Sleep quality in elite athletes : Normative values, reliability and understanding contributors to poor sleep

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Running Head: Sleep in Elite Athletes

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KEY POINTS

- In the present study, 52% of elite athletes were categorised as ‘poor sleepers’ on the PSQI,
- Longer sleep onset latencies and greater daytime dysfunction were observed in female athletes compared to male athletes.
- Team sport athletes reported shorter sleep onset latencies, longer sleep durations, later wake times and spent significantly more time in bed than individual sport athletes but reported lower sleep efficiency compared to individual sport athletes.
- The PSQI components of sleep onset latency and sleep quality made the greatest contribution to the high global PSQI scores. Strategies targeting sleep onset latency may be particularly important in elite athletes.
- Individual questionnaire items or components may be useful for practitioners to guide decision making and recommendations for specific sleep interventions in athletes.

Abstract

Background

The aims of this retrospective study were to 1) provide a description of sleep quality in elite athletes as measured by the Pittsburgh Sleep Quality Index (PSQI), 2) provide normative PSQI data 3) identify differences across sex and sport, 4) identify components that contribute to high PSQI scores and 5) assess PSQI test-retest reliability.

Methods

Four-hundred and seventy-nine athletes (371 female and 108 male) across 20 Olympic team and individual sports completed the PSQI. For ordinal and categorical variables, the Wilcoxon rank sum test and Chi Squared tests were used, respectively. A random forest regression was built to determine the importance of each PSQI component. Test-retest reliability was assessed using two-way mixed effects intraclass correlation coefficients.

Results

Fifty-two percent of athletes had a global PSQI score greater than or equal to 5. Team sport athletes reported significantly longer sleep onset latency times but longer sleep durations compared to individual sport athletes. Sleep onset latency and sleep quality made the greatest contribution to the global PSQI scores. The PSQI demonstrated variability over periods of 2-months or more, with a minimal detectable change of 3 AU.

Conclusion

Long sleep onset latency and poor perceived sleep quality made the greatest contribution to the high PSQI scores observed in approximately half of elite athletes investigated. The PSQI should be administered at regular intervals due to variability within individuals over periods of 2-months or more. Individual questionnaire items or component scores of the PSQI may be useful for practitioners in guiding decision-making regarding sleep interventions in athletes.

1. INTRODUCTION

Sleep is recognised as an important contributor to athlete performance, recovery and wellbeing [1]. Alongside this increase in perceived importance of sleep for athletes, has been an interest in monitoring and quantifying sleep. There are numerous methods to assess sleep in athletes, ranging from polysomnography (considered the gold standard), to activity monitoring, diaries and questionnaires [2]. The determination of which method is most suitable is often based on considerations such as human and financial resourcing, suspected sleep concerns, requirement for expertise and speed with which the results are available.

There is now good evidence to indicate that the majority of athletes experience insufficient sleep quality and/or obtain insufficient sleep quantity when compared to recommended guidelines and/or self-reported sleep needs of athletes [3]. This appears to be independent of the method used to assess sleep, with insufficient sleep reported when assessed by activity monitoring as well as questionnaires [4].

The Pittsburgh Sleep Quality Index (PSQI) is the most commonly used general measure of sleep quality in both clinical and research settings [5]. It has also been utilised in a number of studies investigating sleep in athletes including adolescent, youth and NCAA student athletes [6] [7] [8], Gaelic athletes [9], elite Winter sport athletes [10] and team sport athletes [11]. The PSQI was intended for use with the general population (i.e., absence of clinical sleep problems) and was designed to discriminate between 'good' and 'poor' sleepers by providing an index that is simple and easy to interpret. The PSQI has been validated in a number of diverse populations, and is considered the most rigorously validated tool in sleep diagnostics [12]. However, the PSQI has not been validated in athletes and concern has been raised regarding the use of this questionnaire, particularly given the high scores indicative of 'poor' sleep reported by athletes [13]. Therefore, it has been suggested that the PSQI may overestimate sleep problems in athletes. This is despite similar mean PSQI data (5.64) reported in non-athlete University students of a similar age to athletes in the current study [14].

Mean values of PSQI scores from athletes have been reported as being at or above the threshold for poor sleep (≥ 5) across the literature [4], suggesting poor sleep quality and high levels of sleep disturbance in athletes [4]. This is not surprising due to the challenges that elite sport presents to obtaining optimal sleep (e.g., travel demands, training and/or competition schedules, etc.). However, an increased understanding of PSQI findings in elite male and female athletes, specifically the major contributors to the high scores observed in athletes, may be useful for practitioners. As the PSQI is commonly used and will likely continue to be used widely in both research and practice, providing normative data and specific information on PSQI components in elite athletes is necessary.

When developing the PSQI, the creators acknowledged that sleep quality was a complex measure, is difficult to define and measure objectively and involves various quantitative aspects of sleep quality [2]. Reflecting this, the responses of the PSQI are combined to calculate a global score as well as generate categorical scores representing the seven PSQI component scores (sleep quality, sleep latency, sleep duration, sleep efficiency, sleep disturbances, use of sleep medication and daytime dysfunction). Most studies in athletes report the mean global score and prevalence, with very few studies reporting and exploring component data to understand contributors to the high global scores reported in athletes.

Therefore, the aims of this study were to: 1) provide a detailed description of sleep quality in elite Australian athletes as measured by the PSQI, 2) provide normative data for the PSQI in male and female elite athletes and across individual and team sport athletes, 3) identify potential differences across sex and sport, 4) identify specific aspects of athletes' self-reported sleep that contribute to high PSQI scores through evaluating the seven PSQI components and 5) assess the test-retest reliability of the PSQI.

2. MATERIAL AND METHODS

2.1 Participants and study design

Questionnaires were administered through an electronic management system that is utilised for routine collection of medical records, training loads, wellness monitoring and other related data for Australian Olympic athletes. The PSQI questionnaire was administered through two main methods; as a component of prevalence studies [15-17] or via periodic health evaluation programs conducted by the Australian Institute of Sport between December 2015 and December 2019. Athletes were recruited through their relevant National Sporting Organisation who provided organisational consent. This study was approved by the Australian Institute of Sport Ethics Committee (Approval number 20200203) and complies with the Declaration of Helsinki.

