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Which parameters to use for sleep quality monitoring in team sport athletes? A systematic review and meta-analysis

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ABSTRACT

Background Sleep quality is an essential component of athlete's recovery. However, a better understanding of the parameters to adequately quantify sleep quality in team sport athletes is clearly warranted.

Objective To identify which parameters to use for sleep quality monitoring in team sport athletes.

Methods Systematic searches for articles reporting the qualitative markers related to sleep in team sport athletes were conducted in PubMed, Scopus, SPORTDiscus and Web of Science online databases. The systematic review followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses guidelines. For the meta-analysis, effect sizes with 95% CI were calculated and heterogeneity was assessed using a random-effects model. The coefficient of variation (CV) with 95% CI was also calculated to assess the level of instability of each parameter.

Results In general, 30 measuring instruments were used for monitoring sleep quality. A meta-analysis was undertaken on 15 of these parameters. Four objective parameters inferred by actigraphy had significant results (sleep efficiency with small CV and sleep latency, wake episodes and total wake episode duration with large CV). Six subjective parameters obtained from questionnaires and scales also had meaningful results (Pittsburgh Sleep Quality Index (sleep efficiency), Likert scale (Hooper), Likert scale (no reference), Liverpool Jet-Lag Questionnaire, Liverpool Jet-Lag Questionnaire (sleep rating) and RESTQ (sleep quality)).

Conclusions These data suggest that sleep efficiency using actigraphy, Pittsburgh Sleep Quality Index, Likert scale, Liverpool Jet-Lag Questionnaire and RESTQ are indicated to monitor sleep quality in team sport athletes.

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What is already known

- Good sleep quality is important for physical and mental health, wellness and overall vitality.
- Poor sleep quality may lead to accumulation of fatigue, drowsiness and mood changes.
- The term 'sleep quality' has been poorly defined yet ubiquitously used by researchers, clinicians and patients.
- Researchers, clinicians and practitioners have had difficulty to determine the better parameters for monitoring sleep quality.

What are the new findings

- Thirty measuring instruments were used for monitoring sleep quality in team sport athletes.
- The most prevalent ones were (1) actigraphy, (2) Likert rating scale (no reference), (3) Likert rating scale (based on Hooper), (4) Pittsburgh Sleep Quality Index, (5) Epworth Sleepiness Scale and RESTQ-Sport, (6) Liverpool Jet-Lag Questionnaire and Patient-Reported Outcomes Measurement System, and (7) polysomnography.
- Ten sleep quality parameters were identified; four inferred by actigraphy (sleep efficiency, sleep latency, wake episodes and total wake episode duration) and six other quality parameters obtained from questionnaires and scales (including Pittsburgh Sleep Quality Index (sleep efficiency), Likert scale (Hooper), Likert scale (no reference), Liverpool Jet-Lag Questionnaire, Liverpool Jet-Lag Questionnaire (sleep rating) and RESTQ (sleep quality)).
- The more adequate parameters for monitoring sleep quality should have a small to moderate coefficient of variation and a moderate to large effect size.

INTRODUCTION

Good sleep quality is a well-recognised predictor of physical and mental health, wellness and overall vitality.[1] However, the term 'sleep quality' has been poorly defined yet ubiquitously used by researchers, clinicians and patients.[2] Because of this, the National Sleep Foundation assembled a panel of experts from the sleep community and provide the first report on sleep quality recommendations pointing to these key determinants to be

followed: sleeping more time while in bed (at least 85% of the total time), falling asleep in 30 min or less, waking up no more than once per night, and being awake for 20 min or less after initially falling asleep.[1] Sleep quality of athletes may be altered due to different factors, among them, the congested competition calendar, low sleep priority in relation to other training demands as well as lack of knowledge regarding the role of sleep in optimising sports performance.[3–5] In general, athletes are frequently exposed to circadian rhythm desynchronisation (eg, jet lag during international competitions), changes in sleeping habits (eg, hotel sleep, number of athletes per room), late-night matches, and stress and muscle pain due to competition, intense training and travelling.[6]

A poor sleep quality may lead to accumulation of fatigue, drowsiness and changes in mood.[7] Furthermore, insufficient sleep has been negatively related to physical performance (eg, speed and anaerobic power), neurocognitive function (eg, attention and memory) and physical health (eg, illness and injury risk).[3 7 8] Reduction in sleep quality and quantity may contribute to an imbalance of the autonomic nervous system function, resulting in symptoms of overtraining syndrome and elevation of inflammatory markers and, finally, immune system dysfunction.[8] Furthermore, differences between the characteristics from individual and team sports can influence the quantity (eg, total sleep time) and quality of sleep (eg, sleep efficiency and sleep latency) of the athletes.[4 8] In particular in team sports, it is not uncommon for match or competitions to be held at night to optimise the audience attendance (eg, night football games). From this perspective, it seems reasonable to assume that sleep in team sport athletes depends on many factors, including the type of sport, training demands, age, time of year and team culture.[9] In addition, the main reasons for sleep disorders in team sports are related to night games,[8 9] due to the fact that athletes are often required to travel following the matches,[8] to the congested fixtures calendar[4 6] and to the maladaptation of training in sleep loss.[6] Furthermore, after night games, sometimes the athletes may use this moment for socialising and drinking with family and friends.[6] These factors explain why the time course of recovery for both performance and psychophysiological measures is affected after sleep disorders.[4 7 8]

