Journal Pre-proof

General health complaints and sleep associated with new injury within an endurance sporting population: A prospective study

R. Johnston, R. Cahalan, L. Bonnett, M. Maguire, P. Glasgow, S. Madigan, K. O'Sullivan, T. Comyns

PII: S1440-2440(18)30854-5

DOI: https://doi.org/10.1016/j.jsams.2019.10.013

Reference: JSAMS 2184

To appear in: *Journal of Science and Medicine in Sport*

Received Date: 6 September 2018

Revised Date: 8 October 2019

Accepted Date: 22 October 2019

Please cite this article as: Johnston R, Cahalan R, Bonnett L, Maguire M, Glasgow P, Madigan S, O'Sullivan K, Comyns T, General health complaints and sleep associated with new injury within an endurance sporting population: A prospective study, *Journal of Science and Medicine in Sport* (2019), doi: https://doi.org/10.1016/j.jsams.2019.10.013

General health complaints and sleep associated with new injury within an endurance sporting population: A prospective study

Authors:

R. Johnston[a,i], R. Cahalan[b,c], L. Bonnett[d], M. Maguire[e], P. Glasgow[g], S. Madigan[f], K. O'Sullivan[b,c,h,], T. Comyns[a,c]

[a] Department of Physical Education and Sport Sciences, University of Limerick, Ireland

[b] School of Allied Health, University of Limerick, Ireland

[c] Health Research Institute, University of Limerick, Ireland

[d] Department of Biostatistics, University of Liverpool, Liverpool, Merseyside, United Kingdom

[e] Ulster Rugby, Irish Rugby Football Union, Kingspan Stadium, Belfast, N.Ireland

[f] Sport Ireland Institute, National Sports Campus, Abbotstown, Dublin 15, Ireland

[g] Irish Rugby Football Union, Lansdowne Road, Dublin 4, Ireland

[h] Sports Spine Centre, Aspetar Orthopaedic and Sports Medicine Hospital, Doha, Qatar

[i] La Trobe Sport and Exercise Medicine Research Centre, School of Allied Health, La Trobe University, Bundoora, Australia

Corresponding Author:

Richard Johnston

Department of Physical Education and Sport Sciences, University of Limerick, Ireland.

Tel: +447874006506

Email: Richard.Johnston@ul.ie

Abstract

Objective: To examine the association between subjective health complaints, sleep quantity and new injury within an endurance sport population.

Design: Prospective cohort study.

Methods: Ninety-five endurance sporting participants were recruited from running, triathlon, swimming, cycling and rowing disciplines. Over 52-week period participants submitted weekly data regarding subjective health complaints (SHCs) (cardiorespiratory, gastrointestinal and psychological/lifestyle), sleep quantity, training load and new injury episodes. Applying a 7- and 14-day lag period, a shared frailty model was used to explore new injury risk associations with total SHCs and sleep quantity.

Results: 92.6% of 95 participants completed all 52 weeks of data submission and the remainder of the participants completed ≥ 30 weeks. Seven-day lag psychological/lifestyle SHCs were significantly associated with new injury risk (Hazard ratio (HR)=1.32; CI 95%=1.01-1.72, p<0.04). In contrast, cardiorespiratory (HR=1.15; CI 95%=0.99-1.36, p=0.07) and gastrointestinal (HR=0.77; CI 95%=0.56-1.05, p=0.09) SHCs were not significantly associated with new injury risk. New injury risk had a significant increased association with 14-day lag <7hrs/day sleep quantity (HR=1.51; CI 95%=2.02-1.13, p<0.01) and a significant decreased association with >7hrs/day sleep quantity (HR=0.63, CI 95%=0.45-0.87, p<0.01. A secondary regression analysis demonstrated no significant association with total SHCs and training load factors (Relative Risk (RR)=0.08, CI 95%=0.04-0.21, p=0.20).

Conclusions: To minimise an increased risk of new injuries within an endurance sporting population, this study demonstrates that psychological/lifestyle subjective health complaints and sleep quantity should be considered. The study also highlights a lag period between low sleep quantity and its subsequent impact on new injury risk. No association was demonstrated between subjective health complaints, sleep quantity and training load factors.