A total of 479 athletes across 20 Olympic sports participated in this retrospective study, 371 were female and 108 were male. Athletes were classified as either a team (n = 298) or individual (n = 181), a team sport was classified as such if there was no individual component to the sport (e.g. soccer *vs.* diving). Team sports included basketball (n = 9; 9 female, 0 male), beach volleyball (n = 10; 5 female, 5 male), soccer (n = 16; 16 female, 0 male), field hockey (n = 39; 20 female, 19 male), netball (n = 153; 153 female, 0 male), rugby sevens (n = 36; 17 female, 19 male) and water polo (n = 35; 35 female, 0 male). Individual sports included athletics (n = 4; 3 female, 1 male), boxing (n = 12; 12 female, 0 male), cycling (n = 3; 2 female, 1 male), diving (n = 34; 23 female, 11 male), equestrian (n = 5; 5 female, 0 male) gymnastics (n = 6; 4 female, 2 male), rowing (n = 18; 11 female, 7 male), sailing (n = 2; 1 female, 1 male), surfing (n = 1; 1 female, 0 male), swimming (n = 51; 27 female, 24 male), triathlon (n = 28; 15 female, 13 male) taekwondo (n = 9; 4 female, 5 male) and weightlifting (n = 8; 8 female, 0 male).

2.2 Questionnaire

Sleep was measured using the PSQI with participants reporting on their usual sleep habits during the past month only [18]. For analysis, the published cut-off score of ≥5 was utilised [18]. The seven components of the PSQI were also calculated and represent: (1) sleep duration, (2) sleep disturbance, (3) sleep latency, (4) daytime dysfunction due to sleepiness, (5) sleep efficiency, (6) overall sleep quality, and (7) sleep medication use[18].

2.3 Statistics

All statistical analyses were performed in RStudio (Version1.1.463) using the R programming language (Version 4.0.3). Prior to statistical analysis, all data were checked for normality through the visual inspection of Q-Q plots and objectively via the Shapiro Wilk test. All variables were significantly different from a normal distribution ($p = <0.05$); as such, non-parametric tests were used. To test differences between (1) males and females and (2) team and individual sport athletes, a range of tests were performed based on the structure of the data. The Wilcoxon rank sum test was used for ordinal and continuous variables and the Chi Squared test for categorical variables. The magnitude of differences was assessed by calculating effect sizes (r for ordinal and continuous data and Cramer's V for categorical data) and 95% confidence intervals (CI) using the *rcompanion* package. Effect sizes were interpreted as *trivial* ≤0.10 *small*, ≤0.3; *medium* ≤0.5; and *large*, >0.5 [19]. When there was a significant difference in a component between groups, the difference in the items loading onto that component were explored. Due to the ordinal, skewed nature of the data, median and interquartile range (IQR) were reported for all variables other than for categorical variables, where percentages were used. Due to the multiple comparisons performed, significance was set at $p < 0.01$.

To determine the importance of the seven components to the global PSQI score, a random forest regression model was built using the *caret* package in R; the PSQI components were set as features and global PSQI score as the outcome variable. A random forest is a non-parametric, ensemble learning algorithm that can work with skewed, ordinal data; as is the case with this study [20]. Prior to building the model, data were randomly split into a training and testing set, with 80% (n = 382) of data used to train the model and 20% (n = 97) of data used to test the model. In order to train the model, an arbitrary seed was set, using the *set.seed* function in R to ensure reproducibility of the model. Data were then centred so the mean for each feature was zero. Training of the model was performed, using 10-fold cross-validation, with three repeats. This involves the dataset being randomly divided into 10 equal subsets, where the model is trained using 9 subsets and tested against the 10^{th}, this process is repeated until each subset has been used as a training and testing set. This method reduces the risk of bias and overfitting of the model due to all data being used in both training and testing sets as opposed to a hold-out validation method [21]. The model is then tuned, by selecting the number of predictors available at each node that minimises the root mean squared error (RMSE) and maximises the R^2 value. Subsequently, a final model is generated for which the permuted importance of the predictors can be determined. To do this, the RMSE is determined for each tree in the model, with all features included, this is then repeated with a feature removed, with the RMSE once again assessed; a large increase in error indicates an increase in feature importance to the overall accuracy of the model. The final tuned random forest from the training data achieved an R^2 of 0.97 ± 0.01 and an RMSE of 0.63 ± 0.26, representing a normalised RMSE of 10% error in comparison to the median global PSQI score. When the model was validated on the testing set, an R^2 of 0.97 and an RMSE of 0.44, representing a normalised RMSE of 9% error in comparison to the median global PSQI score showing an appropriate level of performance on unseen data.

The test-retest reliability of the global PSQI score was assessed on a subsample of 80 participants in order to determine the short-term (2- to 3-month; n = 31), medium-term (3 months to 1-year; n = 35) and long-term (>1 year; n = 38) reproducibility of the measure. The subgroup completed the PSQI on two to five occasions. Two-way mixed effects intraclass correlation coefficients (ICC) and 95%CI (*psych* package) were performed to measure the single absolute agreement and correlation between tests [22]. Correlations were interpreted as <0.5, *poor*; ≤0.75, *moderate*; ≤0.9, *good*; >0.9, *excellent*. In order for practitioners to detect changes over time, the standard error of measurement (SEM) and the minimal detectable change (MDC) were also calculated for global PSQI score.

3. RESULTS

3.1 Normative responses

The median global PSQI score for all athletes was five (IQR = 2 to 7), with 52% of athletes scoring ≥5. The distribution of global PSQI scores are shown in Figure 1. Descriptive statistics (median and IQR) and percentage distribution of the PSQI items for male and female athletes and team and individual athletes are presented in Supplementary Tables A and B, respectively.

FIGURE 1 NEAR HERE

3.2 Male and female athletes

The PSQI results for males and females are presented in Table 1. Almost half of all males and over half of all females had a global PSQI score greater than or equal to five, indicating poor sleep. There were no substantial differences between males and females for global PSQI or any of the components (Table 1). There were however *small* differences for sleep onset latency, daytime dysfunction and medication use. Female athletes reported longer sleep latencies and greater daytime dysfunction than male athletes, and male athletes had a *small* greater use of sleep medication than female athletes. Male athletes were significantly older than female athletes and were more likely to have a co-sleeper, although these differences were *small*.

