information.

Procedures

Total wellness was determined for each player based on the sum of 5 variables and interpreted as a "higher-is-better" score.

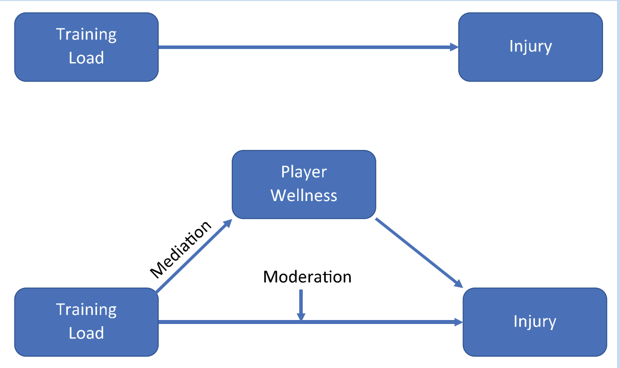

Figure 1. Univariate association between load and injury as well as mediation and moderation between load, wellness, and injury. Player wellness may act as a mediator, a moderator, or in combination (moderated mediation) on the effect of load on injury. Mediators are like "dominoes" and can help to explain why certain loads or changes in load may increase injury risk. Moderators are like "dimmer switches" and help to explain why some athletes are more robust and others more susceptible to injury than others in response to certain loads or changes in load.

Missing data were considered to be completely at random and, therefore, missing data were not imputed nor were considered interval censored. A new injury was defined as arising from a distinct initial injury event unrelated to any other injury, whereas a recurrent injury was defined as associated with a previously reported injury. In order to investigate injury risk (yes/no), only new injuries were used in the analysis. Injuries by reporter (staff vs player) were combined, where appropriate, to provide the precise number of injuries across the season and any injury defined as "recurrent" was cross-checked across medical staff reporting to ensure accuracy. An injury was recorded if the injury event led the player to miss a full training session or match.

Analysis

Initially, a total of 106,141 data points from 28 monitoring variables (outlined in Table 1) were collated into a customized spreadsheet (Microsoft Excel) for analysis. A principal component analysis (PCA) of the 28 monitoring variables was undertaken to identify uncorrelated components to represent distinct elements of the dataset (Online Appendix Table A1). All data were tested for sampling adequacy using the Kaiser-Meyer-Olkin (KMO) measure (=0.655, a threshold of 0.5) and for suitability for component analysis using the Bartlett Test of sphericity (significance accepted at $P \leq 0.05$). Monotony, percentage change in load, and the acute-to-chronic workload ratio variable were each removed from the model due to individual KMO measures substantially less than 0.5. A Varimax orthogonal rotation was used to enhance interpretation of the analysis, whereas principal components were determined by eigenvalues greater than 1, ranging from 3.0 (component 1, stress) to 1.4 (component 6, soreness). The rotated solution with the revised 6 component solution exhibited "simple structure" (69.2% of total variance, 17 variables). Only variables with a factor loading greater than 0.60 were reported (meaning that absolute change in load and 4-week load was not reported). These methods correspond with protocols described elsewhere.[44,45]

Logistic generalized estimating equation (GEE) models[47] were constructed to explain the relationship of load and wellness variables with the outcome variable being whether a player sustained an injury. Pretraining measures of wellness, measured at 3 time points across the week, and the consecutive training and match loads were modeled against injury. The GEE was chosen, as it considers the player based repeated-measures structure of load and wellness data across the season. As such, all models included a repeated measure effect (factor) to identify variance within players (player ID). The logistic link function was chosen for the GEE as the outcome measure, injury status, was binary (yes or no). Models were constructed using a stepwise approach,[9] where the addition of a covariate to the model was determined by both the significance of the Wald chi-square value ($P < 0.05$) and if the quasi-likelihood independence model criterion decreased (ie, model fit was improved). Beta values were converted into exponent values (Exp(β)) to enhance practical interpretation of results. A beta exponent value is an odds ratio (OR), with an OR of more than 1 demonstrating an increased probability of an outcome and ab OR less than 1 indicating a reduced probability of an outcome with the change in odds relative to every unit increase in the significant covariate. Further, 95% CIs were calculated to assess the precision of OR values. All GEE models were constructed using SPSS (Version 27.0, IBM). A 1-week lag was built into the injury modeling to distinguish load and wellness preceding injury rather than injured players then having lower loads, or impaired wellness following an injury event.