The number of studies on sleep involving team sport athletes has considerably increased over the last years,[8] and three recent reviews have discussed the role of sleep in the recovery of team sport athletes.[8 10 11] To date, the emphasis has been on monitoring sleep in team sport athletes using different instruments (eg, polysomnography (PSG), actigraphy, questionnaires and scales). The gold standard is PSG; however, the feasibility of the measurement in the field is limited for monitoring sleep in the team sport athletes. Therefore, questionnaires and scales for sleep monitoring are commonly used as they are inexpensive and easy to implement in the field. Moreover, previous research has indicated good agreement (ie, validity) between some actigraphy measures and PSG, another instrument with easy implementation in the field.[6] Regardless, all these instruments suggest sleep quality is insufficient in team sport athletes due to non-negotiable factors as competition schedules (eg, late evening) and frequent travel as well as negotiable factors as training times (eg, early morning or late evening) and poor sleep habits (eg, light exposure, electronic device use and caffeine consumption).[6]

Therefore, given the importance of sleep quality parameters in an athlete's recovery process, a better understanding of the contribution of these parameters may be helpful for scientists and practitioners. An understanding of which parameters to use for sleep quality monitoring in team sport athletes warrants investigation. Several questions about sleep quality should be appropriately discussed, one of which would be the instruments used to monitor sleep. Considering the importance of these issues, the purpose of this systematic review and meta-analysis was to identify which parameters to monitor sleep quality in team sport athletes.

METHODS

Procedure and registration

The review methodology adopted the Preferred Reporting Items for Systematic Reviews and Meta-Analyses guidelines and was prospectively registered in the PROSPERO database for systematic reviews. The selection process and data extraction methods were completed by three authors (JGC, HdSS and MS). The quality appraisal was completed by two authors (HdSS and MS).

Search strategy

Four electronic databases (PubMed, Scopus, SPORTDiscus and Web of Science) were systematically searched from inception up to October 2017. The command line ("sleep" OR "sleep quality" OR "sleep quantity" OR "sleep behavior" OR "sleep disturbance" OR "sleep deprivation" OR "circadian rhythm") AND ("team sport" OR "team sports" OR "soccer"' OR "football" OR "rugby" OR "hockey" OR "cricket" OR "futsal" OR "volleyball" OR "basketball" OR "korfball" OR "netball" OR "handball" OR "baseball" OR "softball" OR "lacrosse" OR "curling" OR "polo") was used during the electronic search.

Eligibility criteria and selection process

Systematic review

Three authors (JGC, HdSS and MS) reviewed and identified the titles and abstracts based on the following inclusion criteria:

1. The study was written in English.
2. The study was published as original research in a peer-reviewed journal as a full-text article.
3. Data were reported specifically for team sport athletes.
4. Study performed during the athlete's sporting career.
5. The participants were competitive athletes (defined as olympic, international, professional, semiprofessional, national, youth elite or division I collegiate).

Table 1 Risk of bias assessment criteria

Criteria		Definition	Scoring 0	1	2
A	Peer reviewed	Study published in peer-reviewed journal	No	Yes	–
B	No of participants	No of participants included in study findings	<5	6–30	>31
C	Population defined	Age, gender, sport, time experience were described	No	Partly	Yes
D	Experimental design	Experimental design of the study period was described and replicable	No	Partly	Yes
E	Sleep parameters	The sleep parameters were described	No	Yes	–

6. Sleep quality parameters were included.
7. The participants had not used chronic medication/drugs.

Meta-analysis

Three authors (JGC, HdSS and MS) were asked to review the selected articles for inclusion in the meta-analysis. To meet the inclusion criteria for the meta-analysis, the sleep parameters were required to be measured at baseline and postintervention with the aim of verifying team sport practice effects on sleep quality. Moreover, the parameters analysed were required to be reported in more than one study. If pertinent data were absent, the authors were contacted and the necessary information was requested via email. If the original data were not provided by the authors, the mean and SD were extracted from graphical representation using the tool Ycasd[12] or estimated from the median, range and sample size.[13] Sleep parameters were separate in subjective and objective measurements of sleep quality. Subjective parameters were from questionnaires and scales whereas objective parameters were inferred by actigraphy, PSG and other equipment.

Quality assessment

The quality of all studies was evaluated by two authors (HdSS and MS) using evaluation criteria (table 1) based on a study by Saw *et al*.[14] Scores were allocated based on how well each criterion was met, assuming a maximum possible score of 8 (low risk of bias). Studies with a risk of bias score of 4 or less were considered poor, and were excluded. The Kappa agreement (κ) was used to describe the intensity of agreement between the two reviewers, being interpreted from the scale of magnitude proposed by Altman.[15]

Publication bias was determined for the meta-analysis using an approach where differences in baseline assessments were checked for all intervention groups. Then, the interventions were separated into non-significant ($p>0.05$) or significant ($p<0.05$) results to determine the percentage of interventions with non-significant differences (according to other meta-analyses performed previously).[16 17]