TABLE 1 NEAR HERE

3.3 Team and individual sport athletes

There was a *trivially* greater global PSQI score for athletes from team sports compared to individual sport athletes. Over half of all team and individual sport athletes, had a global PSQI score greater than five, indicating poor sleep (Table 2). For the individual components, team sport athletes scored poorer on the component for sleep latency, with a *small* difference for both contributing items (Question 2: p = 0.021; *r* = 0.11 [0.01 to 0.19] Figure 2A and Question 5a: p = 0.026; *r* = 0.10 [0.01 to 0.18], Figure 2B). Team sport athletes reported longer sleep durations, with only one item contributing to the sleep duration component (Question 4). Team sport athletes had later bedtimes, waketimes, and sleep midpoints, and spent significantly more time in bed than athletes from individual sports. Individual sport athletes were significantly older than individual sport athletes (*small* difference).

TABLE 2 NEAR HERE

FIGURE 2 NEAR HERE

3.4 Feature Importance

Sleep onset latency (component 2) and sleep quality (component 1) were the most important features in the random forest model to global PSQI score (Figure 3). Sleep medication (component 6), and duration (component 3) had negligible importance to global PSQI score.

FIGURE 3 NEAR HERE

3.5 Reliability

Time had no effect on the reproducibility of the PSQI, with *poor* to *moderate* reliability over short- (ICC = 0.45 [0.31 to 0.60]) medium- (ICC = 0.51 [0.38 to 0.65]) and long-term (ICC = 0.55 [0.43 to 0.67]) periods. The SEM, which highlights the noise within the PSQI, was 2 AU for global score, with a MDC of 3 AU, and can be utilised as the threshold for a *meaningful* change in sleep quality.

4. DISCUSSION

The broad aims of this study were to provide detailed information on the sleep quality of elite athletes as determined by the PSQI and to provide specific information on the components of the PSQI contributing to the high global scores previously reported in athletes. In summary, this study found 1) approximately half (52%) of athletes had a global PSQI score ≥5, 2) there were *small*, non-significant differences between males and females, with females reporting longer sleep onset latencies and greater daytime dysfunction, 3) team sport athletes had significantly longer sleep onset latencies but a longer sleep duration than individual sport athletes, 4) team sport athletes woke later than individual sport athletes and also had a later sleep midpoint, 5) athletes from team sports reported poorer sleep efficiency than individual sport athletes, 6) the PSQI components of sleep onset latency (component 2) and sleep quality (component 1), were the most important components contributing to the high global PSQI scores, 7) the global PSQI score demonstrates *poor* to *moderate* reliability over periods of 2 months or more, and 8) a change of 3 or more (AU) may be considered meaningful with respect to global PSQI scores.

The high global PSQI scores reported in this study are consistent with previous research in athletes [6-11]. Differences were observed between sexes in sleep onset latency and daytime dysfunction. The majority of research investigating sleep in athletes has either focused on male participants only or has presented data that have been combined for males and females. There is however, some evidence to suggest differences in sleep characteristics between male and female elite athletes. Carter et al [23] reported no differences in global PSQI scores between male and female collegiate athletes, however males significantly overestimated total sleep time. When sleep is measured using actigraphy (over three consecutive nights), sleep efficiency was higher in females than males [23]. In a recent study from our group utilising activity monitors to measure sleep [3], female athletes had earlier sleep onset times compared with male athletes, but all other sleep variables (e.g., sleep offset time, sleep duration) were similar between the sexes. The higher daytime dysfunction reported by females in the current study suggests that they may report greater dysfunction as a result of inadequate sleep than males. This may be related to the longer sleep onset latencies reported by female athletes. As discussed in more detail below, sleep onset latency may be easy to recall and may result in a perception of poor sleep and a resultant increased perception of daytime dysfunction.

Athletes from team sports had a *trivially* greater PQSI global score, with these athletes scoring poorer on the components for sleep latency and daytime dysfunction (*small* difference) but reporting longer sleep durations (*small* difference) compared to individual sport athletes. Previous research using activity monitors to quantify sleep in elite individual and team sports athletes indicates that athletes from individual sports go to bed earlier, wake up earlier and obtain less sleep (individual vs team; 6.5 vs 7.0 h) than athletes from team sports[3]. Our findings of longer sleep onset latencies, later wake times, later sleep midpoint times, and lower sleep efficiency in team sport athletes may be explained by difficulty initiating sleep after afternoon/evening competition [24-28]. Further, individual athletes typically wake earlier due to early training start times, particularly in sports such as swimming, rowing and triathlon, which may result in the lower sleep durations observed in individual sport athletes [29, 30]. This is a likely source of collider bias within our data.

However, we were unable to collect the time of training within this study and the level and extent of this bias is unknown. Future research should collect this information such that stratification within the analysis can occur to limit this potential bias.

As mentioned previously, approximately 50% of all athletes score ≥5 on the PSQI, categorising them as 'poor' sleepers [4]. This has led to discussion regarding the utility of the PSQI in assessing sleep quality in athletic populations, particularly the suggestion that the PSQI overestimates sleep problems in athletes. For this reason, we aimed to identify which components of the PSQI have the greatest contribution to the global score. Our findings suggest that sleep onset latency (component 2) and sleep quality (component 1), were the most important contributors. A high sleep onset latency (>30 min) in athletes may be the consequence of a number of athlete-specific factors such as difficulty initiating sleep after afternoon/evening training/competition, caffeine consumption prior to training/competition [31], the use of social media/electronic devices [32] and stress/anxiety associated with competition, selection, sponsorship etc. [33]. The long sleep onset latencies reported by the athletes in the present study may have influenced the low perceived sleep quality (component 1), which was also identified as an important factor contributing to global scores. Difficulty initiating sleep may be frustrating to many athletes and long sleep onset latencies may be easy to recall in the morning, thereby influencing the perception and dissatisfaction of overall sleep quality. Further, asking an individual to rate their perceived sleep quality is highly subjective with the specifics of quality of sleep likely interpreted differently between individuals.

Our findings suggest that targeting sleep onset latency in athletes may be an important factor in improving sleep quality in elite athletes. Sleep education and/or cognitive behaviour therapy for insomnia (CBT-I) that includes strategies to reduce sleep onset latency may be effective. Jones et al [32] reported that on average, athletes used electronic devices for 0-30 min prior to sleep and that use of multiple devices in the evening was associated with a greater perceived difficulty in falling asleep. However, evidence regarding the removal of electronic devices and the subsequent influence on sleep is conflicting, with studies also suggesting no effect of device removal in athletes [34]. It is also acknowledged that the removal/management of electronic device use prior to sleep is challenging, however decreasing exposure to devices may be important for athletes who have difficulty initiating sleep. Other strategies such as minimising caffeine consumption later in the day, avoiding napping after 4pm [35] and identifying strategies to manage psychological stress may be beneficial [36]. Further, with the increasing attention being placed on the importance of sleep, some athletes may be going to bed earlier in a bid to obtain adequate sleep duration, essentially trying to 'force' sleep. This approach is potentially paradoxical for the athlete, as from a physiological perspective there is a 'forbidden zone' for sleep in the early evening, such that even if one is in bed it may be difficult to initiate sleep [37].