RESULTS

The descriptive statistics for the injury incidence, prevalence, severity, mechanism, and body region of injuries for this cohort are outlined in a previous paper (injury epidemiology).[30] This paper reports most injuries being new (87.3%), occurring during competition (86%), with more than half (51%) being contact in nature. Most injuries were to the lower limb (60%).

Univariate Relationships

In the absence of a dimension reduction approach (ie, PCA), load was associated with injury, with the form of the relationship supporting evidence of a U-curve relationship (Table 2). Further, wellness as a composite measure, as well as individual factors of stress, soreness, and fatigue demonstrated direct relationships with injury. As identified through the PCA

Table 1. Definition of load and wellness measures used in the PCA

Training Load or Wellness Measure	Definition
1. sRPE load 2. 1-week load *3. Monotony* 4. Strain 5. 2-week load 6. 3-week load *7. 4-week load* *8. Absolute change in load* *9. Percentage change in load* *10. Acute to chronic load ratio*	Borg CR-10 × Duration Total session load across the week Mean session load/standard deviation load 1-week load × monotony Sum of 1-week load for 2 consecutive weeks Sum of 1-week load for 3 consecutive weeks Sum of 1-week load for 4 consecutive weeks Current week's load subtracted from previous week's load Current week's load divided by previous week's load Current week's load divided by previous 4 week's load
Sleep quality	
11. 1 day postmatch *12. 3 days postmatch* *13. 6 days postmatch/1 day prematch*	1 to 5 Likert scale, 1 = very poor sleep quality and 5 = maximal sleep quality.
Fatigue	
14. 1 day postmatch *15. 3 days postmatch* *16. 6 days postmatch/1 day prematch*	1 to 5 Likert scale, 1 = very low fatigue and 5 = maximal fatigue.
Soreness	
17. 1 day postmatch 18. 3 days postmatch 19. 6 days postmatch/1 day prematch	1 to 5 Likert scale, 1 = very low soreness and 5 = maximal soreness.
Stress	
20. 1 day postmatch 21. 3 days postmatch 22. 6 days postmatch/1 day prematch	1 to 5 Likert scale, 1 = very low stress and 5 = maximal stress.
Mood	
23. 1 day postmatch 24. 3 days postmatch 25. 6 days postmatch/1 day prematch	1 to 5 Likert scale, 1 = very low mood state and 5 = maximal mood state.
Sleep duration	
26. 1 day postmatch 27. 3 days postmatch 28. 6 days postmatch/1 day prematch	Number of hours slept previous night
Composite wellness measure	Sum of rating for each wellness variable (not including sleep duration)

Note: Values in italics were removed from the PCA due to KMO <0.5: monotony, percentage change in load and the ACWR; and factor load <0.6, interpretability due to "complex structure": sleep quality and fatigue at all 3 time points; 4-week load and absolute change in load. Therefore, 17 constructs were considered in the final PCA model. KMO, Kaiser-Meyer-Olkin; PCA, principal component analysis; sRPE, session rating of perceived exertion.

(outlined in Tables A2 and A3 in the Online Appendix), the stress component (consisting of stress 1 day post-match, 3 days post-match, 6 days post-match) displayed a positive relationship with the occurrence of injury (OR 1.58; 95% CI 1.11-2.23). The individual measure of stress 3 days postmatch also demonstrated a positive relationship with injury (OR 1.55; 95% CI 1.08-2.23). The individual components of sleep duration (OR 0.75; 95% CI 0.55-1.01; $P = 0.06$) and soreness (OR 1.25; 95% CI

Table 2. Univariate relationships between load and injury, as well as wellness and injury, according to nondimension reduction and dimension reduction (PCA) approach. Data only presented for significant ($P < 0.05$) results. See Tables A2 and A3 in the online Appendix for all findings from the GEE analysis