1.0 Introduction

Injury presents a significant health burden to sporting populations influencing both training and competition performance outcomes.[1] Systematic reviews show injury to be a common reason for endurance sporting populations (ESPs) to avoid, or adapt, training load.[1, 2] ESPs are a unique sporting population due to the diversity of disciplines undertaken (e.g. swimming, cycling, triathlon, running and rowing). With the current popularity of single and multidiscipline endurance events[3] it is important to consider the injury profile unique to ESPs' training and competition. Across these endurance disciplines, risk factors for injury are multifactorial and typically classified as extrinsic (factors independent of the athlete) or intrinsic (factors inherent to the athlete).[4] The complex and multifactorial aetiology of injury risk within ESPs and non-ESPs is reflected in Wiese-Bjornstal's sport injury risk model which identifies biological (e.g. nutrition), physical (e.g. training, competition), psychological (e.g. mood state, stressors) and sociocultural (e.g. social pressures) risk factors for injury.[5]

Thygesen et al[6] have defined subjective health complaints (SHCs) as self-reported health concerns which could reflect subjective feelings of being unwell or in distress as much as actual disease. The Subjective Health Complaints Inventory is a validated tool used to measure the occurrence and severity of SHCs in non-ESPs.[7] Previous studies[6, 7] utilising the SHCs inventory have categorised SHCs as cardiorespiratory (e.g. palpitations/ extra heart beats), gastrointestinal (e.g. diarrhoea), and psychological/lifestyles SHCs (e.g. anxiety). A high prevalence of cardiorespiratory SHCs (30-61%),[3, 8] gastrointestinal SHCs (65-84%)[8] and psychological/lifestyle SHCs (26-68%)[9] have been reported within ESPs and non-ESPs.

ESP and non-ESP studies have demonstrated that SHCs may negatively impact upon training load.[3, 7] A recent study of 7000 distance runners[3] found those who reported cardiorespiratory SHCs before an endurance race were 2–3 times less likely to complete the race. They also found a decrease in training load for 2–4 days following recovery from a cardiorespiratory SHC.[3] Another study of 30 triathletes found that psychological/lifestyles SHCs, such as depressed mood and sleep disturbance, had a greater impact than training load factors on injury incidence.[10] Due to the potential negative impact of SHCs on training load, studies[11, 12] have proposed that SHCs may be a risk factor for new injury. However there has been limited prospective ESP research[10] undertaken to date to confirm this association.

Alongside SHCs, sleep is regarded as a vital component of athlete recovery, wellbeing and sport performance.[7, 13] Previous studies have identified poor sleep in up to 85% of ESPs and 47.8% of non-ESPs.[7] Sleep can be defined by different parameters including sleep quantity,[14-16] quality,[11, 14] and efficiency.[16] Measurement of sleep quantity has been shown to predict injury risk in a mixed study[15] of adolescent ESP and non-ESP, however this association has not been demonstrated in two other non-ESP studies.[12, 16] Despite this an International Olympic Consensus statement recognised that 'given the potential consequences of insufficient sleep on health, behaviour, attention and athletic performance, interventions to support adequate sleep should be implemented'.[17] To our knowledge there is no prospective study which has investigated the association between sleep quantity and new injury risk within an ESP.

The primary aim of this prospective study was to examine new injury risk associations with total SHCs, SHC subscales (cardiorespiratory, gastro-intestinal, psychological/lifestyle) and sleep quantity. A secondary aim was to identify if there was an association between total SHCs, sleep quantity and training load factors.

2.0 Methods

From 15 ESP clubs in Ireland, 116 participants (range = 3-19 per club) (Mean age 42±10 years, mean endurance sport training experience 9±7 years and mean weekly number of training sessions per week 5±2) were initially recruited by the lead author who met with each club face to face. Other than age (18-65 years) whereby 3 participants were excluded (2 <18 years and 1 >65 years), no other exclusion criteria were applied. Using no standardised definition, participants subjectively reported their competitive training level as elite (5%) or recreational (95%). Over a 52-week period the participants utilised a weekly electronic online 'training diary' to subjectively report validated training data on; (1) each training/competition event, (2) day of the week, (3) session type (e.g. running, swimming), (4) duration (minutes), (5) distance (meters/kilometers) and (6) session intensity (session training load (session Rating of Perceived Exertion (sRPE)) (Borg CR-10 scale), (7) SHCs and (8) sleep quantity per day over each week/weekend day (hours per day (hrs/d)).[18] Participants had unlimited access to update the weekly electronic training diary. Participants received an email with a link to the diary on the Sunday of each training week and an email reminder four days later from the lead author (RJ). Participants also subjectively recorded any injury episode by body location each week. Twenty-one participants were removed due to submitting insufficient data (<30 weeks of complete data) resulting in a final study population of 95 participants across five endurance disciplines (table 1). Ethical approval was granted by a local university and face to face written and informed consent was provided by all participants.

