Journal of Science and Medicine in Sport 22 (2019) 130–134

Contents lists available at ScienceDirect

Journal of Science and Medicine in Sport

journal homepage: www.elsevier.com/locate/jsams

Original research

The influence of sleep and training load on illness in nationally competitive male Australian Football athletes: A cohort study over one season

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ARTICLE INFO

Article history:
Received 29 January 2018
Received in revised form 4 May 2018
Accepted 11 June 2018
Available online 19 June 2018

Keywords:
Incidence
Epidemiology
Acute illness
Load monitoring
Risk factors

ABSTRACT

Objectives: To determine the incidence of illness, and identify the relationship between sleep, training load and illness in nationally competitive Australian football athletes. Second, to assess multivariate effect between training load and/or sleep variables.
Design: Cohort study.
Methods: Retrospective analyses of prospectively collected cohort data were conducted on forty-four male athletes over a 46-week season. The primary outcome was illness incidence, recorded daily by medical doctors. Independent variables were acute, chronic and acute:chronic ratios of: sleep quality, sleep quantity, internal training load and external training load defined as: total running distance, high speed running distance and sprint distance. Generalised estimating equations using Poisson (count) models were fit to examine both univariate and multivariate associations between independent variables and illness incidence.
Results: 67 incidences of illness were recorded, with an incidence rate of 11 illnesses per 1000 running hours. Univariate analysis showed acute and chronic sleep hours and quality, as well as acute sprint and total running distance to be significantly associated with illness. Multivariate analysis identified that only acute sleep quantity was significantly, negatively associated with illness incidence (OR 0.49, CI 0.25–0.94) once all univariate significant variables were controlled for. There was no relationship between external training load and illness when sleep metrics were controlled for.
Conclusions: In a cohort of Australian football athletes, whose load was well monitored, reduced sleep quantity was associated with increased incidence of illness within the next 7 days. Monitoring sleep parameters may assist in identifying individuals at risk of illness.

1. Introduction

Acute illness negatively impacts individual athletic performance and the overall success of the sporting team.[1] Illness remains a leading cause of training and competition absences, with player absenteeism itself inversely related to number of games won.[2] Emerging evidence identifies training load and sleep as two possible modifiable factors increasing the risk of illness in professional sporting teams.[3,4] Understanding the contributing factors of illness in elite sport, could allow for earlier intervention or program modification to reduce the impact of illness in sport.

Training load describes the 'total volume, intensity and type of physical activity undertaken by the athlete during competition and training'.[5] Current evidence on the relationship between training load and illness follows a J-shaped curve. Training at a moderate load is suggested to stimulate the immune system inducing immunoprotective effects. Whereas high training loads are associated with the highest risk of illness, likely due to immunosuppression effects.[6] During periods of excessive loading, a physiological stress response causes hormonal (e.g. corticotrophin) and biochemical changes such as inflammatory cytokine release (e.g. IL-6) and alterations to reactive oxygen species, which are believed to contribute to this suppression of the immune system.[7] In elite-athlete populations evidence has emerged associating illness with preceding spikes in load.[8] However, the true extent of the relationship remains unclear and requires further sport specific investigation.

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https://doi.org/10.1016/j.jsams.2018.06.011
1440-2440/

The immunosuppression response from excessive training load is similar to those induced from sub-optimal sleep patterns. Chronic sleep deficits cause increased secretion of proinflammatory cytokines (e.g. IL-6 and TNF-α), attenuation of antibodies and alterations in central nervous system regulation of the immune response.[9,10] Although sleep is considered a critical factor for performance, athletes are known to have disrupted or insufficient sleep around competition periods.[11] Sleep deprivation over consecutive days has been linked to increased incidence of an upper respiratory tract infection among elite athletes.[12] Cohen et al.[13] demonstrated a threefold increased risk of developing a common cold in healthy adult participants who slept less than seven hours per night compared to those with over eight hours. As both sleep and training load cause physiological stresses which can suppress immunity, when insufficient sleep was examined in over-reaching athletes, an increased risk of illness was evident.[12]

Australian Rules Football (Australian football) requires athletes to train at high variety of intensities over a 6-month competition period. Although long periods of competition are suggested to result in higher incidences of illness, current research in Australian football athletes has been limited by short observational periods.[7] Both prior studies of Australian football athletes confine their observational periods to the preseason.[8,14] This limited "exposure" risks underestimating the incidence rate of illness, as well as the temporal sequence between exposure to potential risk factors and illness. The current study examines longitudinal data from nationally competitive Australian football players over the course of a 46-week season, i.e. a full pre-season and competitive season.