Statistical analysis

Heterogeneity of the included studies was evaluated by examining forest plots, CIs and I^2. The I^2 values of 25, 50 and 75 indicate low, moderate and high heterogeneity, respectively.[18] Random effects were analysed using the DerSimonian and Laird approach.[19] The meta-analysis was conducted based on the number of sleep quality parameters. Statistical significance was set at p value ≤0.05 and the magnitude of differences for each dependent variable were calculated using Hedges (g) effect size (ES) with 95% CIs.[19] The sensitivity of the sleep parameters was assessed using ES (large effect, >0.80; moderate effect, 0.20–0.80; small effect, <0.20).[20] The coefficient of variation (CV) (ie, (SD/mean)×100,[21] with 95% CI)[22] of each sleep parameter was calculated to interpret its respective level of instability.[23] A scale for the CV has been suggested with CV >30%=large and CV <10%=small.[24] Variables with a large CV are less likely (OR) to detect statistically significant differences.[25] All data were analysed using CMA V.3 trial (Biostat, New Jersey, USA) and Excel 2013 worksheet (Microsoft, Washington, USA).[26]

RESULTS

The initial search returned 1809 articles (figure 1). After the removal of duplicate articles (n=900), a total of 909 studies were retained for full text screening. Following eligibility assessment, 832 studies were excluded as they did not meet the set inclusion criteria. Thus, 77 studies, published between 1993 and 2017, were included in this systematic review. Fifty-six per cent of articles were published in the last 3 years (for details see online supplementary table 1).[9 27–102] In addition, 42 did not meet the meta-analysis criteria. Therefore, 35 studies were included in the meta-analysis. There was good agreement between the two reviewers (κ=0.761, 95% CI (0.677 to 0.845); p<0.0001; agreement percentage=83%).

Characteristics of the studies

The pooled sample size and age were 4083 participants and 23±4 years, respectively, with the vast majority (91%) composed by men. About half of the sample (47%) were Soccer players, 16% Australian Football League players, 12% Basketball, 9% Rugby League, 5% American Football, 5% Rugby Union, 4% Ice Hockey, 4% Netball, 3% Field Hockey, 3% Volleyball and 1% each were Blind Soccer, Cricket, Gaelic Football, Rugby Sevens, Softball, Water Polo, Wheelchair Basketball and Wheelchair Rugby players. The studies were developed in 27 countries around the world with a large majority in Australia (44%), UK (17%), USA (13%) and Qatar (10%) (for

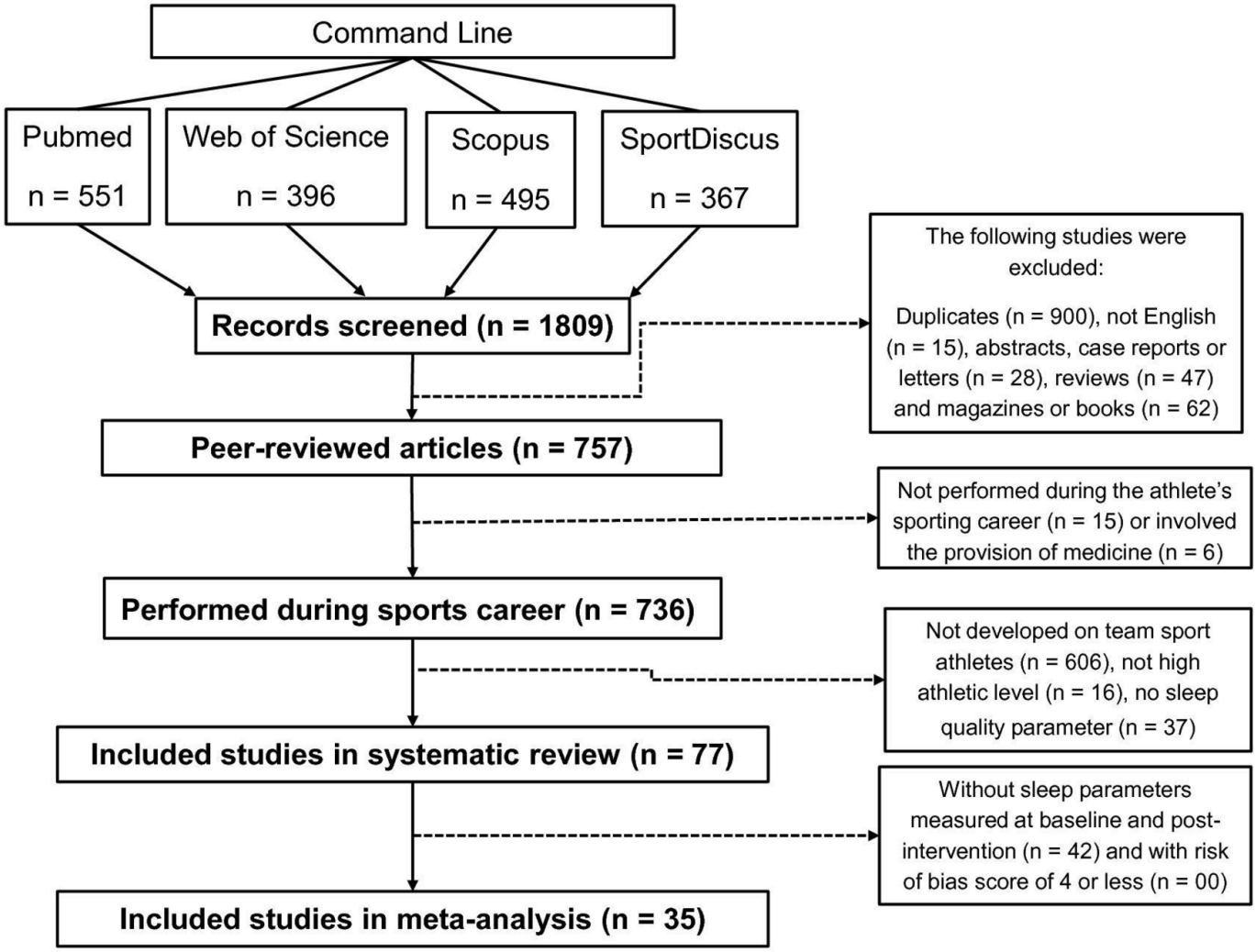

Figure 1 Study selection Preferred Reporting Items for Systematic Reviews and Meta-Analyses flow diagram.