16 of 29 potential SHCs were selected a priori for relevance and convenience.These were collected based on the validated SHC inventory which has been used previously in non-ESP based studies.[7, 11] Participants were asked to select (yes/no) if they had experienced any of the following SHC inventory items during that training week: Cardiorespiratory SHCs (palpitations/extra heart beats, chest pain, heart burn and breathing difficulty), Gastrointestinal SHCs (stomach discomfort, diarrhoea, constipation and low appetite) and Psychological/lifestyle SHCs (anxiety, sadness/depression, low mood, dizziness, tiredness, sleep problems or low energy). The total number of SHCs were calculated over the 52-week period and a mean was generated. Total SHCs were then sub-categorised to provide a number for each SHC subscale reported: cardio-respiratory, gastro-intestinal or psychological/lifestyle SHCs.

Seven hours sleep per day was selected as the reference value based on the median (6.9hrs/d) sleep quantity over a week/weekend within the ESP. To aid analysis, sleep quantity was categorised as < 7hrs/d or >7 hrs/d. These categories were selected to ensure even distribution of the study population across the sleep quantity categories (table 2). To identify if SHCs and sleep quantity significantly contributed to the onset of a new injury episode, a 7 and 14-day time lag was implemented.[19] This means that if a new injury episode was reported in week 10, then SHCs and sleep quantity were analysed for week 9 (i.e. 7-day lag) and week 8 (i.e. 14-day lag) (supplementary figure 2). SHC and sleep quantity from the same week as the reported new injury episode were not analysed as it would be unclear if the SHCs or sleep quantity contributed to, or were the result of, the new injury episode.

A new injury episode was defined as any physical musculoskeletal complaint/impairment, solely due to participation in endurance discipline training and/or competition. A new injury episode may have caused the participant to either not continue to train/compete fully or caused reduced or missed time from training/competition.[20, 21] This definition was provided to participants in the electronic training diary. If a participant reported an initial injury episode in a particular body location it was categorised as a new injury episode. If the participant, then reported another injury episode in the same body location within the subsequent four weeks it was not included as a new injury episode during analysis.

Total SHCs, SHC subscales and ESP baseline characteristics were analysed with chi-squared tests and Fisher's exact tests which summarised normally distributed data as mean and standard deviations and skewed continuous data as median and interquartile ranges. Differences between endurance athlete subgroups, according to continuous variables, were assessed via analysis of variance (table 1). New injury rates were expressed as the total number of new injuries/total number of training sessions performed and reported per 1000 hours of training. Missing data (<5%) was attributed to the participants being unavailable to submit weekly SHCs and sleep data. A variety of options of single imputation ranging from mean and median imputation through to last observation carried forward and regression imputation were considered. Regression imputation was avoided due to the complexity of the approach within a frailty model setting. Last observation carried forward was also discounted on expert advice (LB) that weekly SHC and sleep data varied. Therefore, to account for participants missing data (<5% for each variable) a median response was inputted as the most appropriate option.

Based on previous studies using multilevel analysis approaches within medical[22] and sport medicine research,[4] a shared frailty model using random effects following a gamma distribution, with a mean equal to one and unknown variance to account for the within participant correlation between new injury episodes, was conducted. A restricted maximum likelihood criterion was used to choose the variance of the random effect. Results were presented as Hazard Ratios (HRs) with 95% confidence intervals and a p value (≤ 0.05) indicating results of statistical significance. A parsimonious model was built from a pool of eleven variables (7 and 14-day lag Total SHC, 7 and 14-day lag Cardiorespiratory SHC, 7 and 14-day lag Gastrointestinal SHC, 7 and 14-day lag Psychological/lifestyle SHC, 7 and 14-day lag Sleep quantity and Endurance athlete subgroups) via backwards selection according to Akaike's Information Criterion. Continuous variables were investigated using fractional polynomial transformations with results presented as post-hoc defined categorical variables and categories chosen according to knot positions for a spline model fit to the data. A multi-level linear regression sub-analysis was conducted to identify the influence of training load factors prior to, and after, the SHC was reported, with results reported as Relative Risks (RR).

Discrimination of the parsimonious model was assessed using the c-statistic. Discrimination refers to the ability of the prognostic model to differentiate between those who reported a new injury during the study and those who did not. The c-statistic is equivalent to the area under the Receiver Operator Characteristic (ROC) curve and is measured on a scale ranging from 0.5 (no better than chance) to 1 (perfect prognostic). The c-statistic for IP modelling was 0.73 (0.71 to 0.74) indicating the model was a good fit overall. Analyses were performed using R version 3.2.3.

3.0 Results

89 of the 95 participants (92.6%) submitted SHC, sleep quantity, training load and injury data for all weeks of data collection. Table 1 displays the mean ± standard deviation and median values for each variable across the study period. Of the total SHCs reported, 61% were psychological/lifestyle, 25% gastrointestinal and 14% cardiorespiratory (table 1). The total mean prevalence of all SHCs was 13.6 per participant across the 52-week study period. Runners reported 65.9% of all SHCs, while accounting for 59% of the study population.