This study had three aims: to identify the incidence of illness within nationally competitive Australian football athletes across one complete season; to investigate the individual relationship between training load (internal and external loads) and sleep (quality and quantity) on the incidence of illness; and to assess any multivariate effect between either training load and/or sleep variables.

2. Methods

A retrospective analysis was performed on prospectively collected data from one nationally-competing Australian Football League (AFL) club. Data were collected over the entire 2015/16 AFL season consisting of a 19-week preseason and 27-week competition period (including finals matches). Players' data were collected as part of a pre-existing performance monitoring routine.

Data from forty-four participants were included. All players competed in either the Australian Football League or the North East Australian Football League. Player demographics were collected including age, height, weight, and body mass. Ethical approval was granted by the Macquarie University Human Research Ethics committee (No 5201600707).

The dependent variable was illness. This was defined using the International Olympic Committee definition of any "new or recurring symptomatic sickness or disease incurred during [the AFL preseason and competition season] that received medical attention, regardless of the consequences with respect to absence from competition and/or training".[15] Official team doctors were responsible for recording incidence of illness. In this study, illness was recorded as a daily outcome and expressed in dichotomous terms of 'ill' or 'not ill'.

Independent variables were metrics of external workload, internal workload and sleep parameters. Three outcomes were used to examine external workload: total distance; high speed distance (>17 km/h); and sprint distance (>23 km/h), each expressed in metres (m) travelled. These speed classifications were selected based on previous time-motion analysis studies, and have been used as speed classifications in both Australian football and other team sport populations.[16] A portable Global Positioning System (Optimeye S5 10 HZ, Catapult Innovations, Melbourne, Australia) worn on the torso of each player during every match and training session captured each external workload. Optimeye S5 has demonstrated validity in determining distance, and sensitivity in assessing velocity.[17]

Internal load was measured using Foster's session rating of perceived exertion (session-RPE),[18] where session intensity is subjectively measured (0–10) and multiplied by the session duration (minutes). Session-RPE provides a practical and valid quantification of internal training loads, correlating directly to summated heart rate zones.[18] Immediately following all training and match performances, players recorded Session-RPE using the Smartabase (Fusion sport, Brisbane, Australia) smartphone application (www.fusionsport.com/smartabase-athlete-data-management-software).

Qualitative and quantitative sleep measures were recorded using self-reported outcomes. Sleep quantity was recorded as the duration slept the previous night. Players were asked to 'Enter the number of hours you slept last night'. This directly relates to item 4 on the Pittsburgh Sleep Quality Index, a questionnaire used to assess sleep parameters in multiple populations.[19] Sleep quality was recorded using a 5-point Likert scale (1–5 scale). Each morning, athletes entered their response to 'How would you evaluate your sleep last night?' from 1 (perfect sleep) to 5 (hardly slept). This measure was derived from the Pittsburgh Sleep Quality Index and scores similarly to a previous study on sleep quality.[20] While sleep quality measures have not undergone clinimetric analysis in general, this scale has face validity with both the athletes and medical staff. Both sleep hours and sleep quality were recorded daily, via Smartabase, then collated to provide a weekly average for each player.

Data were analysed using SPSS (version 24.0, IBM, NY, USA). Incidence of illness was calculated as the number of illnesses per 1000 running hours, as recorded through GPS tracking of all training and game performances. Illness per 1000 running hours directly relates illness to the training load variables in the study, with similar outcomes used to explore injury rates in running populations.[21] To examine short and long-term absolute and relative relationships between variables and illness, acute and chronic workloads were calculated for each independent variable, for each week of the pre- and competitive season for each participant. Acute workloads were defined as those occurring within the 7 days prior to recorded illness, excluding the day prior to illness. Chronic workloads were defined as those within 28 days prior to illness episode. During periods without illness, and for those players who remained not ill for the season, weekly and 28-day data was also recorded for each independent variable. The relative workload was determined using the acute:chronic ratio which expresses the change in load/sleep as a ratio of acute (7 days) to chronic (28 days) exposures.[7]

Illness data were modelled using a generalised estimating equation Poisson regression with robust covariance matrix. This model permits multiple entries for each participant and is robust against missing data. The presence of illness or not in each week was the dependent variable. The week of the season was entered as a within-participant repeated variable and 'participant' was entered into the model as the repeated term. To account for the correlation between weeks, and between successive illnesses within a single participant, we utilised an autoregressive working correlation matrix. This approach assumes that adjacent measures are correlated and this correlation between measures exponentially decreases the farther away they are.