details see online supplementary table 1). The pooled duration of the interventions was, on average, 9 weeks (range, 1–60 weeks). Furthermore, the interventions were performed during season (29%), diagnostic of sleep disorders (25%), short and long-haul air travel (16%), pre-season (8%), Ramadan (6%), evening competition (5%), sleep hygiene (5%), sleep deprivation (4%), red or bright light treatment (3%) and early evening training (1%).

Risk of bias

All included studies had a low risk of bias, with a score >4 (see online supplementary table 2). The average bias score for the studies was 7 (range, 5–8). For the included articles in the meta-analysis that reported the p value, 85% of the intervention groups resulted in non-significant (p>0.05) differences at baseline assessments (ie, 208 interventions with non-significant differences/244 overall interventions=85%).

Systematic review findings

Initially, in order to permit an adequate reading flow, the summary of the 77 studies included in the systematic review are described in online supplementary table 3. Thirty measurement instruments were used for monitoring sleep quality in team sport athletes with 24 (ie, 80%) of them being questionnaires and scales (table 2). The following instruments were the most prevalent: (1) actigraphy with seven different type of devices (32%); (2) Likert rating scales without references being provided (19%); (3) Likert rating scale based on Hooper *et al*[103 104] (18%); (4) Pittsburgh Sleep Quality Index (12%); (5) Epworth Sleepiness Scale and Recovery-Stress Questionnaire for Athletes (RESTQ-Sport) (8%); (6) Liverpool Jet-Lag Questionnaire and Patient-Reported Outcomes Measurement System (PROMIS) (6%); (7) PSG with three different type of devices (5%). Information on the validity and reliability of the most prevalent instruments listed above were reported in almost 100% of articles, except for actigraphy (validity=84% and reliability=80%) and Likert rating scales without references being provided (validity=0% and reliability=7%).

The CV of the sleep quality parameters inferred by actigraphy also was calculated to determine their level of instability (see table 3). Variables with a large CV (ie,

Table 2 Instruments used for sleep quality monitoring

Instruments		Percentage of articles (%)*	Validity (%)†	Reliability (%)†
1	Actigraphy (7 different devices were used)‡	32 (25 articles)	84 of articles	80 of articles
2	Rating Likert scales (no references were provided)	19 (15 articles)	0 of articles	7 of articles
3	Rating Likert scale (based on Hooper and Mackinnon 1995[103])	18 (14 articles)	100 of articles	100 of articles
4	Pittsburgh Sleep Quality Index (Buysse *et al* 1989)	12 (9 articles)	100 of articles	100 of articles
5	Epworth Sleepiness Scale (Johns 1991)	8 (6 articles)	100 of articles	100 of articles
6	RESTQ-Sport (Kellmann; Kallus 2001)	8 (6 articles)	100 of articles	100 of articles
7	Liverpool Jet-Lag Questionnaire (Waterhouse *et al* 2000)	6 (5 articles)	100 of articles	100 of articles
8	PROMIS (Yu *et al* 2011)	6 (5 articles)	100 of articles	100 of articles
9	Polysomnography (3 different devices were used)§	5 (4 articles)	Gold standard	Gold standard
10	Rating Likert scale (based on Kölling *et al* 2014)	4 (3 articles)	100 of articles	100 of articles
11	Sleep diary (no reference was provided)	4 (3 articles)	0 of articles	0 of articles
12	Insomnia Severity Index (Bastien 2001)	3 (2 articles)	100 of articles	100 of articles
13	Visual Analogue Scale (no reference was provided)	3 (2 articles)	0 of articles	0 of articles
14	Stanford Sleepiness Scale (Hoddes *et al* 1972, 1973)	3 (2 articles)	100 of articles	100 of articles
15	Basic Nordic Sleep Questionnaire (Partinen; Gislason 1995)	1 (1 article)	0 of articles	0 of articles
16	Competitive Sports and Sleep Questionnaire (Erlacher *et al* 2011)	1 (1 article)	0 of articles	0 of articles
17	Karolinska Sleepiness Scale (Akerstedt 1990)	1 (1 article)	0 of articles	0 of articles
18	Peripheral Arterial Tonometry (PAT, WatchPAT-200; Itamar Medical)	1 (1 article)	100 of articles	100 of articles
19	Photoplethysmography (Morpheus Ox; WideMed)	1 (1 article)	100 of articles	100 of articles
20	Portable sleep apnoea monitoring (Apnealink)	1 (1 article)	100 of articles	100 of articles
21	Question (no reference was provided)	1 (1 article)	0 of articles	0 of articles
22	Rating Likert scale (based on Brandt *et al* 2014)	1 (1 article)	100 of articles	100 of articles
23	Rating Likert scale (based on Carney *et al* 2012[117])	1 (1 article)	0 of articles	0 of articles
24	Rating Likert scale (based on Rains *et al* 2012)	1 (1 article)	0 of articles	0 of articles
25	Self-Assessment Questionnaire of Sleep and Awakening quality (Salute *et al* 1987)	1 (1 article)	100 of articles	100 of articles
26	Sleep-Apnea Screening Questionnaire (no reference was provided)	1 (1 article)	0 of articles	0 of articles
27	Self-report diaries (based on Sargent *et al* 2001)	1 (1 article)	0 of articles	0 of articles
28	Sleep-EEG (Fp2-A1; Somnowatch)	1 (1 article)	0 of articles	0 of articles
29	Subjective sleep questionnaire: Regman (German Federal Institute of Sport Science)	1 (1 article)	100 of articles	100 of articles
30	Total Quality Recovery action (TQRact) (Kenttä; Hassmén 1998)	1 (1 article)	100 of articles	100 of articles