The mean hours of sleep per day for the ESP was 6.9±0.9. There were significant differences ($p<0.000$) across the endurance subgroups where runners had the lowest mean level of sleep per day (6.8±1.0hrs) compared to triathletes who had the highest (7.2±0.7hrs/d). The mean prevalence of new injuries was 6.1 per participant, with a new injury rate of 0.12 per training session and 5.3 new injuries per 1000 hours of training. The lower limb (knee & below) accounted for 33.6% of new injury episodes (supplementary figure 1). An initial parsimonious multivariable analysis of eleven proposed prognostic variables identified four variables which may have had a significant association with new injury risk. A second parsimonious multivariable analysis of these four prognostic variables (table 2) demonstrated that two prognostic variables (i.e. 14-day lag sleep quantity and 7-day lag psychological/lifestyle SHCs) were statically associated with new injury ($p\leq0.05$).

7-day lag total SHCs did not demonstrate a significant association with new injury risk (HR=1.09, CI 95% =0.79-1.21, p=0.06). Of the SHC subscales, only 7-day lag psychological/lifestyle SHCs were significantly associated with an increased risk of a new injury episodes (table 2). Specifically, ESPs who reported a psychological/lifestyle SHC had a 32% increased risk of a new injury episode in the following week (HR=1.32, CI 95%=1.01-1.72, $p<0.04$).

Whilst a 7-day lag sleep quantity was not associated with new injury episodes, a 14-day lag sleep quantity demonstrated a significant, almost linear association with new injury episodes (figure 1). Comparing sleep quantity to the reference of seven hours, a 14-day lag sleep quantity <7 hrs/d increased the risk of new injury by 51% (HR=1.51, CI 95%=2.02-1.13, p<0.01) whilst a 14-day lag sleep quantity >7 hrs/d reduced new IP risk by 37% (HR=0.63, CI 95%=0.45-0.87, p<0.01) (table 2).

A multi-level linear regression sub-analysis did not find a significant association with total SHCs and preceding or subsequent training load factors (weekly training load, 4-weekly cumulative training load and acute chronic workload ratio). For every 1000 arbitrary unit (AU) increase in 14-day lag weekly training load (WL) there were 0.08 more total SHCs reported (RR=0.08, CI 95% =-0.04-0.21, p=0.20) and with every 0.1AU increase in 14-day lag Acute Chronic Workload Ratio (ACWR) (7:28 days) there were 0.03 more total SHCs reported (RR=0.03, CI 95% = -0.18-0.24, p=0.79). A multi-level linear regression sub-analysis did not demonstrate a significant association with sleep quantity and preceding/subsequent training load factors (p>0.05). Whilst these findings did not reach statistical significance, they should be considered practically within an ESP.

4.0 Discussion

The aim of this prospective study was to determine if there was an association between new injury risk, total SHCs, SHC subscales and sleep quantity. The results demonstrate that psychological/lifestyle SHCs reported in the previous 7 days and a sleep quantity of <7 hrs/d over the past 2 weeks were associated with new injury risk and should be considered in injury risk management within an ESP.[4] Seven day lag sleep quantity did not indicate an association to increased new injury risk and a secondary regression sub-analysis did not identify an association between total SHCs, SHC subscales, sleep quantity and training load.

Psychological/lifestyle SHCs were both the most frequently reported (61%) SHC and the only SHC category associated with new injury risk. Participants who reported a psychological/lifestyle SHC had a

32% increased risk of a new injury episode in the following week. Whilst psychological/lifestyle SHCs have received limited attention to date within ESP literature, a study of triathletes[23] found that psychological stressors, such as depressed mood and sleep disturbance, had a greater impact than training load factors on injury incidence. Likewise, non-ESP studies have demonstrated an association with psychological/lifestyle SHCs (i.e. psychological complaints,[11] low mood,[11] anxiety[7]) and increased injury risk. A number of models have been proposed which aim to define the relationship between psychological/lifestyle SHCs and increased injury risk including; Williams and Andersen's[24] 1998 stress-injury model, Johnson and Ivarsson's[25] empirical model of injury risk within non-ESPs and Junge's[26] model of the influence of psychological factors on sports injury. These models identify a number of psychological/lifestyle factors which may influence injury risk including personality traits,[24, 25] psychological stressors,[24-26] coping resources[24-26] and emotional state.[26]

