Citation:
Sawczuk, T and Jones, B and Scantlebury, S and Till, K (2018) The influence of perceptions of sleep on wellbeing in youth athletes. Journal of Strength and Conditioning Research. ISSN 1064-8011 DOI: https://doi.org/10.1519/JSC.0000000000002857

Link to Leeds Beckett Repository record:
http://eprints.leedsbeckett.ac.uk/5232/

Document Version:
Article

The influence of perceptions of sleep on wellbeing in youth athletes

Running head: Influence of sleep on wellbeing in youth athletes

Thomas Sawczuk[1,2], Ben Jones[1,2,3,4], Sean Scantlebury[1,2], Kevin Till[1,3,5]

[1] Institute for Sport, Physical Activity and Leisure, Leeds Beckett University, Leeds, United Kingdom

[2] Queen Ethelburga's Collegiate, Thorpe Underwood, York, United Kingdom

[3] Yorkshire Carnegie Rugby Club, Headingley Carnegie Stadium, Leeds, United Kingdom

[4] The Rugby Football League, Red Hall, Leeds, United Kingdom

[5] Leeds Rhinos Rugby Club, Headingley Carnegie Stadium, Leeds, United Kingdom

Corresponding Author:

Thomas Sawczuk

Room G03, Macaulay Hall

Institute for Sport, Physical Activity and Leisure

Centre for Human Performance

Leeds Beckett University, Headingley Campus

West Yorkshire

LS6 3QS

Phone: (0044) 7530945555

Email: t.sawczuk@leedsbeckett.ac.uk

Abstract

To date, the majority of research considering wellbeing questionnaires has only considered the training stress imposed on the athlete, without evaluating the questionnaire's relationship with a measure of recovery (e.g. sleep). This study aimed to assess the influence of sleep duration ($S_{duration}$), sleep quality ($S_{quality}$) and sleep index (S_{index}; $S_{duration}$ x $S_{quality}$) on wellbeing in youth athletes, whilst accounting for the known training stressors of training load and exposure to match play. Forty-eight youth athletes (age 17.3 ± 0.5 years) completed a daily questionnaire including wellbeing ($DWB_{no-sleep}$; fatigue, muscle soreness, stress and mood) measures, Perceived Recovery Scale (PRS), the previous day's training loads, $S_{duration}$ and $S_{quality}$ every day for 13 weeks. Linear mixed models assessed the impact of $S_{duration}$, $S_{quality}$ and S_{index} on $DWB_{no-sleep}$, its individual subscales, and PRS. $S_{duration}$ had a *small* effect on $DWB_{no-sleep}$ (*d*=0.31; ±0.09), fatigue (*d*=0.42; ±0.11) and PRS (*d*=0.25; ±0.09). $S_{quality}$ had a *small* effect on $DWB_{no-sleep}$ (*d*=0.47; ±0.08), fatigue (*d*=0.53; ±0.11), stress (*d*=0.35; ±0.07), mood (*d*=0.41; ±0.09) and PRS (*d*=0.37; ±0.08). S_{index} had a *small* effect on $DWB_{no-sleep}$ (*d*=0.44; ±0.08), fatigue (*d*=0.55; ±0.11), stress (*d*=0.29; ±0.07), mood (*d*=0.37; ±0.09) and PRS (*d*=0.36; ±0.09). The results indicate that an athlete's perceptions of sleep are associated with deviations in wellbeing measures and should be used as an input to the monitoring process rather than as part of the outcome wellbeing score. The sleep index is suggested as a potential input as it provides information on both the duration and quality of the sleep experienced.

Key words: Recovery, fatigue, youth, training, stress

Abstract word count: 248

Total word count: 3849

INTRODUCTION

In the last decade, there has been a large increase in research surrounding the sleep profiles of athletes (16,22), and the health and performance consequences of sleep disturbances (9,39). Such research has shown that athletes are liable to suffer reduced sleep quantity and quality (16,22,32), which can lead to decrements in sporting performance (7,23), increased risk of illness (6) and deviations in wellbeing measures (19,27). These findings have resulted in practitioners commonly including measures of perceived sleep quality in daily wellbeing questionnaires aimed at monitoring their athletes (2,24,40). Daily wellbeing questionnaires usually consist of items related to muscle soreness, appetite, sleep quality, mood, stress and fatigue, and are tailored to the needs of the practitioners in question (24,26,40). These subscales can be evaluated alone or grouped together to provide a total wellbeing score, which can be compared to the previous day's training load to assess whether changes are congruent with the training stress imposed on the athlete (25,36,37,40). However, given the influence of sleep quality on athlete wellbeing (19,27,29), it is pertinent to question whether perceptions of sleep should be an input, rather than an output measure of this athlete monitoring process.

Although the influence of training stress, measured by training load and exposure to match play, on muscle soreness and fatigue/recovery based measures is well established (2,37,40), its relationship with the overall wellbeing score has been questioned in the only study to consider a measure of recovery alongside the training stress imposed (37). In this study, the authors found self-reported sleep duration, as a measure of recovery, to have a *small* effect on a daily wellbeing scale (DWB; 23), its fatigue subscale and the Perceived Recovery Status scale (PRS; 20), and a *moderate* effect on the sleep quality DWB subscale in youth athletes (37). These findings indicate that poor recovery, rather than increased training stress, may be a greater issue in youth athletes and provide scope for the use of perceptions of sleep as predictors of changes in sport-specific wellbeing questionnaires.

It is unsurprising that there is currently little interest in self-reported sleep duration in the literature given its validity against actigraphy measures has been questioned in the general population (r = 0.45; 19). However, recent studies have indicated that there is strong agreement between actigraphy based measures and self-reported sleep duration in athletic populations (*r* = 0.82-0.90), particularly when participants are asked to record their estimated time in bed rather than specific sleep duration (*r* = 0.90 *vs* *r* = 0.85; 3,16). Furthermore, the usefulness of this estimated time in bed method has previously been shown with regards to illness as self-reported sleep duration, via the estimated time in bed method, of less than seven hours has been related to a three times greater risk of the common cold (6). Consequently, there is support for research considering the influence of self-reported sleep duration on sport-specific athlete wellbeing measures.