Our data is the first to report reliability of the PSQI over time in elite athletes. The finding of only *poor* to *moderate* reliability suggests the need for repeated assessments of sleep quality using the PSQI in athletes. Based on our results, it is suggestive that the results of the PSQI change over a two-month period, highlighting that the PSQI captures sleep state rather than sleep traits. An elite athlete's perceived sleep quality over the previous 4-weeks may be influenced by numerous factors, including phase of training and competition, injury status and non-sport stressors [4]. Therefore, our data suggest that the PSQI is sensitive to changes in perceived sleep quality over time. Further, a change in the global PSQI of 3 or more (AU out of 21) may be considered a true change, as opposed to measurement error, based on the current data. The variability of the PSQI over periods of 2 months or more highlights the need for regular assessment of sleep quality in athletes.

While the PSQI is considered the most rigorously validated sleep questionnaire [12], it has yet to be validated in athletes. And although it cannot be definitively stated that the PSQI indeed overestimates sleep dysfunction in athletes, understanding the components of the PSQI which contribute to the high global scores is important. While subjective in nature, the findings of long sleep onset latencies and poor perceived sleep quality are potentially of concern for the athlete and may result in daytime dysfunction. It is possible that the demands placed on elite athletes may result in poor sleep. On this basis, the data identifying 'poor' sleep in athletes from the PSQI should neither be disregarded nor normalised.

Sleep dysfunction is complex and individuals identified as poor sleepers from one population may present with different symptoms from another. For this reason, strategic utilisation of the PSQI may be warranted. The global score of the PSQI may not be sufficiently specific to provide the necessary insight required. Focussing on individual questionnaire items or components may aid in guiding clinical decision making and recommendations for potential interventions. While the global PSQI score may be limited in the ability to understand the specifics of the sleep disturbance/s, it may be a cost-effective means of screening athletes for further evaluation, including components of sleep quality, when the ability to perform objective monitoring in large groups is limited. Other questionnaires such as the Athlete Sleep Screening Questionnaire [38] and the Athlete Sleep Behaviour Questionnaire, [39] are athlete-specific questionnaires that may provide useful screening and behaviour information for athletes and practitioners [1].

5.1 Limitations

The lack of validation of the PSQI in athletes is an important limitation, however the focus of the current research was to provide additional context around the use of the PSQI in elite athletes. The PSQI does not capture napping behaviour, which may result in more sleep obtained over a 24-hour period. Training and competition information was not collected, and it is acknowledged that this information would provide additional beneficial and important information in this cohort. We report reliability measures to investigate the stability of the score at different time points, however this study is a retrospective design using convenience sampled data whereby the intent of data collection was not to establish the reliability of the tool. Finally, data are collected with elite Australian athletes only and findings may not be generalised to other groups, such as non-elite athletes and athletes from differing socio-economic environments.

5. CONCLUSION

In the present study, 52% of elite athletes were categorised as ‘poor sleepers’, with longer sleep onset latencies and greater daytime dysfunction observed in female athletes compared to male athletes. Team sport athletes reported shorter sleep onset latencies, longer sleep durations, later wake times and spent significantly more time in bed than individual sport athletes but reported lower sleep efficiency compared to individual sport athletes. These findings are likely related to previously reported differences in both training and competition times between individual and team sport athletes. The PSQI components of sleep onset latency (component 2) and sleep quality (component 1) made the greatest contribution to the high global PSQI scores. Strategies targeting sleep onset latency may be particularly important in elite athletes. Individual questionnaire items or components may be useful for practitioners to guide decision making and recommendations for specific sleep interventions in athletes.

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Conflicts of interest/Competing interests

The authors have no conflicts of interest to declare **Availability of data and material**

The authors are willing to discuss data sharing under collaborative agreements. Please contact the corresponding author.

Code availability

Not applicable

Authors' contributions

SLH conceived of the study, participated in its design and coordination and drafted the manuscript; RDJ performed the statistical analysis, creating figures and drafting the manuscript; RNA, MAD, LAT, MKD were involved in data collection, CS and GDR participated in its design and drafting the manuscript. All authors have read and approved the final version of the manuscript and agree with the order of presentation of the authors.

Ethics approval

This study was approved by the Australian Institute of Sport Ethics Committee (approval number 20200203).

Consent to participate

Athletes were recruited through their relevant National Sporting Organisation who provided organisational consent.