Model	Exp(β)	95% CI	*P* value
Nondimension reduction approach			
Load			
Linear	0.60	0.40-0.90	0.01
Quadratic	1.59	1.05-2.40	0.03
Wellness (across 3 time points)[a]			
Composite	0.79	0.67-0.93	0.01
Stress	1.44	1.24-0.67	<0.00
Soreness	1.17	1.03-1.32	0.01
Fatigue	1.21	1.04-1.39	0.01
Dimension reduction (PCA) approach			
Model 1 (stress component, 1, 3, 6 days postmatch)	1.58	1.11, 2.23	0.01
Model 2 (stress at 3 days postmatch only)	1.55	1.08, 2.23	0.02

GEE, generalized estimating equation; PCA, principal component analysis.
[a]Wellness: average of values across the week, with composite measure including original 5 items (sleep quality, fatigue, soreness, stress, and mood).

0.99-1.57; $P = 0.07$) appeared to be of practical interest as the CIs were close to not overlapping 1.0 and the significance values close to 0.05.

Multivariate Relationships

When evaluating load and wellness overall, there was a significant interaction between load and wellness in their relationship with injury (OR 0.76; 95% CI 0.62-0.92; $P < 0.01$), indicating the regression weight of load on injury varied as a function of wellness (ie, with wellness acting as a moderator), as listed in Table 3. Figure 2 demonstrates the influence of wellness on load and injury, where a player's risk of injury along the U-curve relationship between load and injury is more likely to increase at an earlier point in those with lower wellness compared with players who maintain their wellness. When wellness is low, injury risk starts to increase substantially at a 1-week load of 3250 au (see Figure 2A). There was also evidence of moderated mediation (OR 0.71; 95% CI 0.57-0.87; $P < 0.01$), which appeared to demonstrate through the indirect pathway between load and injury (ie, mediation) an attenuation of the amplification effect of wellness on load and injury (ie, moderation model alone). Figure 2B demonstrates the delineation point between those with lower wellness to be later (~3750 au) that than outlined in Figure 2A.

Further, using the dimension reduction (ie, PCA) approach and analyzing via GEE, the soreness and sleep duration components were found to be mediators on the stress and injury relationship (Wald chi-square increased from 6.60 to 6.92 for soreness, but decreased from 6.60 to 6.17 for sleep), as shown in Figure 3. This demonstrates that increased soreness increased the relationship between stress and injury (ie, a slight increase in the chi-square), whereas increased sleep duration, decreased the relationship between stress and injury (ie, a slight decrease in the chi-square). This was further identified when evaluated as an individual component from the PCA (ie, soreness and sleep duration at 3 days postmatch) where the Wald chi-square value for soreness increased from 5.6 to 5.9 and decreased from 5.6 to 6.2 for sleep duration. This demonstrates that although players with higher soreness values who are stressed may have a higher risk of injury, players who have better sleep habits but are stressed may be able to attenuate their risk of injury.

DISCUSSION

The aim of the present study was to assess the relationships between load, wellness and injury in elite junior Australian Football players and build on earlier research identifying a U-curve relationship between load and injury.[31] This study identified that although load is directly associated with injury, poor wellness can amplify this relationship (ie, act as a moderator variable). In the instance of 2 players at the same