Univariate analyses were conducted to investigate any association of illness with each independent variable over acute, chronic and acute:chronic time-frames. Statistical significance was

Table 1
Univariate Poisson Generalised Estimating Equation analysis examining relationships between acute and chronic loads and illness for each training load and sleep variable, and variable Mean (SD).

Variable	Group	Mean (SD)	Odds ratio	95% CI	p-Value
Total distance (m/week)	Acute not ill	19772.1 (6383.9)	Reference		
	Chronic not ill	19954.4 (4272.8)	Reference		
	Acute ill	17978.2 (6889.0)	1.00	1.00, 1.00	0.031
	Chronic ill	19217.1 (4872.1)	1.00	1.00, 1.00	0.256
High speed distance (m/week)	Acute not ill	3938.7 (2068.4)	Reference		
	Chronic not ill	3839.0 (1399.0)	Reference		
	Acute ill	3709.7 (2324.3)	1.00	1.00, 1.00	0.489
	Chronic ill	3631.8 (1293.0)	1.00	1.00, 1.00	0.319
Sprint distance (m/week)	Acute not ill	664.4 (439.7)	Reference		
	Chronic not ill	655.8 (364.4)	Reference		
	Acute ill	552.5 (358.3)	0.99	0.98, 1.00	0.042
	Chronic ill	571.5 (290.8)	1.001	0.98, 1.00	0.085
Internal load (session RPE)	Acute not ill	2911.9 (1184.2)	Reference		
	Chronic not ill	2934.7 (953.4)	Reference		
	Acute ill	3171.5 (1441.5)	1.00	0.99, 1.00	0.094
	Chronic ill	2889.5 (1032.6)	1.00	0.99, 1.001	0.764
Sleep quality (1–5)[a]	Acute not ill	2.87 (0.4)	Reference		
	Chronic not ill	2.87 (0.3)	Reference		
	Acute ill	3.04 (0.3)	3.95	1.71, 9.11	0.001
	Chronic ill	3.0 (0.3)	3.81	1.11, 13.08	0.034
Sleep hours (h/night)	Acute not ill	7.85 (0.7)	Reference		
	Chronic not ill	7.84 (0.6)	Reference		
	Acute ill	7.41 (0.9)	0.52	0.4, 0.69	<0.001
	Chronic ill	7.54 (0.8)	0.52	0.32, 0.85	0.009

[a] Scale anchors: 1 (perfect sleep) to 5 (hardly slept).

accepted as $p < 0.05$. Next, a multivariate analysis were conducted using a forced entry method of statistically significant univariate variables. Goodness of fit, compared with an intercept only model as well as each univariate model using the quasi-likelihood under independence model criteria and corrected quasi-likelihood under independence model in a smaller-is-better form.

3. Results

From the forty-four players included in the study (age 24.8 ± 3.4 years; height 189.67 ± 7.36 cm, weight 87.5 ± 7.84 kg, BMI 24.36 ± 2.2), 67 incidences of illness were recorded over the entire 2015/16 season. This equates to 11.9 illnesses per 1000 h of running or 1 illness incidence per 84 running hours. During the season, 32 (72.7%) players were ill, 14 having one occurrence of illness (32%), 8 having two occurrences (18%) and 10 having more than three occurrences (23%).

Significant associations were found, in univariate analysis, for acute total running distance ($p = 0.031$) and acute sprint distance ($p = 0.042$), implying individuals who became ill ran and sprinted less distance in the 7 days prior to illness. However, inspection of the odds ratio demonstrated no change in odds of illness associated with the incidence of illness (Table 1). There were significant associations between both acute and chronic absolute sleep quality and hours. Poorer sleep quality, both in the short and long term, had greater odds of illness. Similarly, fewer sleep hours increased the odds of illness both acutely and chronically (Table 1). There were no significance associations between relative training load, or changes in training load, and the incidence of illness (Table 2).