Consent for publication

Not applicable

References

1. Walsh NP, Halson SL, Sargent C, Roach GD, Nedelec M, Gupta L, et al. Sleep and the athlete: narrative review and 2021 expert consensus recommendations. Br J Sports Med. 2020 Nov 3.
2. Halson SL. Sleep Monitoring in Athletes: Motivation, Methods, Miscalculations and Why it Matters. Sports Med. 2019 May 15.
3. Sargent C, Lastella M, Halson SL, Roach G. How much sleep does an elite athlete need? International journal of sports physiology and performance. 2021(In Press).
4. Gupta L, Morgan K, Gilchrist S. Does Elite Sport Degrade Sleep Quality? A Systematic Review. Sports Med. 2017 Jul;47(7):1317-33.
5. Mollayeva T, Thurairajah P, Burton K, Mollayeva S, Shapiro CM, Colantonio A. The Pittsburgh sleep quality index as a screening tool for sleep dysfunction in clinical and non-clinical samples: A systematic review and meta-analysis. Sleep Med Rev. 2016 Feb;25:52-73.
6. Anderson ML, Reale RJ. Discrepancies between self-reported current and ideal sleep behaviors of adolescent athletes. Sleep Sci. 2020 Jan-Mar;13(1):18-24.
7. Mah CD, Kezirian EJ, Marcello BM, Dement WC. Poor sleep quality and insufficient sleep of a collegiate student-athlete population. Sleep Health. 2018 Jun;4(3):251-7.
8. Knufinke M, Nieuwenhuys A, Geurts SAE, Coenen AML, Kompier MAJ. Self-reported sleep quantity, quality and sleep hygiene in elite athletes. J Sleep Res. 2018 Feb;27(1):78-85.
9. Biggins M, Cahalan R, Comyns T, Purtill H, O'Sullivan K. Poor sleep is related to lower general health, increased stress and increased confusion in elite Gaelic athletes. Phys Sportsmed. 2018 Feb;46(1):14-20.
10. Bender AM, Van Dongen HPA, Samuels CH. Sleep Quality and Chronotype Differences between Elite Athletes and Non-Athlete Controls. Clocks Sleep. 2019 Mar;1(1):3-12.
11. Swinbourne R, Gill N, Vaile J, Smart D. Prevalence of poor sleep quality, sleepiness and obstructive sleep apnoea risk factors in athletes. Eur J Sport Sci. 2016 Oct;16(7):850-8.
12. Manzar MD, BaHammam AS, Hameed UA, Spence DW, Pandi-Perumal SR, Moscovitch A, et al. Dimensionality of the Pittsburgh Sleep Quality Index: a systematic review. Health Qual Life Outcomes. 2018 May 9;16(1):89.
13. Samuels C, James L, Lawson D, Meeuwisse W. The Athlete Sleep Screening Questionnaire: a new tool for assessing and managing sleep in elite athletes. Br J Sports Med. 2016 Apr;50(7):418-22.
14. Dietch JR, Taylor DJ, Sethi K, Kelly K, Bramoweth AD, Roane BM. Psychometric Evaluation of the PSQI in U.S. College Students. J Clin Sleep Med. 2016 Aug 15;12(8):1121-9.
15. Rogers MA, Appaneal RN, Hughes D, Vlahovich N, Waddington G, Burke LM, et al. Prevalence of impaired physiological function consistent with Relative Energy Deficiency in Sport (RED-S): an Australian elite and pre-elite cohort. Br J Sports Med. 2021 Jan;55(1):38-45.
16. Drew M, Vlahovich N, Hughes D, Appaneal R, Burke LM, Lundy B, et al. Prevalence of illness, poor mental health and sleep quality and low energy availability prior to the 2016 Summer Olympic Games. Br J Sports Med. 2018 Jan;52(1):47-53.
17. Drew MK, Vlahovich N, Hughes D, Appaneal R, Peterson K, Burke L, et al. A multifactorial evaluation of illness risk factors in athletes preparing for the Summer Olympic Games. J Sci Med Sport. 2017 Aug;20(8):745-50.
18. Buysse DJ, Reynolds CF, 3rd, Monk TH, Berman SR, Kupfer DJ. The Pittsburgh Sleep Quality Index: a new instrument for psychiatric practice and research. Psychiatry Res. 1989 May;28(2):193-213.
19. Cohen J. Statistical power analysis for the behavioural sciences. 2nd ed. Erlbaum: Hillsdale, NJ; 1988.
20. Breiman L. Random Forests. Machine Learning. 2001;45(1):5-32.
21. Ambroise C, McLachlan GJ. Selection bias in gene extraction on the basis of microarray gene-expression data. Proc Natl Acad Sci U S A. 2002 May 14;99(10):6562-6.
22. Koo TK, Li MY. A Guideline of Selecting and Reporting Intraclass Correlation Coefficients for Reliability Research. J Chiropr Med. 2016 Jun;15(2):155-63.
23. Carter JR, Gervais BM, Adomeit JL, Greenlund IM. Subjective and objective sleep differ in male and female collegiate athletes. Sleep Health. 2020 Oct;6(5):623-8.

24. Juliff LE, Halson SL, Hebert JJ, Forsyth PL, Peiffer JJ. Longer Sleep Durations Are Positively Associated With Finishing Place During a National Multiday Netball Competition. J Strength Cond Res. 2018 Jan;32(1):189-94.
25. Lalor BJ, Halson SL, Tran J, Kemp JG, Cormack SJ. No compromise of competition sleep compared with habitual sleep in elite Australian footballers. International journal of sports physiology and performance. 2018 Jan 1;13(1):29-36.
26. Sargent C, Roach GD. Sleep duration is reduced in elite athletes following night-time competition. Chronobiol Int. 2016;33(6):667-70.
27. Caffeine can increase brain serotonin levels. Nutr Rev. 1988;46(10):366-7.
28. Dunican IC, Higgin CC, Murray K, Jones MJ, Dawson B, Caldwell JA, et al. Sleep Patterns and Alertness in an Elite Super Rugby Team During a Game Week. J Hum Kinet. 2019 Jun;67:111-21.
29. Sargent C, Halson S, Roach GD. Sleep or swim? Early-morning training severely restricts the amount of sleep obtained by elite swimmers. Eur J Sport Sci. 2014;14 Suppl 1:S310-5.
30. Sargent C, Lastella M, Halson SL, Roach GD. The impact of training schedules on the sleep and fatigue of elite athletes. Chronobiol Int. 2014 Dec;31(10):1160-8.
31. Dunican IC, Higgins CC, Jones MJ, Clarke MW, Murray K, Dawson B, et al. Caffeine use in a Super Rugby game and its relationship to post-game sleep. Eur J Sport Sci. 2018 May;18(4):513-23.
32. Jones MJ, Dawson B, Gucciardi DF, Eastwood PR, Miller J, Halson SL, et al. Evening electronic device use and sleep patterns in athletes. J Sports Sci. 2018 Oct 16:1-7.
33. Juliff LE, Halson SL, Peiffer JJ. Understanding sleep disturbance in athletes prior to important competitions. J Sci Med Sport. 2014 Feb 13.
34. Dunican IC, Martin DT, Halson SL, Reale RJ, Dawson BT, Caldwell JA, et al. The Effects of the Removal of Electronic Devices for 48 Hours on Sleep in Elite Judo Athletes. J Strength Cond Res. 2017 Oct;31(10):2832-9.
35. Lastella M, Halson SL, Vitale JA, Memon AR, Vincent GE. To Nap or Not to Nap? A Systematic Review Evaluating Napping Behavior in Athletes and the Impact on Various Measures of Athletic Performance. Nature and science of sleep. 2021;13:841-62.
36. Halson SL, Appaneal RN, Welvaert M, Maniar N, Drew MK. Stressed and not sleeping: Poor sleep and psychological stress in elite athletes prior to the Rio 2016 Olympic Games. International journal of sports physiology and performance. In Press.
37. Lavie P. Ultrashort sleep-waking schedule. III. 'Gates' and 'forbidden zones' for sleep. Electroencephalogr Clin Neurophysiol. 1986 May;63(5):414-25.
38. Bender AM, Lawson D, Werthner P, Samuels CH. The Clinical Validation of the Athlete Sleep Screening Questionnaire: an Instrument to Identify Athletes that Need Further Sleep Assessment. Sports Med Open. 2018 Jun 4;4(1):23.
39. Driller MW, Mah CD, Halson SL. Development of the athlete sleep behavior questionnaire: A tool for identifying maladaptive sleep practices in elite athletes. Sleep Sci. 2018 Jan-Feb;11(1):37-44.