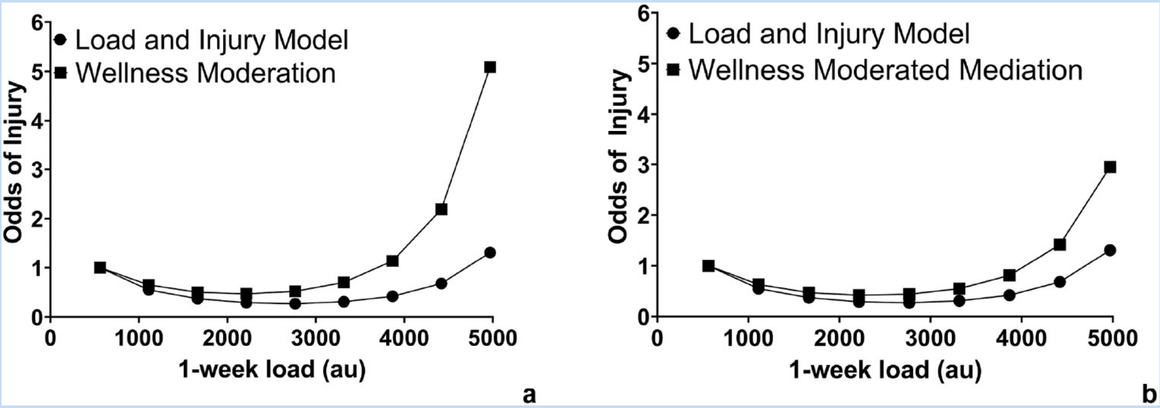

Figure 2. The odds of injury for 1-week load according to (A) the wellness moderation model and (B) the wellness mediating moderation model. The initial effect between load and injury is greater when interactions with wellness are added (as wellness is also associated with injury risk). For example, in the moderation model in (A), an athlete who has poor wellness as a response to high loads will be more susceptible to injury. In (B), the addition of wellness increases the risk of injury at higher loads, yet in a moderated mediation approach the amplification effect of wellness in the moderation model alone is attenuated by the indirect pathway between load and injury (mediation). In this case, load is associated with injury and wellness is associated with injury; however, the effect of wellness in a causal sequence (ie, domino effect) is not as pronounced as that of wellness acting to amplify (moderate) load and injury.

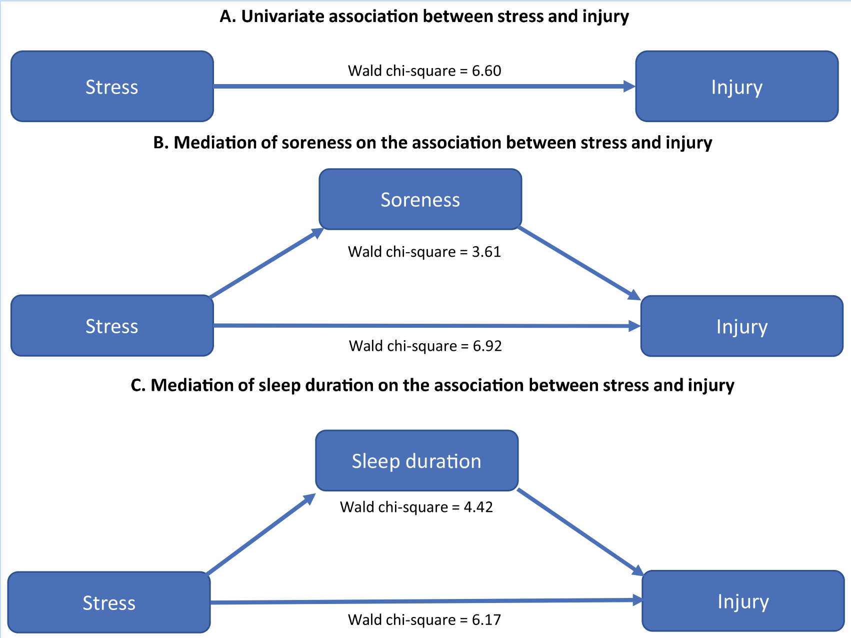

Figure 3. (A) Direct effect of stress on injury demonstrating a statistically significant relationship. Given the significant relationship between stress and injury, each individual wellness item was then assessed for their mediation and moderation effects. (B) When soreness was added to the stress-injury relationship, there was a significant mediation effect from soreness on the stress and injury relationship. This indicates that when a player is stressed, higher levels of soreness can act in sequence to increase the risk of injury further. (C) When sleep duration was added to the stress-injury relationship there was a significant mediation effect from sleep duration on the stress and injury relationship. This indicates that when a player is stressed, better sleep habits (ie, longer sleep) can act in sequence to reduce the effect of stress on the risk of injury.

load, a player with impaired wellness will be at greater risk of injury than one who maintains a constant level of wellness (see Figure 2). Further, by using a dimension reduction approach (ie, PCA in this research), individual wellness variables such as stress, soreness, and sleep have been identified as associated with injury, particularly at the midpoint of the weekly competitive cycle. This is important as previous work has highlighted that players at this level experience high loads (eg, on average 637 au in under-18 state league matches and 452 au in state league training sessions) across several training modes and various levels of competition.[29] This study also demonstrates that soreness and sleep can mediate the stress-injury relationship, indicating that recovery strategies focused on both psychological aspects (eg, stress) and physiological recovery and restorative aspects (eg, muscle soreness and sleep) may assist in reducing a player's predisposition to injury, particularly at higher weekly loads.