The multivariate generalised estimating equation was a significantly better fit than all univariate models. Acute sleep hours were significantly negatively correlated with the incidence of illness indicating that when all other training load variables are considered, reduced sleep hours increased the odds of illness in this study of Australian football athletes (Table 3).

4. Discussion

The present study is the first to examine both absolute and relative influences of sleep and training load on illness within nationally competitive Australian football athletes. This study provides evidence that reduced sleep quantity is associated with a higher incidence of illness in nationally competitive Australian football athletes. While univariate relationships were identified with acute

Table 2
Univariate Poisson Generalised Estimating Equation analysis examining relationships between acute:chronic and illness for each training load and sleep variable, and variable Mean (SD). Values <1 indicates acute load is less than chronic load. Values >1 indicate acute load is greater than chronic load.

Variable	Group	Mean (SD)	Odds ratio	95% CI	p-Value
Total distance (m/week)	Not ill	0.99 (0.3)	Reference		
	Ill	0.95 (0.5)	0.65	0.15, 2.73	0.557
High speed distance (m/week)	Not ill	0.97 (0.3)	Reference		
	Ill	1.0 (0.5)	1.28	0.5, 3.31	0.605
Sprint distance (m/week)	Not ill	1.01 (0.4)	Reference		
	Ill	0.99 (0.6)	0.89	0.43, 1.82	0.745
Internal load (session RPE)	Not ill	0.97 (0.2)	Reference		
	Ill	0.97 (0.3)	1.03	0.19, 5.51	0.968
Sleep quality (1–5)[a]	Not ill	1.0 (0.1)	Reference		
	Ill	1.02 (0.1)	25.2	0.76, 83.6	0.076
Sleep hours (h/night)	Not ill	1.0 (0.04)	Reference		
	Ill	0.99 (0.06)	23.8	0.71, 79.7	0.077

[a] Scale anchors: 1 (perfect sleep) to 5 (hardly slept).

Table 3
Multivariate Poisson Generalised Estimating Equation analysis examining the relative relationships between acute:chronic parameters and illness, for those significant univariate training load and sleep variables. Not ill is the reference group for all odds ratios.

Variable	Odds ratio	95% CI	p-Value
Acute total distance (m/week)	1.00	1.00, 1.00	0.325
Acute sprint distance (m/week)	1.00	0.99, 1.00	0.834
Acute sleep quality (1–5)[a]	2.23	0.4, 11.7	0.351
Acute sleep hours (h/night)	0.49	0.25, 0.94	0.032
Chronic sleep quality (1–5)[a]	1.03	0.19, 5.53	0.972
Chronic sleep hours (h/night)	1.25	0.54, 2.93	0.602

[a] Scale anchors: 1 (perfect sleep) to 5 (hardly slept).

sprint distance, and acute total distance, no training load variable remained significant when applied in the multivariate model.

This study is the first to establish the incidence of illness over a complete season (preseason and competition) for nationally competitive male Australian football athletes. At least one illness throughout the entire season was reported by 72% of the athletes. The 67 illnesses recorded equate to 1.5 illnesses per athlete, a result similar to the 1.4 illnesses per athlete found in national rugby players over a complete season, albeit a 29-week period.[22] Professional rugby union, football and distance running populations report 70–92% of players will sustain at least one illness throughout a season,[23–25] similar to the 76% of Australian males who will visit the doctor at least once annually.[26]

Interestingly, the study has shown an association between all sleep variables and illness on the univariate level, indicating the significance of overall sleep upon illness. Furthermore, in the presence of all potentially influencing variables, it is acute sleep quality that remains associated with the incidence of illness. This particular relationship between sleep quantity and the seven days prior to an illness has also been shown in prior studies. Prather et al.[27] measured sleep duration over 7-days prior to administering participants with rhinovirus, showing a similar linear relationship between clinical infection and sleep duration, i.e. less sleep increased the likelihood of illness. Restricted sleep over a 7-day period has also been shown to be associated with biological changes to cytokine and increased inflammatory mediators.[28] The ability for sleep to alter immune and endocrine factors may provide a biological rationale for the relationship between sleep and illness in this population. Alternatively, low sleep duration in the days prior to recorded illness may occur in response to the incubation period of illness. Infectious agents usually enter the body 24–72 h before the onset of clinical signs.[29] While our study is unable to distinguish a cause or effect between acute low sleep duration and illness, the importance of understanding this sleep pattern prior to illness remains. Identification of acutely low sleep quality, with future research, may help identify ill or at risk of illness athletes, and subsequent intervention.