Despite the promise of self-reported sleep duration as a measure of recovery in sport (37), studies using students in education have shown the influence of perceptions of sleep quality on wellbeing measures to be greater than sleep duration alone (27,29). Furthermore, pre-competition sleep quality has been related to increased feelings of fatigue and tension, and reduced vigour on the morning of competition as measured by the Brunel Mood Scale in marathon running participants (19). However, perhaps because of its popularity as a subscale within sport specific wellbeing questionnaires, to the authors' knowledge no study has considered the influence of sleep quality on athlete wellbeing alongside training load and exposure to match play. Consequently, a study comparing the influence of self-reported sleep quality and sleep duration on wellbeing alongside the training stressors of training load and exposure to match play is merited. In addition to sleep duration and sleep quality alone, it may be useful to consider the interaction between the two measures (termed 'sleep index' here) as a predictor of changes in wellbeing. To date, no study has considered the influence of a sleep index on wellbeing, but it is reasonable to expect that nine hours of "good" sleep will provide greater recovery benefit than six hours of "good" sleep, as it involves two further full cycles of sleep (4). Therefore, assessing the two measures in unison (i.e. a sleep index) could prove more predictive of outcome measures than considering either sleep duration or sleep quality alone.

To date, there is a body of research suggesting that training load and exposure to match play, as inputs, affect athlete wellbeing (25,37,40), however there is little research considering the use of perceptions of sleep as mediators of the wellbeing response (37). As a result of this gap in the literature, the aim of this study is to assess the influence of self-reported sleep duration, sleep quality and sleep index on the wellbeing response, while controlling for the known training stressors of training load and exposure to match play.

Methods

Experimental Approach to the Problem

This study explored the influence of self-reported sleep duration, sleep quality and sleep index on the wellbeing response, while accounting for the known training stressors of training load and exposure to match play. $DWB_{no\text{-}sleep}$ (a four item DWB, created by removing the sleep quality measure), its individual subscales (fatigue, muscle soreness, stress and mood) and PRS were used as wellbeing measures. The study was conducted seven days per week over a 13-week period from February to May. Participants completed a customised questionnaire to provide current details on $DWB_{no\text{-}sleep}$, PRS, and the previous day's self-reported sleep duration, sleep quality, training load and exposure to match play. Training and match sessions continued as normal throughout the duration of the study. Types of training sessions included: technical training, strength and conditioning training and recovery sessions, all of which could be completed at school, for a club or in the participants personal time. No restrictions were placed on participants' activities and the time these activities took place was not recorded. Relationships between the independent and dependent variables were estimated in separate models for each wellbeing scale and subscale.

Subjects

Forty-eight male and female youth athletes aged 16-18 years (age 17.3 ± 0.5 years, height 172.8 ± 18.3 cm, body mass 73.6 ± 12.8 kg) participated in this study. Participants were recruited from a local independent school in the United Kingdom (UK), where they were members of the school's sport scholarship programme. The sports; cricket (*n*=5), soccer (*n*=10), hockey (*n*=10), netball (*n*=10) and rugby union (*n*=13) were represented by athletes competing at club/school (*n*=29), professional academy (*n*=6), county/regional (*n*=10) and international (*n*=3) standard in their respective sports.

Ethics approval was granted by the University Ethics Committee and written informed consent was provided by all participants and their parents prior to the study.

Procedures

The study was conducted seven days per week over a 13-week period from February to May. Participants completed an online Google Docs (Google Forms, Google, CA, USA) questionnaire before 11am every morning. On training days, the questionnaire was completed prior to the first training session of the day. The form included a DWB related to sleep quality, fatigue, muscle soreness, stress and mood (24), the PRS (21), self-reported sleep duration (in hours, using the estimated time in bed method) and 24 hour training load recall. All participants had been familiarised to the questionnaires prior to the study.

To assess the impact of perceptions of sleep on the wellbeing measures, the sleep quality subscale was removed from DWB to create a four item $DWB_{no\text{-}sleep}$ scored out of 20.. The sleep quality subscale was analysed alone and multiplied by self-reported sleep duration to create the sleep index. For the 24-hour training load recall, participants provided information with regards to the type, duration and intensity of each session from the previous day. Type included technical training, strength and conditioning training, personal gym and matches. Participants could complete multiple session types on a single day, but every day where they participated in a match was used to calculated the additive effect of exposure to match play on $DWB_{no\text{-}sleep}$ and PRS. The intensity of each session was rated using the Borg category ratio-10 scale (8) choosing the respective descriptor, which was converted to the associated rating of perceived exertion (RPE) number and multiplied by the session duration (in minutes) to provide the session-RPE (s-RPE). The sum of all s-RPE's on a single day gave the daily training load. The temporal robustness of the s-RPE method over 24 hours has previously been confirmed (28,38), and the between-day reliability (typical error as a coefficient of variation) of PRS has previously been evaluated in this population as 8.5% (36). The between-day reliability (typical error as a coefficient of variation) of $DWB_{no\text{-}sleep}$ was calculated as 9.8% in this study.

Statistical Analyses

Data were analysed using SAS University Edition (SAS Institute, Cary, NC). A linear mixed model (via Proc Mixed) was used to evaluate the influence of sleep duration, sleep quality and sleep index on $DWB_{no\text{-}sleep}$, its subscales (fatigue, muscle soreness, stress and mood) and PRS, whilst controlling for the effects of training load and match play exposure. Sport (referring to the athlete's sport), week (referring to the week of the study), and day (referring to the day of the week) were added as fixed factors. Training load, sleep duration, sleep quality and sleep index were mean centred by individual. Each model contained training load as a time varying covariate and the dummy covariate match play exposure, which was added on any day where a participant had competed in a match and accounted for the additive influence of exposure to match play on wellbeing measures. Sleep duration, sleep quality and sleep index were added as time varying covariates in separate models. Athlete*training load*sleep (duration, quality or index dependent on the model) was added as an unstructured random effect. This allowed the variation in the effect of training load and sleep on $DWB_{no\text{-}sleep}$ and PRS between individuals to be assessed. Three models were calculated for each scale/subscale analysis, one using sleep duration, sleep quality and sleep index, resulting in the calculation of eighteen models in total. Due to the difficulty in obtaining correlation coefficients from linear mixed models with complicated random effects structures (30), the effect of the covariates was calculated by assessing a two standard deviation (2 SD) difference in the covariate. This evaluates the difference between a typically high and typically low training load or sleep characteristic and falls in line with previous research (13,25).