The present study was able to contribute further to the literature by supporting the hypothesis that although load and injury are associated, wellness acts to influence this relationship. In doing so, when a player has a degree of wellness that is impaired in contrast to their baseline or that of their peers, they are at a higher risk of injury at moderate to heavy loads. By acting as a moderator variable that can amplify or dampen the U-curve relationship between load and injury, coaches can monitor player wellness (including sleep, fatigue, stress, and soreness) to help identify a potential increased risk of injury, particularly at higher levels of training load (>4000 au). In addition to using wellness as a composite measure, through the use of a PCA, this research has identified single-item questionnaires such as stress, soreness, and sleep, at different time points across the week, as useful in monitoring the response to training and competition. Therefore, there is now evidence to suggest that monitoring these variables once a week (most likely 3 days postmatch) is sufficient in elite junior football and will reduce the burden on both players and coaches; although, load still needs to be monitored daily to quantify total load exposure throughout the week.

Recent literature outlining the preparation of athletes for major international competition, has highlighted key links between stress and other recovery aspects such as sleep.[19] For example, higher stress state and perceived stress were associated with poorer sleep, regardless of sport or gender. Such monitoring can be useful in enabling action in terms of training prescription and athlete management, consistent with contemporary conceptual frameworks outlining how individual and contextual factors contribute to training prescription, training effects and sport performance outcomes.[24] In such cases of impaired wellness, these individual and contextual factors could be addressed through a range of preventive measures. For example, relaxation strategies such as mindfulness training have potential to assist with performance improvements across a range of sports.[5,7] Further, repeated and regular exposure to manageable amounts of high-speed running and eccentric loading, alongside appropriate recovery strategies,[2] can help to minimize muscle damage and player reported soreness[16] and decrease injury risk. Improving sleep quantity and/or quality through sleep hygiene strategies[19,21,34] has the potential to improve overall wellness and, therefore, help to reduce the risk of injury, as identified in previous research,[21] and supported here.

From a practical standpoint, recent efforts to help guide interpreting and applying training monitoring data[15] have aligned both external and internal load with perceptual wellness and an athlete's readiness to train or compete. In doing so, the authors recommended making adjustments to training based on an athlete's response (ie, internal load, wellness, readiness) to external load. If, for example, an athlete is exposed to a high external load but reports low internal load and stable or positive self-reports, the recommendation might be to increase external load on the assumption that a higher load can be tolerated. In contrast, high loads that are not well tolerated, indicated by high internal loads and impaired wellness, suggest a more conservative approach to training prescription.

Synergistic modeling in the present study was used to evaluate the influence of key variables. As identified by Figure 2, there was evidence of both an interaction effect (moderation) and moderated mediation for wellness on the load-injury relationship. These combined approaches demonstrate that although univariate analyses can be useful, statistical approaches that address not only the sequential relationships between variables (ie, mediation: load → wellness → injury) but interactive and combined links can help to explain these constructs.[36] In fact, given the confusion regarding specific terms in applied sports science/medicine, it is advisable that the goals of research be more clearly defined according to whether they aim to describe variables (ie, how may athletes sustain injury), predict who is at the risk of injury or understand why an injury occurs.[36] The present research provides key contributions to help answer the question of why injury might occur in some players but not others when exposed to moderate and high loads (ie, a player at increased injury risk when self-reported wellness suggests a sustained poor response or delayed recovery).