*Percentage of total articles (number of articles).
†Percentage of the articles that present information on validity and reliability of measuring instruments or reference
‡Philips Respironics (n = 10); Fatigue Science (n = 4); Actigraph (n = 4); Ambulatory Monitoring (n = 3); Cambridge Neurotechnology (n = 3); SenseWear (n =2); Zeo (n = 1).
§Compumedics (n = 1); Medcare Embla/Somnologica System (n = 1); Randersacker (n = 1).

CV>30%=large) are less likely (OR) to detect statistically significant differences during repetitive measurement.[25] The definition and procedures used to measure objective parameters inferred by actigraphy are presented in table 4.

Meta-analysis findings

Meta-analyses were performed on the 15 sleep quality parameters (figure 2). Five objective parameters were inferred by actigraphy: (1) sleep efficiency (ES=0.46 (0.32 to 0.61), p<0.01; I^2=59.3, p<0.01), (2) sleep latency (ES=0.34 (0.20 to 0.47), p<0.01; I^2=00.0, p=0.84), (3) time awake (ES=0.28 (−0.01 to 0.57), p=0.06; I^2=30.4, p=0.22), (4) wake episodes (ES=0.55 (0.35 to 0.75), p<0.01; I^2=43.8, p<0.01) and (5) total wake episodes duration (ES=0.58 (0.39 to 0.77), p<0.01; I^2=12.4, p=0.03). Ten subjective parameters were obtained from questionnaires

Table 3 Coefficient of variation (CV) of the objective parameters inferred by actigraphy

	Objective parameters	CV (95% CI)
1	Mean activity score, min*	2 (2 to 2)
2	Sleep efficiency, %	7 (6 to 8)
3	Time asleep, min*	10 (7 to 14)
4	Actual sleep, %*	11 (10 to 12)
5	Moving time, %*	34 (31 to 37)
6	Wake variance, min*	41 (39 to 42)
7	Time awake, min	41 (26 to 56)
8	Sleep onset variance, min*	45 (35 to 55)
9	Wake episodes, n	58 (51 to 64)
10	Total wake episode duration, min	74 (66 to 82)
11	Sleep latency, min	83 (75 to 90)
12	Variance from mean bed time, min*	679 (157 to 1200)

*This variable was used in just one study.

and scales: (1) Pittsburgh Sleep Quality Index (PSQI) (ES=0.34 (−0.03 to 0.71), p=0.07; I^2=00.0, p=0.70), (2) PSQI—sleep efficiency (PSQI_efficiency) (ES=0.57 (0.08 to 1.07), p=0.02; I^2=00.0, p=0.43), (3) PSQI—sleep latency (PSQI_latency) (ES=0.82 (−0.15 to 1.78), p=0.10; I^2=71.8, p=0.03), (4) Epworth Sleepiness Scale (ESS) (ES=0.86 (−0.22 to 1.95), p=0.12; I^2=82.2, p<0.01), (5) Likert scale (based on Hooper) (ES=0.55 (0.23 to 0.87), p<0.01; I^2=52.0, p=0.01), (6) Likert scale (no reference) (ES=0.66 (0.44 to 0.89), p=0.00; I^2=31.6, p=0.12), (7) Liverpool Jet-Lag Questionnaire (LJLQ) (ES=0.93 (0.42 to 1.45), p<0.01; I^2=67.6, p<0.01), (8) Liverpool Jet-Lag Questionnaire—Sleep rating (LJLQ_sleep) (ES=0.63 (0.32 to 0.94), p<0.01; I^2=53.3, p=0.02), (9) RESTQ (Sleep quality) (ES=0.56 (0.25 to 0.87), p<0.01; I^2=52.5, p=0.04, (10) Visual Analogue Scale—no reference (ES=0.20 (−0.09 to 0.48), p=0.18; I^2=00.0, p=1.00).

DISCUSSION

In this study, we sought to better understand the sensitivity, level of instability, reliability and efficacy of tools for monitoring sleep quality in team sport athletes. In this sense, we can understand sleep quality as a variable of complex definition and diagnosis which depends directly on some parameters related to sleep architecture such as sleep efficiency, latency and wakefulness duration[105 106] as well as indirect measures such as perception of sleep quality and level of sleepiness.[107 108] A more comprehensive understanding of which parameters can adequately indicate sleep quality in team sport athletes has yet to be reported in the literature. In general, 30 measuring instruments were used for sleep quality monitoring (for details see table 2). A meta-analysis was undertaken concerning 15 of these parameters. Four objective parameters inferred by actigraphy had significant results with sleep efficiency presenting a moderate ES with small CV. In addition, three parameters (sleep latency, wake episodes and total wake duration) also showed moderate ES but with large CV. Six other subjective parameters obtained from questionnaires and scales had significant results with moderate and large ES: PSQI_efficiency, Likert scale (based on Hooper), Likert scale (no reference), LJLQ, LJLQ_sleep and RESTQ (Sleep quality).