Whilst the mechanisms by which psychological/lifestyle SHCs impact upon injury risk remain unclear, studies have demonstrated that psychological/lifestyle SHCs can impact upon training load factors and conversely training load factors can impact upon psychological/lifestyle SHCs.[27, 28] A study of 400 swimmers[27] and a recent non-ESP systematic review[28] demonstrated acute increases in training load factors resulted in increased psychological/lifestyle SHCs (e.g. mood, anxiety, depression, sleep problems). A study of adolescent athletes found that personality traits such as perfectionism can lead to maladaptive training load management and overtraining.[29] However, a further sub-analysis found no association between psychological/lifestyle SHCs and training load factors within this study of ESPs. Other mechanisms by which psychological/lifestyle SHCs may be associated with injury risk have been proposed. Psychological/lifestyle SHCs, including sleep, may affect an individual's sensitivity to musculoskeletal injury or pain.[30] Lower back pain (LBP) research has shown that individuals with psychological/lifestyle SHCs, in particular stress, are at a greater risk of chronic LBP.[30] Psychological/lifestyle SHCs may also impact upon an individual's response to previous injury experiences. For example, the fear-avoidance model suggests that an injury episode may lead to movement avoidance and maladaptive training approaches.[30] Therefore, whilst the precise mechanisms involved require further study, there is a growing evidence to support consideration of psychological/lifestyle SHCs within both ESPs[23] and non-ESPs.[11]

Low sleep quantity and quality[14] has been identified within an ESP. The current study reported a mean sleep duration of 6.9hrs per day, similar to that reported in another ESP study.[14] Training load factors, adrenaline levels, pain/inflammation and lifestyle/family factors have been proposed as potential factors which may account for these low levels of sleep quantity and/or quality,[31, 32] however this study did not find an association between training load and psychological/lifestyle factors and sleep quantity. This current study did identify that a 14-day lag sleep quantity > 7hrs/d reduced the risk of new injury by 37% and a 14-day lag sleep quantity of <7hrs/d increased the risk of new injury by 51% (figure 1). Whilst both previous ESP[15] and non-ESP[31] studies have identified low sleep quantity <8hrs/day to be associated with increased injury risk, this is the first study to demonstrate a ‘lag’ effect between low sleep quantity and increased injury risk.[16] The identification of a ‘lag’ between low sleep quantity and injury risk has important implications for future research. A previous sleep study has proposed that not only can low sleep quantity/quality negatively impact upon the athlete’s motor and cognitive functions,[32] but that physiological mediators may also impair immune responses, impair micro-trauma healing and increase muscle tension.[32] The impact of these individual factors on new injury risk requires further investigation, particularly within ESPs.

Previous studies within non-ESPs have demonstrated an association between high training load factors and both cardiorespiratory and gastrointestinal SHCs.[19, 31] These studies have proposed that training load can affect immune system responses with moderate training loads helping to stimulate the immune system and prevent illness whilst acute spikes in training loads may suppress the immune system increasing the risk of SHCs.[19] Whilst there was a higher percentage of weekly reported Psychological/lifestyle SHCs (61%)

compared to Cardiorespiratory (14%) and Gastrointestinal (25%) SHCs within the current study population, our analysis did not demonstrate an association with weekly reported SHCs and training load spikes over a weekly and four weekly period. However, this is in contrast with another ESP study,[3] which demonstrated higher training loads were associated with cardiorespiratory and gastrointestinal SHCs, suggesting SHCs be considered during the application of training loads.

5.0 Limitations

A limitation of this prospective study is the subjective reporting of SHCs, sleep quantity and new injury by the ESP population which introduces the potential for reporting bias. There was no independent assessment on the confirmation or severity of SHCs or new injuries reported by the participants. However, definitions relating to SHCs and injury were provided to the participants. The selection of 4 weeks as a cut-off for another injury in the same location being considered a new injury was somewhat arbitrary. Generalisability of results and selection bias must also be considered between the ESP disciplines recruited, and the study population sub-groups not being equally represented (elite/recreational, and sex). Runners accounted for 59% of the study population and swimmers only accounted for 2.1% of the population. Whilst only mean and median week/weekend sleep quantity was analysed within this study, there was no measurement of sleep disorders or sleep quality and future studies should consider more detailed and robust measures of sleep quantity and quality.

6.0 Conclusions

This study demonstrates that both psychological/lifestyle SHCs and low sleep quantity are associated with increased new injury risk within an ESP. This study also highlighted a potential lag between low sleep quantity and its subsequent impact on new injury risk and has important implications for future research. No association was demonstrated between SHCs or sleep quantity and training load factors. These findings highlight the importance of considering psychological/lifestyle SHCs and sleep quantity when managing new injury risk within an ESP. Further research investigating the mechanism by which psychological/lifestyle SHCs and sleep quantity impact upon new injury risk may allow the development of injury prevention strategies within ESPs.