LIMITATIONS

Our research supports existing recommendations on the use of self-report measures (individual and combined) to monitor recovery in team sport athletes[41] as they are easy to use, cost-effective, simple, and sensitive to alterations in training variables and competition.[26] Although practically useful and a well-supported method to enhance athlete, coach, and support staff communication,[11,40] we acknowledge the need for further rigorous validation to help address current psychometric limitations[6,12,25,39] and improve clinical utility[10] associated with wellness measures. In addition to concerns in relation to the psychometric qualities (eg, content validity) of self-report measures such as the wellness scale used in this study and alignment with relevant guidelines (eg, COSMIN),[25] the definition of wellness as a construct and how it may differ from other similar constructs such as "well-being" is complex and presents as an issue needing clarification.[17] Therefore, continued efforts are needed to (1) further clarify the construct of wellness, (2) improve the identification of the psychometric properties of single-item measures of wellness, and (3) identify conceptually how wellness factors (eg, soreness, fatigue, and stress) as measures of training effects may integrate with external and internal measures of load as well as readiness for training and competition. This research focuses on load, wellness and injury information reported during the 2014 season; however, the results and applications are still relevant, with the implications from this research being a key contribution to the literature focusing on elite junior team sport athletes.

PRACTICAL APPLICATIONS

The present research builds on the evidence of a nonlinear relationship between load and injury[31] and that impaired wellness (as a composite and single-item measures) is linked to increased injury risk.[21,32] Further, by influencing player wellness coaches may reduce the risk of injury at high loads. This research extends recommendations[9,38] that wellness data be reported using an easy-to-administer index on a semiregular basis, by suggesting players report their wellness once a week (at the midpoint of the week, usually 3 days postmatch), alongside daily load monitoring. Further, we recommend monitoring of specific wellness measures (stress, soreness, and sleep) to help detect where there are any underlying issues requiring further investigation. An example of this may be when high loads are not well tolerated, as indicated by high internal loads and impaired wellness. In such cases, a more conservative approach to training prescription may be required.

CONCLUSIONS

This research identified that although load is directly associated with injury, poor wellness can amplify this relationship (ie, act as a moderator variable). Further, there is evidence that higher stress is linked with injury and that soreness and sleep mediates the stress-injury relationship. Coaching efforts to manage training load and how players cope and respond to load may help to reduce the risk of injury.