For the most prevalent instruments, some advantages and disadvantages deserve discussion. Actigraphy was the most commonly used method from practitioners and sports scientists, probably due to the ease of its field application and their high validity and reliability. This assessment uses an accelerometer, similar to a wrist watch which continuously monitors body movements and provides information on long-term sleep–wake patterns in athletes' natural environment.[83] Additionally, actigraphy in combination with sleep diaries has been useful in tracking sleep and ensuring adequate time in bed.[6] One of the limitations of activity monitors is that sitting for prolonged periods (eg, on a plane) can be mistakenly scored as sleep by the software algorithm. This highlights the importance of using them in combination with a sleep diary. However, this recommendation was not followed by all studies included in this review (for details see table 4). Actigraphy is particularly suitable for the assessment of sleep schedule disorders because it enables continuous monitoring for extended periods of time.[109] Another potential application of actigraphy is monitoring sleep during naturalistic studies of sleep restriction and other imposed demands for athletes (training, travel and competition days).[110] It has been shown that actigraphy can validate the compliance of athletes during a sleep restriction/extension home study.[111 112] However, we must consider that the main limitations of this method are (1) it only measures activity and rest; (2) it does not provide data on sleep stages, breathing or specific behaviours; and (3) artefacts of movements as induced movements, device removal and motionless wakefulness are threats to validity. In addition, the devices identified in the present study, sold commercially, contain different algorithms, making it difficult to standardise the measured parameters. Specific software uses algorithms to process data based on one of three sleep–wake threshold settings (ie, low, medium or high) for processing actigraphy data. Study reported that a medium sleep–wake threshold (activity counts above 40) should be used to process sleep data for team sport male athletes.[83] Therefore, there is a need for a consensus to define the parameters (for details see table 4) and the algorithms used to calculate them.

Based on the actigraphy findings to date, sleep efficiency is recommended for monitoring sleep quality due to its small level of instability (ie, CV <10%) and moderate effect size. On the other hand, the remaining parameters had a large CV (ie, CV >30%) for sleep latency, wake episodes and total wake episode duration presenting a moderate ES. However, the use of these variables would seem problematic in tracking sleep quality. A large CV makes it difficult to detect statistical differences between distinct moments (eg, pre,

Table 4 Definitions of the objective parameters inferred by actigraphy

	Actigraphy					Sleep diary	
Author	Parameter	Definition in the manuscript	Reference	Marker button	Sensor	Reported	Reference
2004 Richmond[30]	Sleep efficiency, %	(sleep duration–wake time)/sleep duration)×100	No	Unclear	Micro Mini-Motion Logger, Ambulatory Monitoring	No	No
	No of waking	No					
2007 Richmond[32]	Sleep efficiency, %	(sleep duration–wake time)/sleep duration)×100	No	Unclear	Micro Mini-Motion Logger, Ambulatory Monitoring	No	No
	No of waking	No					
2014 Abedelmalek[54]	Sleep efficiency, %	Percentage of sleep in the total time in bed	No	Unclear	Actiwatch sleep—Cambridge Neurotechnology	Unclear	No
	Sleep latency	Time period measured from 'lights out' or bedtime to the beginning of sleep					
	Mean activity score, min	Average value of the activity counts per epoch over the assumed sleep period					
2014 Fowler[99]	Sleep efficiency, %	No	No	Not applicable	ReadiBand, Fatigue Science	No	No
	Sleep–wake episodes, n	No					
	Sleep latency, min	No					
	Sleep mean wake duration, min	No					
	Variance from mean bed time, min	No					
2015 Shearer[64]	Sleep efficiency, %	Ratio between total sleep time and time in bed	Leeder, Glaister, Pizzoferro, Dawson and Pedlar (2012)	Yes	Actiwatch 2; Philips Respironics	No	No
	Sleep latency	Time to fall asleep from 'time to bed'					
	Time asleep	No					
	Time awake	No					
	Actual sleep, %	No					
	Moving time, %	No					
2015 Staunton[66]	Sleep efficiency, %	Percentage time in bed that was spent sleeping	No	No	Actigraph GTX3	No	No
2016 Eagles[101]	Sleep efficiency, %	A percentage score calculated by incorporating movement and physiological measures over the sleep duration as determined by the BodyMedia SenseWear unit	No	No	SenseWear actigraphy; BodyMedia	No	No
2016 Fullagar[75]	Sleep onset latency, min	Time at which bed was entered to when the individual first fell asleep	No	No	ReadiBand, Fatigue Science	No	No
	Sleep efficiency, %	Sleep time expressed as a % of time in bed					
	Wake episodes, n	No					
	Wake episode duration, min	No					