Practical applications:

- Psychological/lifestyle subjective health complaints and low sleep quantity can increase the risk of new injury within an endurance sporting population.
- Psychological/lifestyle SHCs and sleep quantity should be considered, and actively managed, with a view to reducing injury rates within an endurance sporting population.
- A time lag for sleep should be used when monitoring new injury risk within an endurance sporting population.

Acknowledgements: The Faculty of Education and Health Sciences at the University of Limerick funded RJ through a PhD scholarship.

References

1. Hulme A, Nielsen RO, Timpka T et al. Risk and protective factors for middle- and long-distance running-related Injury. *Sports med.* 2017; 47(5):869-886.
2. Johnston R, Cahalan R, O'Keeffe M et al. The associations between training load and baseline characteristics on musculoskeletal injury and pain in endurance sport populations: A systematic review. *J Sci Med Sport.* 2018; 910-918.
3. Van Tonder A, Schwellnus M, Swanevelder et al. A prospective cohort study of 7031 distance runners shows that 1 in 13 report systemic symptoms of an acute illness in the 8-12 day period before a race, increasing their risk of not finishing the race 1.9 times for those runners who started the race: SAFER study IV. *Br J Sports Med.* 2016; 50(15):939-945.
4. von Rosen P, Frohm A, Kottorp A et al. Multiple factors explain injury risk in adolescent elite athletes: Applying a biopsychosocial perspective. *Scand J Med Sci Sports.* 2017; (27): 2059-2069.
5. Wiese-Bjornstal DM. Psychology and socioculture affect injury risk, response, and recovery in high-intensity athletes: a consensus statement. *Scand J Med Sci Sports.* 2010; 20 Suppl 2:103-111.
6. Thygesen E, Lindstrom TC, Saevareid HI et al. The Subjective Health Complaints Inventory: a useful instrument to identify various aspects of health and ability to cope in older people? *Scand J Public Health.* 2009; 37(7):690-696.
7. Biggins M, Cahalan R, Comyns T et al. Poor sleep is related to lower general health, increased stress and increased confusion in elite Gaelic athletes. *Phys Sportsmed.* 2018; 46(1):14-20.
8. Schwellnus M, Derman W, Page T, et al. Illness during the 2010 Super 14 Rugby Union tournament – a prospective study involving 22 676 player days. *Br J Sports Med.* 2012; 46(7):499.
9. Gouttebarge V, Frings-Dresen MH, Sluiter JK. Mental and psychosocial health among current and former professional footballers. *Occupat Med.* 2015; 65(3):190-196.
10. Main LC, Landers GJ. Overtraining or burnout: A training and psycho-behavioural case study. *Int J Sports Sci Coach.* 2012; 7(1):23-31.
11. Cahalan R, Purtill H, O'Sullivan P et al. A cross-sectional study of elite adult Irish dancers: biopsychosocial traits, pain, and injury. *J Dance Med Sci.* 2015; 19(1):31-43.
12. Killen NM, Gabbett TJ, Jenkins DG. Training loads and incidence of injury during the preseason in professional rugby league players. *J Strength Cond Res.* 2010; 24(8):2079-2084.
13. Samuels C. Sleep, recovery, and performance: the new frontier in high-performance athletics. *Phys rehabil clin N Am.* 2009; 20(1):149-159, ix.
14. Lastella M, Lovell GP, Sargent C. Athletes' precompetitive sleep behaviour and its relationship with subsequent precompetitive mood and performance. *Eur J Sport Sci.* 2014; 14 Suppl 1:S123-130.
15. Milewski M, Skaggs D, A Bishop G, et al. Chronic lack of sleep is associated with increased sports injuries in adolescent athletes. *J Pediatr Orthop.* 2014; 34:129-133.
16. Dennis J, Dawson B, Heasman J et al. Sleep patterns and injury occurrence in elite Australian footballers. *J Sci Med Sport.* 2016; 19(2):113-116.
17. Reardon CL, Hainline B, Aron CM, et al. Mental health in elite athletes: International Olympic committee consensus statement. *Br J Sports Med.* 2019; 53(11):667-699.
18. Johnston R, Cahalan R, Bonnett L, et al. Training load and baseline characteristics associated with new injury/pain within an endurance sporting population: A prospective study. *Int J Sport Physiol.* 2019; 14(5):590-597.