Following the recent criticisms of both p-values (43) and magnitude based inferences (31), results were analysed for practical significance by observing the effect sizes (ES) and their 90% confidence intervals. A full breakdown of null-hypothesis significance testing and magnitude based inferences for the covariates in each model is provided as supplementary content (Table, supplemental digital content 1-3). The threshold for a change to be considered practically important (the smallest worthwhile change) was set as 0.2 x observed between participant SD, based on Cohen's *d* ES principle. Thresholds for ES were set as: 0.2 *small;* 0.6 *moderate;* 1.2 *large;* 2.0 *very large.* The ES of random effects were doubled to fit the same ES criteria, as opposed to halving the thresholds (12).

Results

2727 data points were collected and analysed for this study at a median response rate of 54/91 completions (range 14-91). Overall, 2181 training sessions, 292 matches and 991 rest days were included. The mean daily training load was 250 ± 317 AU and a 2 SD change was equivalent to 556 ± 208 AU. The mean sleep duration was 7.7 ± 1.5 hours, the mean sleep quality score was 4 ± 1 AU and the mean sleep index was 29 ± 9 AU. A 2 SD change was equivalent to 2.6 ± 1.3 hours, 3 ± 1 AU and 14 ± 6 AU for sleep duration, sleep quality and sleep index respectively.

Figure 1 provides a graphical representation of the effect of self-reported sleep duration, sleep quality and sleep index on $\text{DWB}_{\text{no-sleep}}$, its individual subscales and PRS. With the exception of the muscle soreness subscale and the influence of sleep duration on stress, the relationships between perceptions of sleep and wellbeing measures were *small*. Sleep quality and sleep index showed stronger relationships with all wellbeing measures than sleep duration. Table 1 shows the between participant variation in the impact of the sleep characteristics on the wellbeing measures. Sleep quality showed the smallest between participant variation of the three sleep characteristics for all wellbeing measures except $\text{DWB}_{\text{no-sleep}}$, where sleep index was smallest.

INSERT FIGURE 1 AND TABLE 1 AROUND HERE

Table 2 provides standardised effect sizes for the influence of training load and exposure to match play on $\text{DWB}_{\text{no-sleep}}$, its individual subscales and PRS for the models containing sleep duration, sleep quality and sleep index. The random effects of training load and exposure to match play for $\text{DWB}_{\text{no-sleep}}$ (*trivial* to *small* effects; *d*=0.18-0.20), its individual subscales (*small* to *moderate* effects dependent on the subscale; *d*=0.22-0.85) or PRS (*small* to *moderate* effects; *d*=0.55-0.62) showed no difference between sleep duration, sleep quality and sleep index models.

INSERT TABLE 2 AROUND HERE

Discussion

The aim of this study was to assess the influence of self-reported sleep duration, sleep quality and sleep index on $DWB_{no\text{-}sleep}$, its individual subscales and the PRS in youth athletes, while controlling for the known effects of training load and exposure to match play. Our results indicate sleep duration, sleep quality and sleep index all had a *small* effect on $DWB_{no\text{-}sleep}$, fatigue and PRS. Sleep quality and sleep index also exhibited a *small* influence on stress and mood. On all occasions, the influence of sleep quality and sleep index was greater than sleep duration (Figure 1). In all models, training load and match play exposure had a *small* effect on muscle soreness and PRS. All other effects were *trivial* or were not considered practically significant.

$DWB_{no\text{-}sleep}$

Our results suggest sleep duration, sleep quality and sleep index have a *small* effect on $DWB_{no\text{-}sleep}$ in youth athletes. The *small* influence of sleep duration on $DWB_{no\text{-}sleep}$ supports previous research showing the same association with DWB (37). However, upon removal of the sleep quality measure from DWB, the influence of sleep duration on $DWB_{no\text{-}sleep}$ was reduced. Although little correlation has been reported between sleep duration and sleep quality in non-athletic adolescents (29), research in youth athletes has indicated a *moderate* relationship between self-reported sleep duration and the sleep quality subscale used in this study (37). It is therefore possible that this association between sleep duration and sleep quality, coupled with the relationship between sleep quality and other wellbeing subscales shown in our study may have skewed the DWB score in line with the sleep durations experienced, resulting in an inaccurately strong relationship between sleep duration and DWB in previous studies (36,37). Regardless, our study suggests that both sleep quality and sleep index measures are better predictors of changes in the overall wellbeing score than sleep duration and provides support for their use as an input to, rather than an output of, the monitoring process.

PRS and fatigue

We observed that sleep quality and sleep index have a greater influence on PRS and the fatigue subscale than sleep duration, however all three sleep characteristics had the same *small* effect on both wellbeing measures. The influence of sleep quality on fatigue is remarkably similar in size to the *small* correlation observed in marathon participants prior to competitive performance (19), and the relationship between sleep duration and these fatigue measures is consistent with previous studies using both actigraphy (32) and self-report measures (27). However, the between participant variation in the effect of sleep quality on PRS and fatigue was much lower than that of sleep duration and sleep index (Table 1). This difference could be explained by the variation in athletes' perceptions of good sleep quality and its influence on recovery (18). For some athletes, good sleep quality may refer to uninterrupted sleep, regardless of the duration, in which case the inclusion of the sleep duration term in the sleep index could result in multiplicative error (i.e. if a participant reports sleep duration that is one hour wrong, the difference will be multiplied by the sleep quality score to magnify this error). For others, however, sleep duration may play a role in their perceptions of sleep quality, potentially resulting in smaller differences between participants. These differences in the importance of sleep duration to perceptions of recovery and fatigue could explain the discrepancy between sleep quality and sleep index at an individual level. Furthermore, the discrepancies indicate that, for the purposes of measuring an athlete's perceptions of fatigue/recovery, sleep quality is the most consistent and therefore potentially most useful measure of the sleep characteristics considered in this study.