Continued

Table 4 Continued

	Actigraphy					Sleep diary	
Author	Parameter	Definition in the manuscript	Reference	Marker button	Sensor	Reported	Reference
2016 Fullagar[74]	Sleep onset latency	No	No	No	SenseWear actigraphy; BodyMedia	No	No
	Sleep efficiency, %	No					
	Wake episodes, n	No					
	Wake episode duration, min	No					
2017 Fowler [81]	Sleep efficiency, %	Sleep duration expressed as a percentage of time in bed	No	Unclear	wActiSleep+, Actigraph	Unclear	No
2017 O'Donnell[90]	Total sleep time	Total time spent asleep	Driller, McQuillan, O'Donnell (2016)	No	ReadiBand, Fatigue Science	No	No
	Sleep efficiency, %	Total time in bed divided by total sleep time					
	Sleep latency	Time taken for sleep onset					
	Wake episodes	Total no of awakenings per night					
	Sleep onset variance, min	Sleep onset consistency relative to mean					
	Wake variance, min	Wake time consistency relative to mean					
	Wake episode duration	Mean wake episode duration					
	Sleep onset time	Time of transition from wakefulness into sleep					
2017 Pitchford[102]	Sleep efficiency	No	No	No	Actiwatch 2, Philips Respironics Actigraph wGTX3 monitor	Yes (bed time, wake time)	No
	Wake after sleep onset, min	No					
2017 Van Ryswyk[91]	Sleep efficiency, %	No	No	No	Philips Respironics Actiwatches (versions 1 and 2)	Yes (time in bed, daytime naps, intake of caffeine and alcohol, and the time at which they turned lights out for sleep)	No
	Wake after sleep onset	No					
	Sleep onset latency	No					
2017 Staunton[92]	Sleep efficiency, %	Ratio of sleep time to total time in bed×100	No	No	Actigraph wGTX3 monitor	No	No

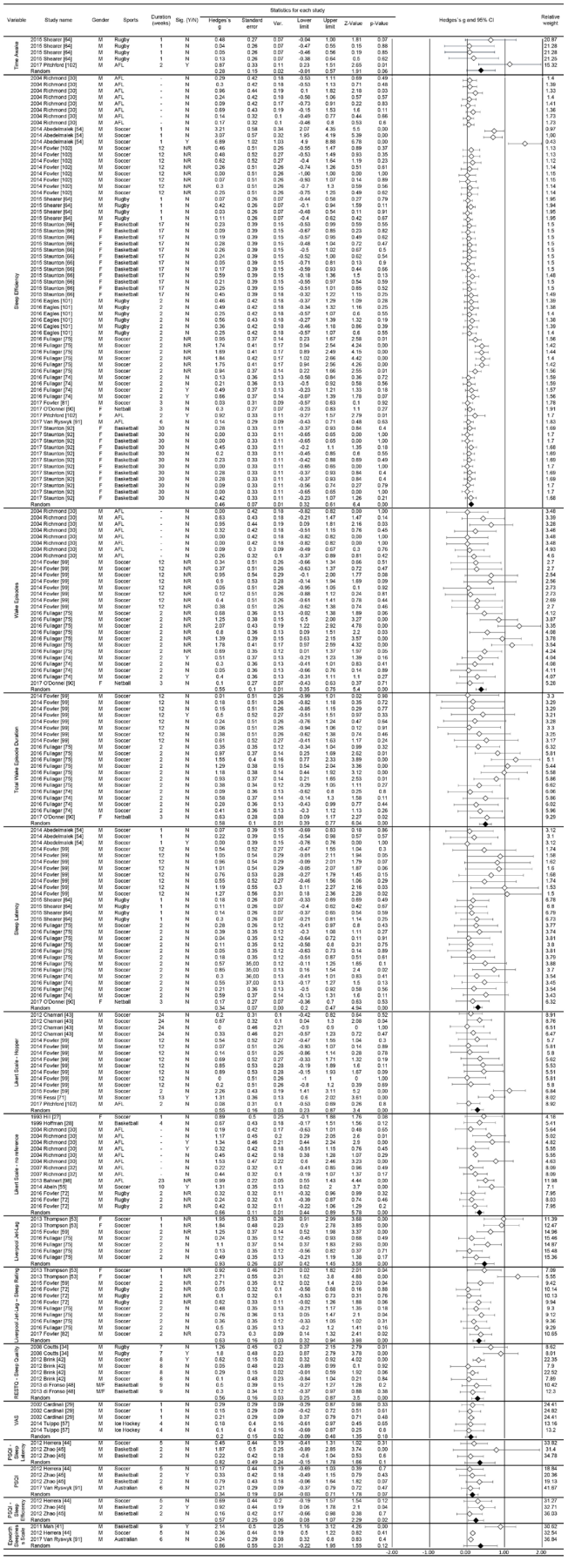

Figure 2 Meta-analysis of short-term intervention studies.

mid, post) and intervention groups, unless these differences are also very large.[25] In practice, this means that when using any of these parameters with large CV to monitor sleep quality, the ES should be large in order to be in a position to identify real variations. When they sought to understand the impact of the games played at night by team sport athletes, researchers found significant differences in sleep efficiency, but not in sleep latency and wake episodes.[113] Furthermore, the results of a recent systematic review and meta-analysis on the effects of training and competition on the sleep of elite athletes are in agreement with our findings. The former study found that the sleep quality, measured by sleep efficiency, was lower (3%–4%) the night of night competition compared with previous nights.[114] Concerning sleep efficiency, there is inconsistency in operationally defining as other sleep parameters what creates confusion with regard to the conceptualisation and use of the construct by researchers and clinicians (for details see table 4). The source of the inconsistency are the number of equations used to calculate it. Therefore, a proposed equation to minimise error sources uses the ratio of total sleep time (TST) to duration of the sleep episode (DSE). Considering that DSE is defined as sleep onset latency+TST+time awake after initial sleep onset but before the final awakening+time attempting to sleep after final awakening. The proposed formula for sleep efficiency would be sleep efficiency=TST/DSE (×100). TST and DSE can be easily calculated using standard sleep diary entries along with one item from the Expanded Consensus Sleep Diary.[115] However, it still needs to be verified for the application with actigraphy.