19. Piggott B, Newton, MJ, McGuigan, MR. The relationship between training load and incidence of injury and illness over a pre-season at an Australian football league club. *J Austr Strength Cond Res.* 2009; 17(3):4-17.
20. Soligard T, Schwellnus M, Alonso J-M, et al. How much is too much? (Part 1) International Olympic Committee consensus statement on load in sport and risk of injury. *Br J Sports Med.* 2016; 50(17):1030-1041.
21. O'Sullivan K, O'Sullivan PB, Gabbett TJ. Pain and fatigue in sport: are they so different? *Br J Sports Med.* 2018; 52(9):555.
22. Bonnett LJ, Powell GA, Tudur Smith C et al. Risk of a seizure recurrence after a breakthrough seizure and the implications for driving: further analysis of the standard versus new antiepileptic drugs (SANAD) randomised controlled trial. *BMJ Open.* 2017; 7(7).
23. Main LC, Landers GJ, Grove JR et al. Training patterns and negative health outcomes in triathlon: longitudinal observations across a full competitive season. *J Sports Med Phys Fitness.* 2010; 50(4):475-485.
24. Williams JM, Andersen MB. Psychosocial antecedents of sport injury: Review and critique of the stress and injury model'. *J Appl Sport Psychol.* 1998; 10(1):5-25.
25. Johnson U, Ivarsson A. Psychological predictors of sport injuries among junior soccer players. *Scand J Med Sci Sports.* 2011; 21(1):129-136.
26. Junge A. The influence of psychological factors on sports injuries. Review of the literature. *Am J Sports Med.* 2000; 28(5 Suppl):S10-15.
27. Morgan WP, Brown DR, Raglin JS et al. Psychological monitoring of overtraining and staleness. *Br J Sports Med.* 1987; 21(3):107-114.
28. 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(5):281-291.
29. Madigan DJ, Stoeber J, Passfield L. Perfectionism and training distress in junior athletes: a longitudinal investigation. *J Sports Sci.* 2017; 35(5):470-475.
30. Linton SJ, Shaw WS. Impact of psychological factors in the experience of pain. *Phys Ther.* 2011; 91(5):700-711.
31. Jones CM, Griffiths PC, Towers C et al. Pre-season injury and illness associations with perceptual wellness, neuromuscular fatigue, sleep and training in elite rugby union. *J Austr Strength Cond.* 2018; 26(2):6-16.
32. Andersen MB, Williams JM. Athletic injury, psychosocial factors and perceptual changes during stress. *J Sports Sci.* 1999; 17(9):735-741.

Figure 1: Association between 14-day lag sleep quantity (mean hours of sleep per day) and new injury.