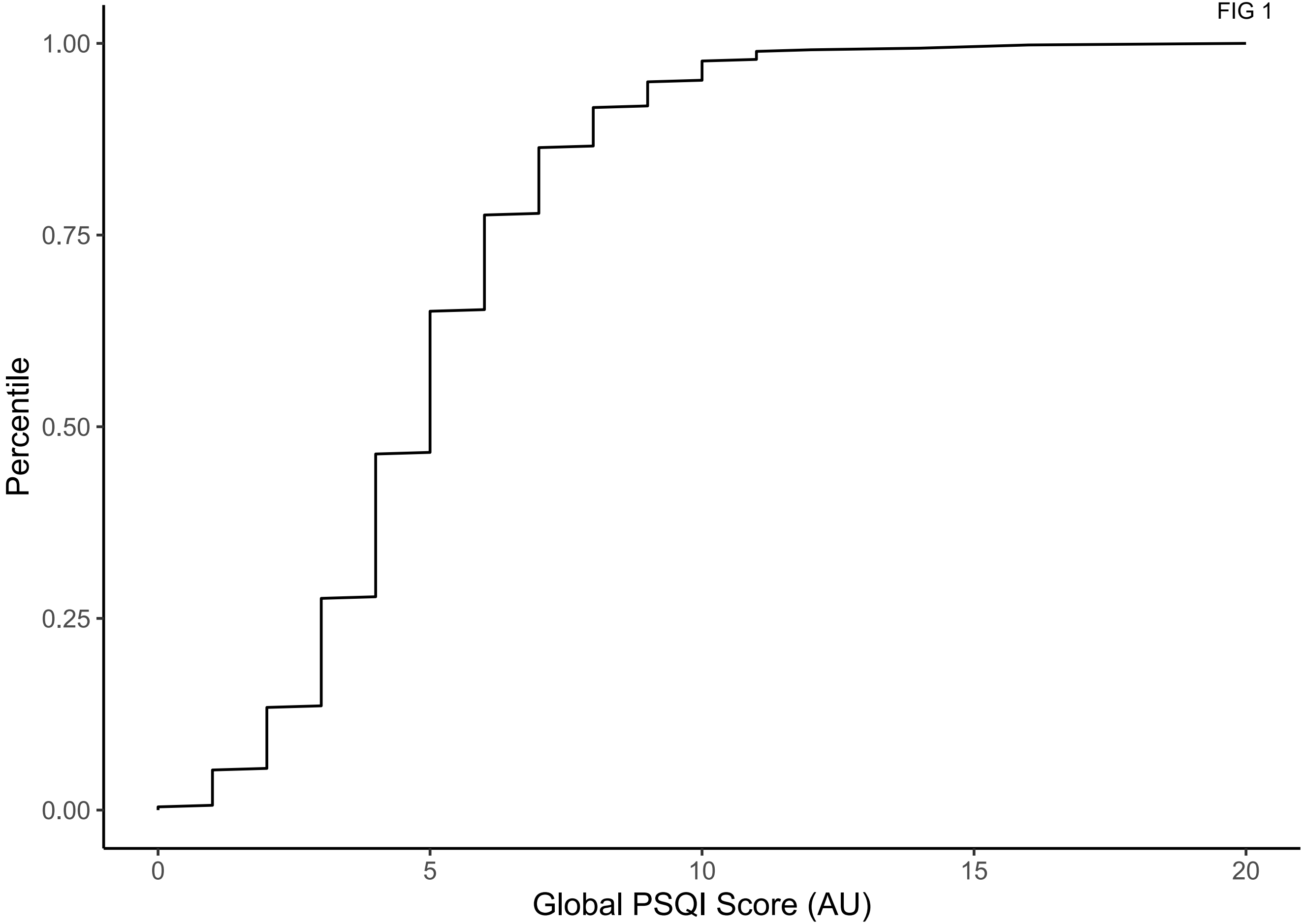
Figure Legends

Figure 1. Percentile distribution of global PSQI score across all athletes.

Figure 2. Difference in the distribution of items loading onto the sleep onset latency component for (A) how long it takes to fall asleep (PSQI, Question 2) and (B) how often it took longer than 30 minutes to fall asleep (PSQI, Question 5a) for individual and team sport athletes.

Figure 3. Importance of each component of global PSQI score from the random forest model. Permutation feature importance was used, with importance scaled to 100.

FIG 1



1.00
0.75
0.50
0.25
0.00
Percentile
0
5
10
15
20
Global PSQI Score (AU)