Mood and stress

Figure 1 depicts the *small* influence of sleep quality and sleep index on mood and stress, which was more certain than the *small* relationship observed between mood and sleep duration, and greater than the *trivial* relationship reported between stress and sleep duration. Sleep duration and sleep quality have previously been related to changes in mood in longer questionnaires (19,27), but in a previous study considering the influence of sleep duration on mood and stress in a short sport-specific questionnaire, no relationship was observed (37). Sleep quality can have a highly individual meaning, but it may include number of sleep disturbances, sleep onset latency, sleep efficiency or total sleep duration dependent on the individual (18), each of which could reduce the restorative capacity of sleep by limiting rapid eye movement or non-rapid eye movement sleep durations (42). Given stress is normally considered along a stress-recovery continuum (14), it is logical that if recovery (in this case measured by perceptions of sleep) is reduced, it would result in greater feelings of stress. Both sleep quality and sleep index showed *small* between participant variation in their impact on mood and stress. This contrasts with the widely varying responses they showed in their effect on perceptions of recovery and suggests that when assessing mood and stress, the two measures could be used interchangeably with consistent results.

Muscle soreness

None of the sleep measures had an influence on muscle soreness, but training load and match stress both had a *small* effect on the measure. This confirms previous findings (37) and it is logical that the more intense the stimulus, as measured by training load and exposure to match play, the more severe the muscle damage and remodelling experienced. It is possible that sleep was not related to muscle soreness as delayed onset muscle soreness can increase in intensity for up to 72 hours as part of the recovery process (5).

Limitations

Despite our data providing useful additions to the literature, particularly with regards to the removal of a sleep-based measure from current wellbeing questionnaires, the validity of this finding cannot be fully confirmed until further research is completed. Self-report wellbeing measures are cost effective, time efficient and easy to analyse (34); however, whilst their validity relative to objective measures has been confirmed in longer questionnaires (e.g.the recovery-stress questionnaire for athletes (REST-Q; 15), the validity of shorter sport specific questionnaires, like the one used here, is still uncertain (35). In order to fully evaluate the validity of subjective wellbeing measures, Saw and colleagues (33) have produced a 13 point checklist of information to include. Whilst our study provides appropriate information for the majority of these points, it does not fully answer points 6, 7 and 12 relating to the validity, reference values and smallest meaningful change of the questionnaire. The aim of this study was to establish whether subjective sleep measures influenced the other subscales of commonly used wellbeing questionnaires. Now that this has been observed, there is a rationale for further research to consider reference values and meaningful changes of the questionnaire in relation to the true outcome measures of performance, injury and illness. However, it is acknowledged that this task could prove difficult as the use of self-report measures alone to understand match performance or within injury monitoring can be criticised because they provide little understanding of the external work undertaken. Specific external workload measures (e.g. high speed running via GPS measurements) have shown good accuracy within this domain via acute:chronic workload injury prevention models (11). However, whereas there is a clear break point for injury monitoring (i.e. medical attention or time loss injuries (10)), there is no definitive point where match performance may improve or decline in response to changes in a wellbeing questionnaire. Consequently, it could be that perceptions of previous training or sleep activities could be more important than objective measures as this perception of events may have the greatest impact on an athlete's ability to achieve their optimal flow state for performance (1). Additionally, although our study has considered the influence of sleep and training load on wellbeing measures, it is unable to account for the indirect relationship these measures may have on each other. Intensive training in the evening, for example, has been shown to impact upon sleep quality (41), which our study has shown can considerably influence wellbeing measures. Similarly, when training is scheduled in the early morning, this has been shown to reduce sleep duration, which can influence wellbeing (32). It is therefore essential that practitioners consider a holistic approach to monitoring and understand that there could be direct and indirect relationships between sleep, training load, exposure to match play and wellbeing measures. Finally, it should be noted that the response rate for this study (median 54/91 completions, range 14-91) may have impacted upon the findings observed. However, it could be argued that this increases the ecological validity of the results as it is extremely difficult in practice to obtain 100% compliance from athletes in monitoring programmes.

PRACTICAL APPLICATIONS

In conclusion, our results provide support for the use of sleep quality and sleep index as inputs to the monitoring process, alongside training load and exposure to match play, rather than as outputs. The sleep quality measure showed the largest and most consistent relationship with $DWB_{no\text{-}sleep}$, fatigue, mood, stress and PRS, but the difference between sleep quality and sleep index was negligible, except for in the individual responses to the recovery based measures of PRS and fatigue. This is important due to the raw change required to elicit the statistical change observed. On a 1-5 scale, a 2 SD difference in sleep quality was equivalent to a change of 3 ± 1 units, whereas for sleep index it was 14 ± 6 AU. A change of 3 units in the sleep quality subscale is a large proportion of the overall score suggesting it may be unlikely to happen, however a change of 14 units in the sleep index scale is more likely. Based on this difference and its incorporation of both sleep duration and quality measures into one score, the authors would recommend the use of sleep index as a measure of perceptions of sleep within monitoring models. However, future studies may wish to consider larger sleep quality scales (i.e. 0-100 rather than 1-5), which may provide greater sensitivity to deviations in wellbeing, as this measure maintains considerable promise as a predictor of changes in wellbeing.