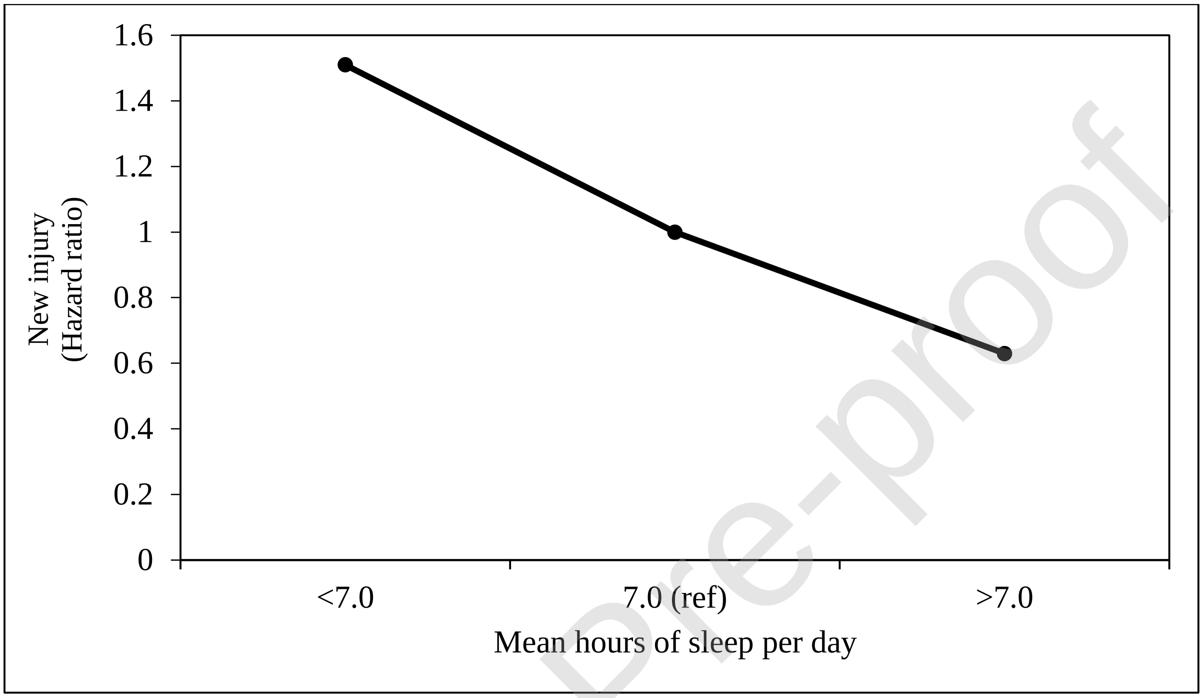

Table 1: Endurance population characteristics

Variable	Total population n=95	Runners n=56 (59.0%)	Triathletes n=18 (18.9%)	Swimmers n=2 (2.1%)	Cyclists n=10 (10.5%)	Rowers n=9 (9.5%)	Differences between groups (p-value)
Males, N (%)	61 (64.2%)	29 (47.6%)	16 (26.2%)	1 (1.6%)	9 (14.8%)	6 (9.8%)	**0.02***
Age (yrs) (mean ±sd)	42.2 ± 10.0	42.3 ± 8.8	40.2 ± 7.4	34.5 ± 20.5	42.1 ± 11.3	48.1 ±16.5	0.30
Weekly number of training sessions (IQR)	4 (3:6)	4 (2:6)	5 (4:7)	2 (2:6)	3 (2:4)	3 (3:5)	**<0.001***
Total new injury, N (%)	585 (100)	311 (53.1)	140 (23.7)	17 (2.9)	70 (11.8)	50(8.5)	**<0.001***
WL (AU) (IQR)	1130 (630:1740)	1005 (530:1599)	1465 (870:2160)	1890 (360:4905)	1225 (783:1735)	1070 (690:1520)	**<0.001***
CL (AU) (IQR)	4370 (2550:6405)	3930 (2070:5915)	5498 (3520:7985)	9303 (840:17749)	4800 (3465:6311)	4235 (3045:5720)	**<0.001***
ACWR rolling average (7:28 days) (IQR)	1.02 (0.78:1.26)	1.02 (0.78:1.26)	1.01 (0.82:1.23)	1.05 (0.87:1.33)	1.04 (0.69:1.33)	1.05 (0.76:1.29)	**0.81**
Total SHCs	N=1303 (100%)	N=859 (65.9%)	N=306 (23.4%)	N=6 (0.5%)	N=81 (6.3%)	N=51 (3.9%)	**0.000***
Cardiorespiratory SHCs	N=188 (14% of total SHCs)	N=137 (72.8%)	N=31 (16.4%)	N=1 (0.5%)	N=5 (2.6%)	N=14 (7.7%)	**0.028***

Gastrointestinal SHCs	N=313 (25% of total SHCs)	N=200 (63.9%)	N=100 (32.1%)	N=2 (0.6%)	N=6 (1.9%)	N=5 (1.5%)	**0.001***
Psychological/ lifestyle SHCs	N=802 (61% of total SHCs)	N=522 (65.1%)	N=175 (21.9%)	N=3 (0.3%	N=70 (8.8%)	N=32 (3.9%)	**0.000***
Sleep quantity (hrs/d) (mean±std)	6.92±0.97	6.82±1.01	7.28±0.73	7.19±0.66	6.55±1.15	7.17±0.65	**0.000***

N=number; p-value; =significant difference; yrs=years; SD=Standard Deviation; IQR=Inter Quartile Range; WL=weekly training load; AU=Arbitrary Unit; CL=4-weekly cumulative training load; ACWR= acute chronic workload ratio; SHCs=subjective health complaints; hrs/d = mean hours per day*

Table 2: Parsimonious multivariable model data for Endurance athlete subgroups, SHC and mean hours of sleep associated to new injury episode.

Variable	Population Reference group (%)	Population Comparison Groups (%)	p-value	HR (95% CI)	HR (95% CI) – post-hoc categorisation
Endurance athlete subgroup	Runner (59%)	Triathlete (18.9%)	0.19	1.53 (0.91-2.89)	
		Swimmer (2.1%)	0.49	0.58 (0.12-2.71)	
		Cyclist (10.5%)	0.20	1.79 (0.74-4.35)	
		Rower (9.5%)	0.60	1.24 (0.55-2.80)	
14-day lag sleep quantity	7 hrs/d (38%)	<7 hrs/d (30%)	**0.01***	0.89 (0.82-0.97)	1.51 (2.02-1.13)
		>7 hrs/d (32%)			0.63 (0.45-0.87)
7-day lag psychological/ lifestyle SHCs	No (81%)	Yes (19%)	**0.04***	1.32 (1.01-1.72)	
7-day lag total SHCs	No 71%	Yes (29%)	0.06	1.09 (0.79-1.21)	
7-day lag gastrointestinal SHCs	No (86%)	Yes (14%)	0.09	0.77 (0.56-1.05)	
7-day lag cardiorespiratory SHCs	No (82%)	Yes (18 %)	0.07	1.16 (0.95-1.36)	

HR=hazard ratio; CI=confidence intervals; p-value;=significant association; hrs/d=mean hours per day; SHCs= subjective health complaints*