FIG 2

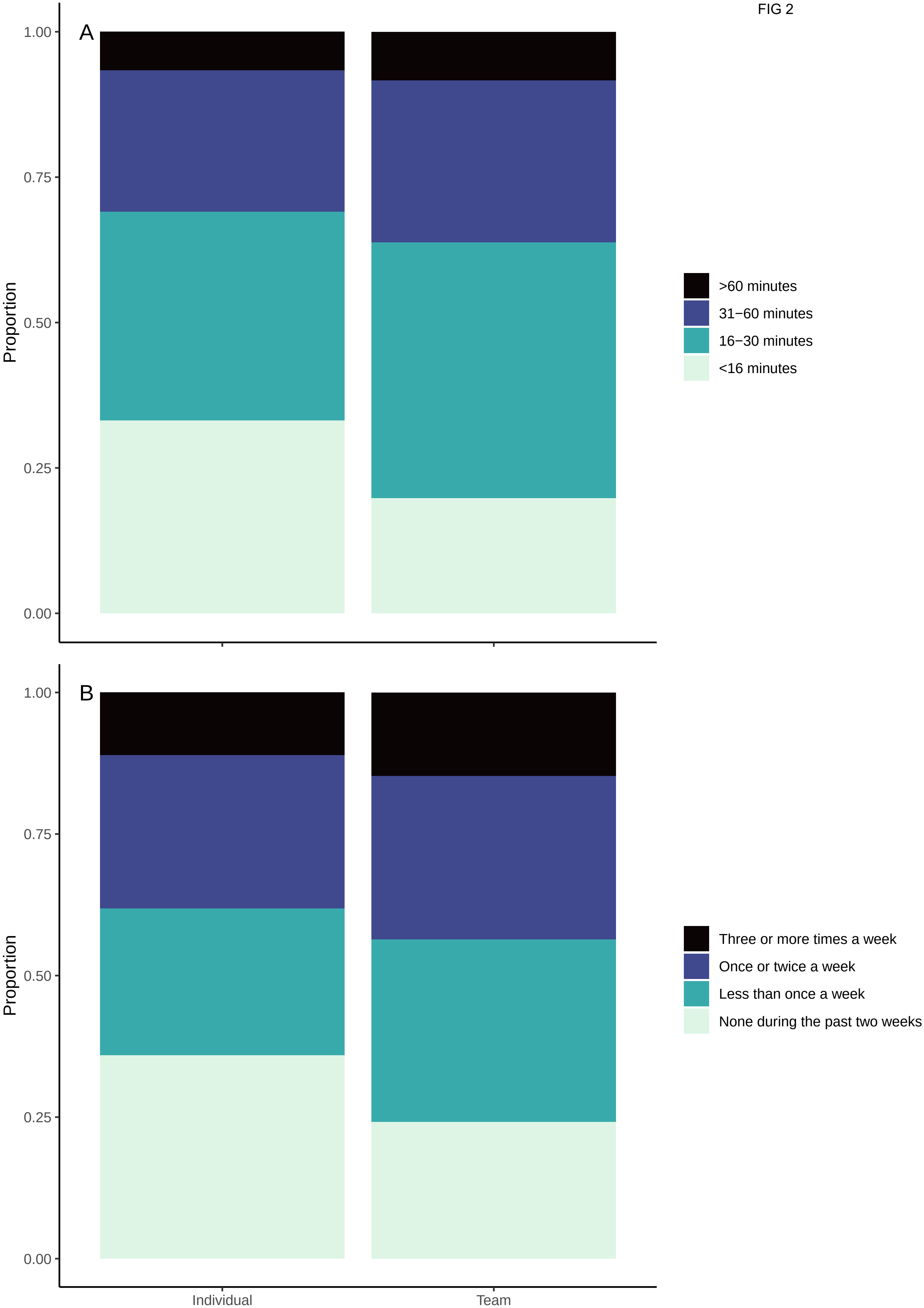

A
B
Proportion
1.00
0.75
0.50
0.25
0.00
Individual
Team
>60 minutes
31−60 minutes
16−30 minutes
<16 minutes
Three or more times a week
Once or twice a week
Less than once a week
None during the past two weeks

FIG 3

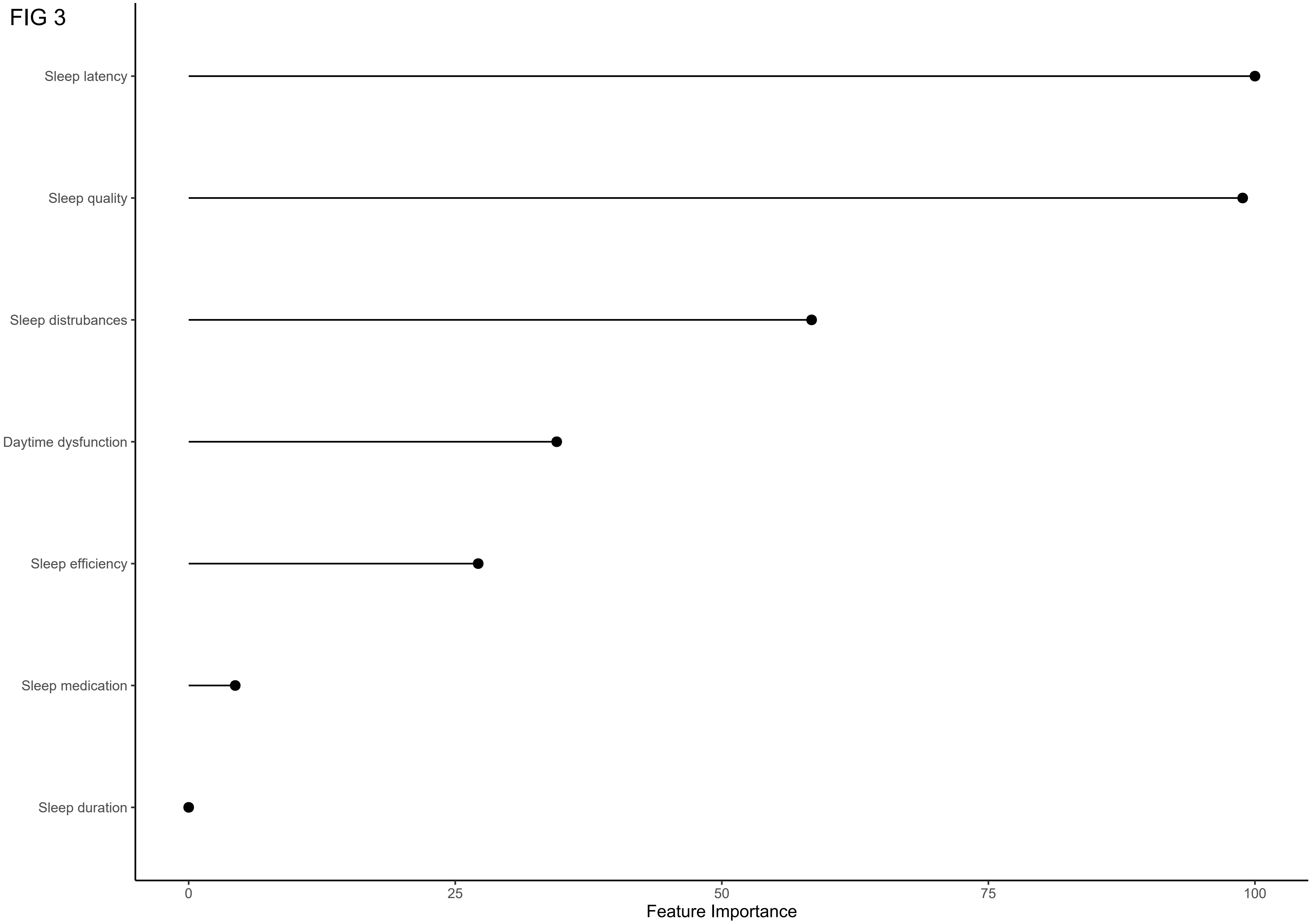

Sleep latency
Sleep quality
Sleep distrubances
Daytime dysfunction
Sleep efficiency
Sleep medication
Sleep duration
0
25
50
75
100
Feature Importance

Table 1. Descriptive data for characteristics, Pittsburgh Sleep Quality Index (PSQI) components, and total score for male and female athletes.