References

1. Anderson, R, Hanrahan, SJ, and Mallett, CJ. Investigating the optimal psychological state for peak performance in Australian elite athletes. *J Appl Sport Psychol* 26: 318–333, 2014.
2. Buchheit, M, Racinais, S, Bilsborough, JC, Bourdon, P, Voss, SC, Hocking, J, et al. Monitoring fitness, fatigue and running performance during a pre-season training camp in elite football players. *J Sci Med Sport* 16: 550–555, 2013.
3. Caia, J, Thornton, HR, Kelly, VG, Scott, TJ, Halson, SL, Cupples, B, et al. Does self-perceived sleep reflect sleep estimated via activity monitors in professional rugby league athletes? *J Sports Sci* 36: 1492–1496, 2018.
4. Carskadon, MA and Dement, WC. Normal human sleep: An overview. In: Principles and Practice of Sleep Medicine. Kryger, MH, Roth, T, and Dement, WC, eds. . St. Louis: Elsevier Saunders, 2011. pp. 16–26
5. Cheung, K, Hume, PA, and Maxwelf, L. Delayed onset muscle soreness: Treatment strategies and performance factors. *Sport Med* 33: 145–164, 2003.
6. Cohen, S, Doyle, WJ, Alper, CM, Janicki-Deverts, D, and Turner, RB. Sleep habits and susceptibility to the common cold. *Arch Intern Med* 169: 62–67, 2009.
7. Dumortier, J, Mariman, A, Boone, J, Delesie, L, Tobback, E, Vogelaers, D, et al. Sleep, training load and performance in elite female gymnasts. *Eur J Sport Sci* 18: 151–161, 2018.
8. Foster, C, Florhaug, JA, Franklin, J, Gottschall, L, Hrovatin, LA, Parker, S, et al. A new approach to monitoring exercise training. *J Strength Cond Res* 15: 109–15, 2001.
9. Fullagar, HHK, Skorski, S, Duffield, R, Hammes, D, Coutts, AJ, and Meyer, T. Sleep and athletic performance: The effects of sleep loss on exercise performance, and physiological and cognitive responses to exercise. *Sport Med* 45: 161–186, 2015.
10. Fuller, CW, Molloy, MG, Bagate, C, Bahr, R, Brooks, JHM, Donson, H, et al. Consensus statement on injury definitions and data collection procedures for studies of injuries in rugby union. *Br J Sports Med* 41: 328–331, 2007.
11. Gabbett, TJ. The training-injury prevention paradox: Should athletes be training smarter and harder? *Br J Sports Med* 50: 273–280, 2016.

12. Hopkins, WG. Individual responses made easy. *J Appl Physiol* 118: 1444–1446, 2015.

13. Hopkins, WG, Marshall, SW, Batterham, AM, and Hanin, J. Progressive statistics for studies in sports medicine and exercise science. *Med Sci Sports Exerc* 41: 3–12, 2009.

14. Kellmann, M. Preventing overtraining in athletes in high-intensity sports and stress/recovery monitoring. *Scand J Med Sci Sports* 20: 95–102, 2010.

15. Kellmann, M and Kallus, KW. Recovery-stress questionnaire for athletes: User manual. Champaign, IL: Human Kinetics, 2001.

16. Knufinke, M, Nieuwenhuys, A, and Geurts, SAE. Self-reported sleep quantity , quality and sleep hygiene in elite athletes. *J Sleep Res* 27: 78–85, 2018.

17. Kölling, S, Endler, S, Ferrauti, A, Meyer, T, and Kellmann, M. Comparing subjective with objective sleep parameters via multisensory actigraphy in German physical education students. *Behav Sleep Med* 14: 389–405, 2016.

18. Krystal, AD and Edinger, JD. Measuring sleep quality. *J Sleep Med* 9: S10–S17, 2008.

19. Lastella, M, Lovell, GP, and Sargent, C. Athletes' precompetitive sleep behaviour and its relationship with subsequent precompetitive mood and performance. *Eur J Sport Sci* 14: S123–S130, 2014.

20. Lauderdale, DS, Knutson, KL, Yan, LL, Liu, K, and Rathouz, PJ. Sleep duration: How well do self-reports reflect objective measures? The CARDIA Sleep Study. *Epidemiology* 19: 838–845, 2008.

21. Laurent, CM, Green, JM, Bishop, PA, Sjokvist, J, Schumacher, RE, Richardson, MT, et al. A practical approach to monitoring recovery: Development of a perceived recovery status scale. *J Strength Cond Res* 25: 620–628, 2011.

22. Leeder, J, Glaister, M, Pizzoferro, K, Dawson, J, and Pedlar, C. Sleep duration and quality in elite athletes measured using wristwatch actigraphy. *J Sports Sci* 30: 541–545, 2012.

23. Mah, CD, Mah, KE, Kezirian, EJ, and Dement, WC. The effects of sleep extension on the athletic performance of collegiate basketball players. *Sleep* 34: 943–950, 2011.

24. McLean, BD, Coutts, AJ, Kelly, V, McGuigan, MR, and Cormack, SJ. Neuromuscular, endocrine, and perceptual fatigue responses during different length between-match

microcycles in professional rugby league players. *Int J Sports Physiol Perform* 5: 367–383, 2010.

25. Montgomery, PG and Hopkins, WG. The effects of game and training loads on perceptual responses of muscle soreness in Australian Football. *Int J Sports Physiol Perform* 8: 312–318, 2013.

26. Noon, MR, James, RS, Clarke, ND, Akubat, I, and Thake, CD. Perceptions of well-being and physical performance in English elite youth footballers across a season. *J Sports Sci* 33: 2106–2115, 2015.

27. Oginska, H and Pokorski, J. Fatigue and mood correlates of sleep length in three age-social groups: School children, students, and employees. *Chronobiol Iternational* 23: 1317–1328, 2006.

28. Phibbs, P, Roe, G, Jones, B, Read, D, Darrall-Jones, J, Weakley, J, et al. Validity of daily and weekly self-reported training load measures in adolescent athletes. *J Strength Cond Res* 31: 1121–1126, 2017.

29. Pilcher, JJ, Ginter, DR., and Sadowsky, B. Sleep quality versus sleep quantity: Relationships between sleep and measures of health, well-being and sleepiness in college students. *J Psychosom Res* 42: 583–596, 1997.

30. Roy, A. Estimating correlation coefficient between two variables with repeated observations using mixed effects model. *Biometrical J* 48: 286–301, 2006.

31. Sainani, KL. The problem with “magnitude-based inference.” *Med Sci Sports Exerc* epub ahead of print, 2018.

32. Sargent, C, Lastella, M, Halson, SL, and Roach, GD. The impact of training schedules on the sleep and fatigue of elite athletes. *Chronobiol Int* 31: 1160–1168, 2014.

33. Saw, AE, Kellmann, M, Main, LC, and Gastin, PB. Athlete self-report measures in research and practice: Considerations for the discerning reader and fastidious practitioner. *Int J Sports Physiol Perform* 12: S127–S135, 2017.