ORCID ID

Timothy J.H. Lathlean https://orcid.org/0000-0001-7340-1567

REFERENCES

1. Abbott W, Brownlee TE, Harper LD, Naughton RJ, Clifford T. The independent effects of match location, match result and the quality of opposition on subjective wellbeing in under 23 soccer players: a case study. *Res Sports Med.* 2018;26:262-275.
2. Akinci B, Zenginler Yazgan Y, Altinoluk T. The effectiveness of three different recovery methods on blood lactate, acute muscle performance, and delayed-onset muscle soreness: a randomized comparative study. *J Sports Med Phys Fitness.* Mar 2020;60:345-354.
3. Bache-Mathiesen LK, Andersen TE, Dalen-Lorentsen T, Clarsen B, Fagerland MW. Not straightforward: modelling non-linearity in training load and injury research. *BMJ Open Sport Ex Med.* 2021;7e001119.
4. Blanch P, Gabbett TJ. Has the athlete trained enough to return to play safely? The acute:chronic workload ratio permits clinicians to quantify a player's risk of subsequent injury. *Br J Sports Med.* 2016;50:471-475.
5. Buhlmaer L, Birrer D, Rothlin P, Faude O, Donath L. Effects of mindfulness practice on performance - relevant parameters and performance outcomes in sports: a meta-analytical review. *Sports Med.* 2017;47:2309-2321.
6. Carling C, Lacome M, McCall A, et al. Monitoring of post-match fatigue in professional soccer: welcome to the real word. *Sports Med.* 2018;48:2695-2702.
7. Coimbra DR, Bevilacqua GG, Pereira FS, Andrade A. Effect of mindfulness training on fatigue and recovery in elite volleyball athletes: a randomized controlled follow-up study. *J Sports Sci Med.* 2021;20:1-8.
8. Cross MJ, Williams S, Trewartha G, Kemp SPT, Stokes KA. The influence of in-season training loads on injury risk in professional rugby union. *Int J Sports Phys Perf.* 2016;11:350-355.
9. Crowcroft S, Slattery K, McCleave E, Coutts AJ. Do athlete monitoring tools improve a coach's understanding of performance change? *Int J Sports Phys Perf.* 2020;15:847-852.
10. Duignan C, Doherty C, Caulfield B, Blake C. Single-item self-report measures of team-sport athlete wellbeing and their relationship with training load: a systematic review. *J Athl Train.* 2020;55:944-953.
11. Duignan CM, Slevin PJ, Caulfield BM, Blake C. Exploring the use of mobile athlete self-report measures in elite Gaelic games: a qualitative approach. *J Strength Cond Res.* 2021;35(12):3491-3499.
12. Fitzpatrick JF, Akenhead R, Russell M, Hicks KM, Hayes PR. Sensitivity and reproducibility of a fatigue response in elite youth football players. *Sci Med Football.* 2019;3:214-220.
13. Foster C, Boullosa D, McGuigan M, et al. 25 years of session rating of perceived exertion: historical perspective and development. *Int J Sports Phys Perf.* 2021;16:612-621.
14. Foster C, Florhaug JA, Franklin J, et al. A new approach to monitoring exercise training. *J Strength Cond Res.* 2001;15:109-115.
15. Gabbett TJ, Nassis GP, Oetter E, et al. The athlete monitoring cycle: a practical guide to interpreting and applying training monitoring data. *Br J Sports Med.* 2017;51:1451.
16. Gastin PB, Hunkin SL, Farhner B, Robertson S. Deceleration, acceleration and impacts are strong contributors to muscle damage in professional Australian football. *J Strength Cond Res.* 2020;33:3374-3383.
17. Giles S, Fletcher D, Arnold R, Ashfield A, Harrison J. Measuring well-being in sport performers: where are we now and how do we progress? Review. *Sports Med.* 2020;50:1255-1270.
18. Griffin A, Kenny IC, Comyns TM, Lyons M. The association between the acute:chronic workload ratio and injury and its application in team sports: a systematic review. *Sports Med.* 2020;50:561-580.
19. Halson SL, Appaneal RN, Welvaert M, Maniar N, Drew MK. Stressed and not sleeping: poor sleep and psychological stress in elite athletes prior to the Rio 2016 Olympic Games. *Int J Sports Physiol Perform.* 2022;17:195-202.
20. Hills SP, Rogerson DJ. Associations between self-reported well-being and neuromuscular performance during a professional rugby union season. *J Strength Cond Res.* 2018;32:2498-2509.
21. Horgan BG, Drew MK, Halson SL, et al. Impaired recovery is associated with increased injury and illness: a retrospective study of 536 female netball athletes. *Scand J Med Sci Sports.* 2021;31:691-701.
22. Impellizzeri FM, Marcora SM, Coutts AJ. Internal and external training load: 15 years on. *Int J Sports Phys Perf.* 2019;14:270-273.
23. Ivarsson A, Johnson U, Andersen MB, Tranaeus U, Stenling A, Lindwal M. Psychosocial factors and sport injuries: meta-analyses for prediction and prevention. *Sports Med.* 2017;47:353-365.
24. Jeffries AC, Marcora SM, Coutts AJ, Wallace L, McCall A, Impellizzeri FM. Development of a revised conceptual framework of physical training for use in research and practice [published online ahead of print, 2021 Sep 14]. *Sports Med.* 2021;10.1007/s40279-021-01551-5.
25. Jeffries AC, Wallace L, Coutts AJ, McLaren SJ, McCall A, Impellizzeri FM. Athlete-reported outcome measures for monitoring training responses: a systematic review of risk of bias and measurement property quality according to the COSMIN guidelines. *Int J Sports Phys Perf.* 2020;15:1203-1215.
26. Jones CM, Griffiths PC, Mellalieu SD. Training load and fatigue marker associations with injury and illness: a systematic review of longitudinal studies. *Sports Med.* 2017;47:943-974.