Questionnaires and diaries are user-friendly instruments, have low cost and can measure a wide range of sleep parameters in several contexts.[116] Sleep diary data may be more accurate for the assessment of some sleep parameters than questionnaires.[117] Whereas the correlation between subjective and objective measures of quality is modest, subjective reports can provide unique and relevant information. Additionally, diaries can provide information on sleep schedule, night awakenings and related topics.[117] Many studies have developed tailored questionnaires that preclude comparisons between studies and populations.[116] However, some questionnaires have been validated and established in the field. For instance, the PSQI and ESS are validated and established questionnaires for assessing sleep problems in the general population, but not in athletes. On the other hand, there is the Athlete Sleep Screening Questionnaire proposed by Samuels *et al*[116] that contains a subjective, self-report, sleep-screening questionnaire for elite athletes. These factors may have contributed to the different findings of the present study regarding the sensitivity level of these instruments. Considering that a large majority (ie, 24 instruments, 80%) used to monitor the sleep quality were obtained from questionnaires and scales, significant results for sensitivity were only found in 25% of these instruments in this meta-analysis.

PSG is considered the gold standard for sleep assessment, based on laboratory or ambulatory monitoring,[118 119] as it provides detailed information on sleep architecture and clinical diagnosis.[120] In this review, we present evidence that PSG can be useful for objective assessment of daytime sleepiness (eg, multiple sleep latency test, maintenance of wakefulness test) (online supplementary table 3). On the other hand, this method is expensive and usually only one or two nights of monitoring may be afforded. It is necessary to consider that PSG can generate discomfort due to the amount of cables needed, and eventually change the sleeping pattern. Due to its associated discomfort, it is not the preferred method from the sleep pattern of high-performance athletes. This fact hinders its use in most field sports science studies[83 118] and explains why there is no study included in this review that have performed pre-evaluations and post-evaluations using PSG. Considering the difficulty of using PSG, many researchers have used indirect methods to evaluate the sleep of athletes and one of the most used evaluations is the actigraphy. This instrument is generally a good choice for those interested in documenting sleep for extended periods of time in the sporting-specific environment due to the ease of application in athletes. Usually associated with actigraphy, some questionnaires and specific scales for sleep investigation are used, perhaps with the intention of complementing the information extracted from the actogram.

Three recent reviews have discussed the role of sleep in the recovery of team sport athletes.[8 10 11] These reviews suggested that the physiological and psychological processes that occur during sleep are considered critical to optimal recovery[10 11]; the detrimental effects of sleep disturbance on postmatch fatigue mechanisms include retardation of muscle glycogen resynthesis, delayed recovery from match-induced muscle damage and/or impairment of muscle repair, impaired cognitive function and increased mental fatigue.[10] Moreover, sleep hygiene strategies can be used to reduce sleep disruption following night matches and during recovery days to promote restorative sleep.[11] As presented, the recovery and performance of the athlete are associated with good quality and quantity of sleep, but it is modulated by individuals' characteristics, such as sleep habits, diurnal preferences (chronotype) and daily need for sleep.[119] Despite having a relatively standardised ideal sleep amount of time (ie, ~7–8 h/day) for most of the population, many individuals have different needs for hours of sleep per night.[120] Individuals are classified according to the duration of sleep as short or long sleepers.[121 122] Short sleepers may present good sleep quality perception and recovery status with few hours of sleep, while long sleepers need nine or more hours of sleep to feel recovered or rested.[121 122]

The preference for bedtime and wake time may also be relevant for a good quality of sleep assessments. The chronotype characteristics present three main classifications: (1) 'evening types', who have the habit of dragging

the beginning of sleep and the time to wake up, that is, to sleep and wake up later; (2) 'morning types', which have the opposite behaviour, they tend to sleep in the first hours of the night and wake up in the early hours of the morning; whereas the (3) 'indifferent types' do not present any of the characteristics of these two chronotypes, thus they adapt more easily to circadian alterations of the wake–sleep cycle.[123 124]

Some limitations of the present study are the inability to access the subjects' chronotype when quantifying the efficiency of the evaluated parameters. Another possible limitation is that the included studies did not report the causes of the wake episodes (eg, if it was for urination, pain or other discomfort, hunger, thirst, etc). Thus, it is important that the characteristics of the subjects are also taken into account in the search for the best strategy for monitoring sleep quality. Furthermore, we recognise the importance of the sleep quantity for the recovery process, but it was not the focus of this review.

Caution and attention is needed on the part of coaches and researchers when choosing parameters to measure and monitor sleep quality in team sport athletes. In addition to the statistical issues (eg, sensitivity, level of instability, reliability), the advantages and disadvantages of each of the sleep monitoring methods, evaluation logistics and sports modality should be taken into account.

CONCLUSIONS

Our results show that sleep efficiency should be measured to monitor sleep quality by actigraphy in team sport athletes. Moreover, the PSQI (sleep efficiency), Likert scale (based on Hooper and no reference), Liverpool Jet-Lag Questionnaire, Liverpool Jet-Lag Questionnaire (sleep rating) and RESTQ (sleep quality) may also be used in this regard. For the remaining parameters, more studies are needed to verify their efficacy. A consensus regarding (1) the definition of parameters inferred by actigraphy, (2) uniformity in the algorithms used to calculate sleep quality and (3) validation of sleep questionnaires with competitive athletes are warranted.

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