34. Saw, AE, Main, LC, and Gastin, PB. Monitoring athletes through self-report: Factors influencing implementation. *J Sport Sci Med* 14: 137–146, 2015.

35. Saw, AE, Main, LC, and Gastin, PB. Monitoring the athlete training response: Subjective self-reported measures trump commonly used objective measures: A systematic review. *Br J Sports Med* 50: 281–291, 2016.

36. Sawczuk, T, Jones, B, Scantlebury, S, and Till, K. Relationships between training load, sleep duration, and daily wellbeing and recovery measures in youth athletes. *Pediatr Exerc Sci* 30: 345-352, 2018.

37. Sawczuk, T, Jones, B, Scantlebury, S, and Till, K. The influence of training load and sleep length on daily wellbeing measures in youth sport athletes. *J Sport Sci* 36: 2431-2437, 2018.

38. Scantlebury, S, Till, K, Sawczuk, T, Phibbs, P, and Jones, B. The validity of retrospective session-rating of perceived exertion to quantify training load in youth athletes. *J Strength Cond Res* 32: 1975–1980, 2018.

39. Taylor, L, Chrismas, BCR, Dascombe, B, Chamari, K, and Fowler, PM. The importance of monitoring sleep within adolescent athletes: Athletic, academic, and health considerations. *Front Physiol* 7: 101, 2016.

40. Thorpe, RT, Strudwick, AJ, Buchheit, M, Atkinson, G, Drust, B, and 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 Physiol Perform* 12: S2107–S2113, 2017.

41. Vitale, JA, Bonato, M, Galasso, L, La Torre, A, Merati, G, Montaruli, A, et al. Sleep quality and high intensity interval training at two different times of day: A crossover study on the influence of the chronotype in male collegiate soccer players. *Chronobiol Int* 34: 260–268, 2017.

42. Vyazovskiy, V V and Delogu, A. NREM and REM sleep: Complementary roles in recovery after wakefulness. *Neurosci* 20: 203–219, 2014.

43. Wasserstein, RL and Lazar, NA. The ASA’s statement on p-values: Context, process, and purpose. *Am Stat* 70: 129–133, 2016.

Figure 1: Graphical depiction of influence of sleep duration, sleep quality and sleep index on $DWB_{no\text{-}sleep}$, its individual subscales (fatigue, muscle soreness, stress and mood) and PRS. Effect sizes (ES) are provided for a 2 standard deviation difference in the covariate and are presented ES ± 90% confidence intervals. Shaded area represents smallest worthwhile change.

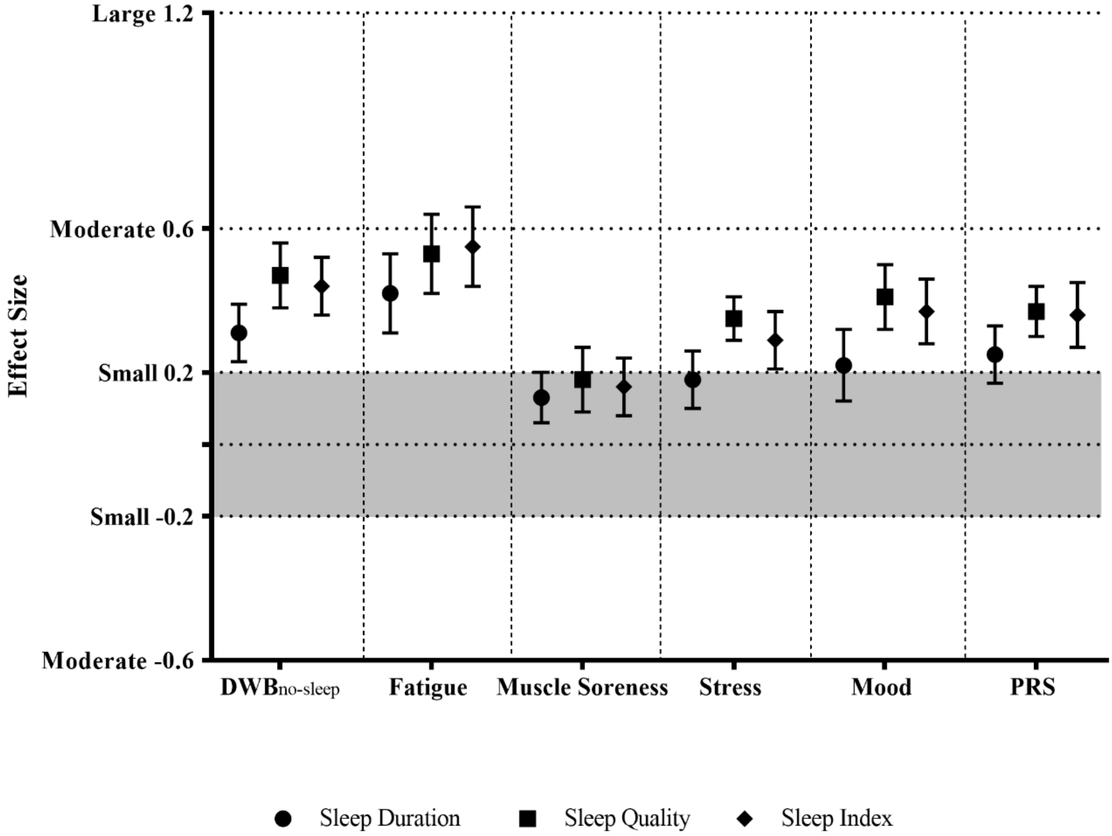

Table 1: Between participant variation in the impact of self-reported sleep duration, sleep quality and sleep index on $DWB_{no\text{-}sleep}$, its individual subscales (fatigue, muscle soreness, stress and mood) and PRS. Data are effect size (90% confidence interval lower bound, 90% confidence interval upper bound). Qualitative descriptions of the effect size are provided in italics.