27. Kalkhoven JT, Watsford ML, Coutts AJ, Edwards WB, Impellizzeri FM. Training load and injury: causal pathways and future directions. *Sports Med.* 2021;51:1137-1150.
28. Kupperman N, Hertel J. Global positioning system-derived workload metrics and injury risk in team-based field sports: a systematic review. *J Athl Train.* 2020;55:931-943.
29. Lathlean TJH, Gastin PB, Newstead SV, Finch CF. Elite junior Australian football players experience significantly different loads across levels of competition and training modes. *J Strength Cond Res.* 2018;32:2031-2038.
30. Lathlean TJH, Gastin PB, Newstead SV, Finch CF. The incidence, prevalence, severity, mechanism and body region of injury in elite junior Australian football players: a prospective cohort study over one season. *J Sci Med Sport.* 2018;21:1013-1018.
31. Lathlean TJH, Gastin PB, Newstead SV, Finch CF. Absolute and relative load and injury in elite junior Australian football players over 1 season. *Int J Sports Phys Perf.* 2019;15:511-519.
32. Lathlean TJH, Gastin PB, Newstead SV, Finch CF. Player wellness (soreness and stress) and injury in elite junior Australian football players over 1 season. *Int J Sports Phys Perf.* 2020;15:1422-1429.
33. McLean BD, Coutts AJ, Kelly V, McGuigan MR, Cormack SJ. Neuromuscular, endocrine and perceptual fatigue responses during different length between-match microcycles in professional rugby league players. *Int J Sports Phys Perf.* 2010;5:367-383.
34. Nedelec M, Halson SL, Delecroix B, Abd-Elbasset A, Ahmaidi S, Dupont G. Sleep hygiene and recovery strategies in elite soccer players. *Sports Med.* 2015;45:1547-1559.
35. Nielsen RO, Bertelsen ML, Møller M, et al. Training load and structure-specific load: applications for sport injury causality and data analyses. *Br J Sports Med.* 2018;52:1016-1017.
36. Nielsen RO, Simonsen NS, Casals M, Stamatakis E, Mansournia MA. Methods matter and the 'too much, too soon' theory (part 2): What is the goal of your sports injury research? Are you describing, predicting or drawing a causal inference? *Br J Sports Med.* 2020;54:1307-1309.
37. Ramírez-López C, Till K, Weaving D, et al. Does perceived wellness influence technical-tactical match performance? A study in youth international rugby using partial least squares correlation analysis [published online ahead of print, 2021 Jun 22]. *Eur J Sport Sci.* 2021;1-9.
38. Ryan S, Kempton T, Impellizzeri FM, Coutts AJ. Training monitoring in professional Australian football: theoretical basis and recommendations for coaches and scientists. *Sci Med Football.* 2020;4:52-58.
39. Saw AE, Kellmann M, Main LC, Gastin PB. Athlete self-report measures in research and practice: considerations for the discerning reader and fastidious practitioner. *Int J Sports Phys Perf.* 2016;12:S2127-S2135.
40. Saw AE, Main LC, Gastin PB. Role of a self-report measure in athlete preparation. *J Strength Cond Res.* Mar 2015;29:685-691.
41. Saw AE, Main LC, Gastin PB. Monitoring the athlete training response: subjective self-reported measures trump commonly used objective measures: a systematic review. *Br J Sports Med.* 2016;50:281-291.
42. Thorpe RT, Strudwick AJ, Buchheit M, Atkinson G, Drust B, Gregson W. The influence of changes in acute training load on daily sensitivity of morning-measured fatigue variables in elite soccer players. *Int J Sports Phys Perf.* 2017;12:S2107-S2113.
43. Vanrenterghem J, Nedergaard NJ, Robinson MA, Drust B. Training load monitoring in team sports: a novel framework separating physiological and biomechanical load-adaptation pathways. *Sports Med.* 2017;47:2135-2142.
44. Weaving D, Dalton NE, Black C, et al. The same story or a unique novel? Within-participant principal-component analysis of measures of training load in professional rugby union skills training. *Int J Sports Phys Perf.* 2018;13:1175-1181.
45. Williams S, Trewartha G, Cross MJ, Kemp SPT, Stokes KA. Monitoring what matters: a systematic process for selecting training-load measures. *Int J Sports Phys Perf.* 2017;12:101-106.
46. Windt J, Zumbo BD, Sporer BC, Macdonald KJ, Gabbett TJ. Why do workload spikes cause injuries, and which athletes are at higher risk? Mediators and moderators in workload-injury investigations. *Br J Sports Med.* 2017;51:993-994.
47. Zeger SL, Liang KY, Albert PS. Models for longitudinal data: a generalized estimating equation approach. *Biom.* 1988;44:1049-1060.