	Male (n = 138)	Female (n = 462)	p-value	Effect Size (95% CI) Male *vs.* Female
Characteristics				
Age	24 (21-27)	19 (17-24)	<0.001*	0.31 (0.23 to 0.38), *small*
Proportion with a partner or roommate (%)	47.2	22.9	<0.001*	0.23 (0.13 to 0.33), *small*
Bed time (hrs:min)	22:00 (21:30-22:30)	22:00 (21:30-22:30)	0.936	-0.03 (-0.09 to 0.09), *trivial*
Wake time (hrs:min)	06:30 (05:30-07:00)	07:00 (06:00-07:30)	<0.001*	-0.13 (-0.21 to -0.04), *small*
Sleep midpoint (hrs:min)	02:15 (01:45-02:45)	02:30 (02:00-03:00)	0.052	-0.04 (-0.12 to 0.04), *trivial*
Time in bed (hrs)	8 (7.5-9)	8.5 (8-9.5)	0.003*	-0.14 (-0.22 to -0.05), *small*
Sleep efficiency (%)	93.3 (88.9-100)	93.8 (87.5-100)	0.986	-0.00 (-0.09 to 0.08), *trivial*
PSQI Components (0-3 score)				
Sleep quality (AU)	1 (1-1)	1 (1-1)	0.142	-0.07 (-0.15 to 0.02), *trivial*
Sleep latency (AU)	1 (0-2)	1 (1-2)	0.021	-0.11 (-0.19 to -0.02), *small*
Sleep duration (AU)	0 (0-1)	0 (0-1)	0.134	0.07 (-0.02 to 0.17), *trivial*
Sleep efficiency (AU)	0 (0-0)	0 (0-0)	0.081	-0.08 (-0.16 to 0.01), *trivial*
Sleep disturbances (AU)	1 (1-1)	1 (1-1)	0.282	-0.05 (-0.14 to 0.04), *trivial*
Sleep medication (AU)	0 (0-0)	0 (0-0)	0.034	0.10 (0.01 to 0.20), *small*
Daytime dysfunction (AU)	1 (0-1)	1 (0-1)	0.028	-0.10 (-0.19 to -0.00), *small*
PSQI Total				
Total (AU)	4 (3-6)	5 (3-6)	0.038	-0.09 (-0.19 to -0.01), *trivial*
Proportion PSQI total ≥ 5 (%)	45.3	55.8	0.072	0.09 (0.00 to 0.18), *trivial*

Data are presented as the median and interquartile range; categorical data are presented as a percentage. Sleep midpoint = midpoint between sleep time and wake time; Sleep efficiency = the proportion of time in bed spent sleeping; PSQI Total % = overall sleep quality score from the PSQI; Proportion ≥5 = the percentage of athletes scoring 5 AU or above on the PSQI. *denotes statistically significant difference (p <0.01); effect sizes interpreted as *trivial*, ≤0.1; *small*, ≤0.3; *medium* ≤0.5; and *large*, >0.5; CI = confidence interval, AU= Arbitrary Units.

Table 2. Descriptive data for characteristics, Pittsburgh Sleep Quality Index (PSQI) components, and total score for team and individual athletes.

	Team Sports (n = 372)	Individual Sport (n = 228)	p-value	Effect Size (95% CI) Team *vs.* Individual
Characteristics				
Age	18 (17-24)	22 (19-26)	<0.001*	-0.20 (-0.28 to -0.11), *small*
Proportion with a partner or roommate (%)	27.9	29.3	0.817	-0.02 (-0.11 to 0.01), *trivial*
Bed time (hrs:min)	22:00 (22:00-22:30)	22:00 (21:30-22:30)	0.010*	0.12 (0.03 to 0.21), *small*
Wake time (hrs:min)	07:00 (06:30-07:30)	06:00 (05:00-07:00)	<0.001*	0.39 (0.30 to 0.48), *medium*
Sleep midpoint (hrs:min)	02:30 (02:15-03:00)	02:00 (01:30-02:30)	<0.001*	0.33 (0.24 to 0.41), *medium*
Time in bed (hrs)	9 (8-9.5)	8 (7-9)	<0.001*	0.34 (0.25 to 0.41), *small*
Sleep efficiency (%)	93.8 (87.5-99.1)	93.8 (88-100)	0.27	-0.05 (-0.14 to 0.03), *trivial*
PSQI Components (0-3 score)				
Sleep quality (AU)	1 (1-1)	1 (1-1)	0.132	0.07 (-0.02 to 0.17), *trivial*
Sleep latency (AU)	1 (1-2)	1 (0-2)	0.010*	0.12 (0.03 to 0.21), *small*
Sleep duration (AU)	0 (0-0)	0 (0-1)	<0.001*	-0.25 (-0.34 to -0.16), *small*
Sleep efficiency (AU)	0 (0-0)	0 (0-0)	0.231	0.05 (-0.03 to 0.14), *trivial*
Sleep disturbances (AU)	1 (1-1)	1 (1-1)	0.055	0.09 (-0.01 to 0.18), *trivial*
Sleep medication (AU)	0 (0-0)	0 (0-0)	0.548	0.03 (-0.06 to 0.12), *trivial*
Daytime dysfunction (AU)	1 (0-1)	1 (0-1)	0.152	0.07 (-0.02 to 0.15), *trivial*
PSQI Total				
Total (AU)	5 (3-7)	5 (3-6)	0.112	0.07 (0.03 to 0.16), *trivial*
Proportion PSQI total ≥ 5 (%)	55	50.8	0.424	0.04 (0.00 to 0.13), *trivial*

Data are presented as the median and interquartile range; categorical data are presented as a percentage. Sleep midpoint = midpoint between sleep time and wake time; Sleep efficiency = the proportion of time in bed spent sleeping; PSQI Total % = overall sleep quality score from the PSQI; Proportion ≥5 = the percentage of athletes scoring 5 AU or above on the PSQI. *denotes statistically significant difference (p <0.01); effect sizes interpreted as *trivial*, ≤0.1; *small*, ≤0.3; *medium* ≤0.5; and *large*, >0.5; CI = confidence interval, AU= Arbitrary Units.