	Sleep duration	**Sleep quality**	**Sleep index**
$DWB_{no\text{-}sleep}$	0.46 (0.28, 0.92)	0.45 (0.27, 0.91)	0.39 (0.23, 0.83)
	Small	*Small*	*Small*
Fatigue	1.56 (1.01, 2.81)	1.19 (0.73, 2.31)	1.43 (0.92, 2.60)
	Large	*Moderate*	*Large*
Muscle Soreness	0.33 (0.17, 0.98)	0.69 (0.40, 1.49)	0.49 (0.28, 1.16)
	Small	*Moderate*	*Small*
Stress	0.42 (0.22, 1.14)	0.30 (0.16, 0.86)	0.39 (0.20, 1.13)
	Small	*Small*	*Small*
Mood	0.68 (0.42, 1.37)	0.42 (0.23, 1.10)	0.53 (0.31, 1.16)
	Moderate	*Small*	*Small*
PRS	0.64 (0.38, 1.35)	0.33 (0.16, 1.28)	0.65 (0.35, 1.70)
	Moderate	*Small*	*Moderate*

452

Table 2: Influence of training load (TL) and exposure to match play (EMP) on $DWB_{no\text{-}sleep}$, its individual subscales (fatigue, muscle soreness, stress and mood) and PRS. Sleep duration, sleep quality and sleep index headers denote the third covariate in the model (effect sizes for these covariates are shown in Figure 1). Effect sizes (ES) are ES; ± 90% confidence interval. Qualitative description of effect size is given in italics.

	Sleep Duration		**Sleep Quality**		**Sleep Index**	
	TL	**EMP**	**TL**	**EMP**	**TL**	**EMP**
$DWB_{no\text{-}sleep}$	-0.19; ±0.07	-0.12; ±0.06	-0.18; ±0.07	-0.13; ±0.07	-0.19; ±0.06	-0.12; ±0.08
	Trivial	*Trivial*	*Trivial*	*Trivial*	*Trivial*	*Trivial*
Fatigue	-0.15; ±0.08	-0.07; ±0.08	-0.16; ±0.08	-0.10; ±0.08	-0.16; ±0.08	-0.08; ±0.08
	Trivial	*Trivial*	*Trivial*	*Trivial*	*Trivial*	*Trivial*
Muscle Soreness	-0.43; ±0.09	-0.26; ±0.09	-0.44; ±0.10	-0.26; ±0.09	-0.44; ±0.10	-0.26; ±0.09
	Small	*Small*	*Small*	*Small*	*Small*	*Small*
Stress	0.02; ±0.07	0.01; ±0.08	0.02; ±0.07	0.00; ±0.08	0.02; ±0.07	0.01; ±0.08
	Trivial	*Trivial*	*Trivial*	*Trivial*	*Trivial*	*Trivial*
Mood	0.02; ±0.06	-0.02; ±0.10	0.00; ±0.06	-0.02; ±0.10	0.00; ±0.06	-0.02; ±0.10
	Trivial	*Trivial*	*Trivial*	*Trivial*	*Trivial*	*Trivial*
PRS	-0.37; ±0.08	-0.25; ±0.08	-0.37; ±0.09	-0.26; ±0.08	-0.37; ±0.09	-0.25; ±0.08
	Small	*Small*	*Small*	*Small*	*Small*	*Small*

N.B: TL = Training load; EMP = Exposure to match play

Supplemental Digital Content 1: Table showing influence of covariates on wellbeing measures for model including sleep duration as time varying covariate. Standardised effect sizes (ES) are provided for a 2 standard deviation change in the time varying covariates (sleep duration and training load) and for the presence of the dummy covariate (exposure to match play; EMP). They are presented ES; ± 90% confidence intervals for magnitude based inferences (MBI) and ES; ± 95% confidence intervals for null hypothesis significance testing (NHST). A qualitative description of effect size is given in italics. For MBIs, likelihood of effect size is denoted by asterixes: * *possibly; ** likely; *** very likely; **** most likely*. For NHST, significance is denoted by superscripted letters: [a] significant at p<0.05; [b] significant at p<0.01; [c] significant at p<0.001.

	MBI ES	MBI Descriptor	NHST ES	NHST ES Descriptor	NHST P-value
DWB$_{no\text{-}sleep}$					
Sleep duration	0.31; ±0.08	*Small****	0.31; ±0.10	*Small*	P<0.0001[c]
Training Load	-0.19; ±0.07	*Trivial**	-0.19; ±0.07	*Trivial*	P<0.0001[c]
EMP	-0.12; ±0.08	*Trivial***	-0.12; ±0.09	*Trivial*	P=0.01[a]
Fatigue					
Sleep duration	0.42; ±0.11	*Small*****	0.42; ±0.14	*Small*	P<0.0001[c]
Training Load	-0.15; ±0.08	*Trivial***	-0.15; ±0.09	*Trivial*	P=0.002[b]
EMP	-0.07; ±0.08	*Trivial*****	-0.07; ±0.10	*Trivial*	P=0.16
Muscle Soreness					
Sleep duration	0.13; ±0.07	*Trivial***	0.13; ±0.09	*Trivial*	P=0.007[b]
Training Load	-0.43; ±0.10	*Small*****	-0.43; ±0.12	*Small*	P<0.0001[c]
EMP	-0.26; ±0.09	*Small***	-0.26; ±0.11	*Small*	P<0.0001[c]
Stress					
Sleep duration	0.18; ±0.08	*Trivial**	0.18; ±0.09	*Small*	P<0.001[b]
Training Load	0.02; ±0.07	*Trivial*****	0.02; ±0.08	*Trivial*	P=0.58
EMP	0.01; ±0.08	*Trivial*****	0.01; ±0.11	*Trivial*	P=0.84
Mood					
Sleep duration	0.22; ±0.10	*Small**	0.22; ±0.12	*Small*	P<0.001[b]
Training Load	0.02; ±0.06	*Trivial*****	0.02; ±0.07	*Trivial*	P=0.64
EMP	-0.02; ±0.10	*Trivial*****	-0.02; ±0.12	*Trivial*	P=0.77
PRS					
Sleep duration	0.25; ±0.08	*Small***	0.25; ±0.10	*Small*	P<0.0001[c]
Training Load	-0.37; ±0.09	*Small*****	-0.37; ±0.10	*Small*	P<0.0001[c]
EMP	-0.25; ±0.09	*Small***	-0.25; ±0.10	*Small*	P<0.0001[c]

Supplemental Digital Content 2: Table showing influence of covariates on wellbeing measures for model including sleep quality as time varying covariate. Standardised effect sizes (ES) are provided for a 2 standard deviation change in the time varying covariates (sleep quality and training load) and for the presence of the dummy covariate (exposure to match play; EMP). They are presented ES; ± 90% confidence intervals for magnitude based inferences (MBI) and ES; ± 95% confidence intervals for null hypothesis significance testing (NHST). A qualitative description of effect size is given in italics. For MBIs, likelihood of effect size is denoted by asterixes: * *possibly; ** likely;* *** *very likely;* **** *most likely*. For NHST, significance is denoted by superscripted letters: [a] significant at p<0.05; [b] significant at p<0.01; [c] significant at p<0.001.