When examining the mean hours slept by each group, there is a 27-min difference in acute sleep measures between the ill and not ill athletes. Whilst this may seem a small difference, research on typical 8-h sleepers showed that a 2–8% reduction in sleep duration (10–40 min) was enough to increase cold susceptibility by 3.9 times.[13] Interestingly implementation of a one-hour sleep hygiene session improved sleep time and wake variance by 22 and 21 min respectively in a group of female athletes.[30] Further studies should investigate whether implementation of sleep hygiene programs have an impact on incidence of illness within nationally competing Australian football athlete populations.

In regards to training load, despite an association between lower sprint distance and lower total distances in the seven days prior to an illness, these variables were not significant once sleep metrics were controlled for in a multivariate model. In contrast to previous literature,[7] we have found no association between higher training loads and illness. However, the populations under examination may explain this. Models associating high levels of physical activity to illness have been based on a wide range of populations including sedentary individuals as well as elite athletes.[7,31] When examining training load and illness within the elite athlete population (excluding for mixed ability and sub-elite athletes) the evidence pertaining to training load and illness is conflicting.

Within nationally competitive Australian football athletes, Piggott[8] reported an association between a preceding spike (>10%) in training load and illness, yet the study's conclusion found no significant association between training load and illness in Australian football athletes. Fricker et al.[25] showed no significant difference in mean weekly or monthly running distances, intensity, or internal training load in male distance runners. Variation in the literature may be due to; inconsistencies in illness recording (whether self-reported or medically assessed) the periods assessed prior to illness, and the effect of differing sporting environments e.g. water compared to land based sports.[7,31] It is also possible that by only examining elite athletes of the same club this may have resulted in insufficient variation in load as all players follow similar training protocols under strict guidance of coaches. This could also help explain the lack of association between relative training load variables and illness. As professional clubs currently monitor and control for load variation, the existence of potentially illness-inciting, or extreme loading is likely to be rare. Further research would benefit from examining a greater number of participants over several clubs and multiple seasons.

Relative workloads and relative sleep parameters showed no significant relationship to illness. In regards to sleep, this can be explained because the sleep parameters for the ill group were lower in both acute and chronic periods. The lack of difference could also be due to the way acute and chronic loads are calculated. Both acute and chronic training loads include the past week of data,[7] meaning that there is a double counting of days. Despite data inspection to ensure that any cases of extreme data were known (there were none) it is possible that this overlap of days results in a dilution of effect. Further discussion is required on whether chronic workload should include or exclude the past 7-days. A number of other limitations of the overall study are recognised including the small sample size and the self-reported recording of sleep measures. Self-reported sleep hours become less accurate when objectively recorded sleep is less than 7 h as there is a false recording of more hours slept.[32] Interestingly, this indicates that there is a potential under-reporting of the true influence of sleep hours on illness within the current study.

A key strength of this study was approaching illness as a multidimensional concept, and assessing the interaction of illness with several measurable variables through multivariate analysis. Bittencourt et al.[33] describes the multifactorial nature of sports injuries and how the focus of research should be made towards interactions as opposed to isolated factors. To more effectively understand illness in sport, a similar approach needs to be taken. Future research should seek to build upon this model to further understand the multiple interactions that influence illness, which ultimately could lead to better illness recognition and earlier intervention. Future research should seek to investigate the impact of applied sleep education and sleep hygiene programs on the incidence of illness within nationally competitive Australian football athletes.

5. Conclusion

This study provides evidence that poor sleep quantity is associated with a higher incidence of illness in elite Australian football athletes. Within the 7 days prior to illness, athletes are likely to

report significantly lower sleep quantity. Both internal and external training loads, do not appear to be influencing factors for illness within a multivariate model. The use of multivariate models supports the notion that illness needs to be examined as a complex multifactorial interaction within the sporting realm. Understanding the associations of sleep and illness in Australian football athletes may help lead to earlier illness identification and to potentially implement preventative action.

Practical implications

- Australian football athletes experience an illness incidence of 11.9 per 1000 running hours.
- Poor sleep duration correlates with increased odds of illness incidence within Australian football athletes.
- Univariate analysis indicates that multiple sleep metrics and sprint distance are associated with illness, suggesting that illness needs to be investigated using multifactorial models.

Acknowledgements

No financial assistance was provided for this study.

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