	MBI ES	MBI Descriptor	NHST ES	NHST ES Descriptor	NHST P-value
$DWB_{no\text{-}sleep}$					
Sleep quality	0.47; ±0.09	*Small*****	0.47; ±0.10	*Small*	P<0.0001[c]
Training Load	-0.18; ±0.07	*Trivial**	-0.18; ±0.08	*Trivial*	P<0.0001[c]
EMP	-0.13; ±0.07	*Trivial***	-0.13; ±0.09	*Trivial*	P=0.003[b]
Fatigue					
Sleep quality	0.53; ±0.11	*Small*****	0.53; ±0.13	*Small*	P<0.0001[c]
Training Load	-0.16; ±0.08	*Trivial***	-0.16; ±0.10	*Trivial*	P=0.003[b]
EMP	-0.10; ±0.08	*Trivial****	-0.10; ±0.10	*Trivial*	P=0.04[a]
Muscle Soreness					
Sleep quality	0.18; ±0.09	*Trivial**	0.18; ±0.11	*Trivial*	P=0.002[b]
Training Load	-0.44; ±0.10	*Small*****	-0.44; ±0.12	*Small*	P<0.0001[c]
EMP	-0.26; ±0.10	*Small***	-0.26; ±0.11	*Small*	P<0.0001[c]
Stress					
Sleep quality	0.35; ±0.06	*Small*****	0.35; ±0.08	*Small*	P<0.0001[c]
Training Load	0.02; ±0.07	*Trivial*****	0.02; ±0.09	*Trivial*	P=0.64
EMP	0.00; ±0.08	*Trivial*****	0.00; ±0.10	*Trivial*	P=0.95
Mood					
Sleep quality	0.41; ±0.09	*Small*****	0.41; ±0.10	*Small*	P<0.0001[c]
Training Load	0.00; ±0.06	*Trivial*****	0.00; ±0.07	*Trivial*	P=0.94
EMP	-0.02; ±0.10	*Trivial*****	-0.02; ±0.10	*Trivial*	P=0.75
PRS					
Sleep quality	0.37; ±0.07	*Small*****	0.37; ±0.09	*Small*	P<0.0001[c]
Training Load	-0.37; ±0.09	*Small*****	-0.37; ±0.10	*Small*	P<0.0001[c]
EMP	-0.26; ±0.08	*Small***	-0.26; ±0.10	*Small*	P<0.0001[c]

Supplemental Digital Content 3: Table showing influence of covariates on wellbeing measures for model including sleep index as time varying covariate. Standardised effect sizes (ES) are provided for a 2 standard deviation change in the time varying covariates (sleep index and training load) and for the presence of the dummy covariate (exposure to match play; EMP). They are presented ES; ± 90% confidence intervals for magnitude based inferences (MBI) and ES; ± 95% confidence intervals for null hypothesis significance testing (NHST). A qualitative description of effect size is given in italics. For MBIs, likelihood of effect size is denoted by asterixes: * *possibly; ** likely;* *** *very likely;* **** *most likely*. For NHST, significance is denoted by superscripted letters: [a] significant at p<0.05; [b] significant at p<0.01; [c] significant at p<0.001.

	MBI ES	MBI Descriptor	NHST ES	NHST ES Descriptor	NHST P-value
DWB$_{no\text{-}sleep}$					
Sleep index	0.44; ±0.08	*Small*****	0.44; ±0.09	*Small*	P<0.0001[c]
Training Load	-0.19; ±0.07	*Trivial**	-0.19; ±0.08	*Trivial*	P<0.0001[c]
EMP	-0.12; ±0.08	*Trivial****	-0.12; ±0.09	*Trivial*	P=0.009[b]
Fatigue					
Sleep index	0.55; ±0.11	*Small*****	0.55; ±0.13	*Small*	P<0.0001[c]
Training Load	-0.16; ±0.08	*Trivial***	-0.16; ±0.09	*Trivial*	P=0.002[b]
EMP	-0.08; ±0.08	*Trivial*****	-0.08; ±0.10	*Trivial*	P=0.09
Muscle Soreness					
Sleep index	0.16; ±0.08	*Trivial***	0.16; ±0.10	*Trivial*	P=0.002[b]
Training Load	-0.44; ±0.10	*Small*****	-0.44; ±0.12	*Small*	P<0.0001[c]
EMP	-0.26; ±0.09	*Small***	-0.26; ±0.11	*Small*	P<0.0001[c]
Stress					
Sleep index	0.29; ±0.08	*Small****	0.29; ±0.09	*Small*	P<0.0001[c]
Training Load	0.02; ±0.07	*Trivial*****	0.02; ±0.08	*Trivial*	P=0.66
EMP	0.01; ±0.08	*Trivial*****	0.01; ±0.10	*Trivial*	P=0.84
Mood					
Sleep index	0.37; ±0.09	*Small*****	0.37; ±0.11	*Small*	P<0.0001[c]
Training Load	0.00; ±0.06	*Trivial*****	0.00; ±0.07	*Trivial*	P=0.90
EMP	-0.02; ±0.10	*Trivial*****	-0.02; ±0.12	*Trivial*	P=0.78
PRS					
Sleep index	0.36; ±0.09	*Small*****	0.36; ±0.10	*Small*	P<0.0001[c]
Training Load	-0.37; ±0.09	*Small*****	-0.37; ±0.10	*Small*	P<0.0001[c]
EMP	-0.25; ±0.08	*Small***	-0.25; ±0.10	*Small*	P<0.0001[c]