BASES Expert Statement: Methods to monitor athletes' sleep

Produced on behalf of the British Association of Sport and Exercise Sciences by Paul Hough, Dr Amy Bender, Dr Matt Driller and Prof Charles Pedlar FBASES.

Introduction

Sleep is an essential biological process for physical and cognitive health and is particularly important for athletes due to the regenerative processes that occur during sleep (Walsh *et al*., 2021). Recently, numerous studies have investigated the impact of sleep on health, performance and recovery, leading to an increased recognition of the importance of sleep and application of sleep monitoring methods amongst sport scientists (Hough *et al*., 2021).

Background and evidence

The gold standard for measuring sleep is polysomnography (PSG), which involves recording multiple physiological variables. PSG is primarily used in the laboratory to diagnose sleep disorders, although at-home self-applied devices are available (see Table 1). Yet, PSG equipment is expensive, can be cumbersome, and impractical for long-term monitoring of athletes. Research-grade activity monitors (i.e., actigraphy) and subjective methods (e.g., sleep diaries and questionnaires) were traditionally the most practical sleep monitoring methods available to practitioners. However, the rapid increase in commercially available wearable and non-contact devices (i.e., nearables), offer an inexpensive, practical, and a user-friendly way to monitor sleep. This statement provides an overview of practical sleep monitoring methods for athletes.

Actigraphy

Actigraphs are typically wrist-worn devices that use accelerometers to measure activity patterns, with algorithms providing a binary classification of sleep or wake. Several actigraphs, validated against PSG in athletes, are widely used in research and practice as they can be worn for long periods with minimal burden (e.g., Sargent *et al*., 2016). Most actigraphs require the practitioner to download and process the data. Despite manual data analysis being time-consuming, accessing firmware and raw data allows the customisation of sleep-wake thresholds to improve precision (Sargent *et al*., 2016). However, selected devices that use an automated scoring algorithm offer acceptable accuracy in detecting sleep and wake measures (Chinoy *et al*., 2021).

All validated actigraphs have a lower specificity (ability to detect wake) relative to their sensitivity (ability to detect sleep). Thus, a limitation of actigraphy is an inability to distinguish periods of motionless wake from sleep, which reduces measurement accuracy in individuals experiencing fragmented sleep.

Consumer wearable devices

The recent development of lightweight, wireless electroencephalography (EEG) caps and headbands that use dry-contact electrodes, enables EEG to be recorded in the field.

Table 1. Summary of sleep monitoring methods for athletes

*Does not apply to all examples provided

Method	Advantages	Disadvantages	Examples
Polysomnography (PSG)	• Gold standard method. • Measures sleep architecture with EEG. • Ability to diagnose sleep disorders.	• Expensive. • Expertise/time required for data processing. • Impractical for long-term monitoring.	• Nihon Kohden PSG-1100 • Respironics Alice 6 • Cerebra Sleep System
Actigraphy	• Validated against PSG. • Access to raw data.* • Minimal user burden. • Suitable for long-term use.	• Can be expensive. • Expertise/time required for manual data processing. • Does not measure sleep architecture. • Not always clear if sleep data has been captured until download.	• GT9X Link (ActiGraph) • Motionlogger (Ambulatory Monitoring) • MotionWatch 8 (CamNtech) • Readiband (Fatigue Science)
Consumer wearable devices	• Inexpensive • Validated against PSG.* • Minimal user burden. • Automatic data processing. • Additional metrics (e.g., HRV). • Data integration with athlete management systems.* • Suitable for long-term use.	• Undisclosed algorithms (poor access to raw data). • Unreliable sleep architecture metrics. • Firmware updates could affect data in unknown ways. • Third party cloud storage (potential privacy issues). • Readiness/recovery scores could be distracting.	• WHOOP Strap • Ōura Ring • Muse S • Fitbit • Apple Watch
Non-contact devices	• Inexpensive. • No wearable required. • Automatic data processing. • Suitable for long-term use.	• Few validation studies. • The presence of a bed partner influences accuracy. • Impractical when sleeping in different locations. • Some systems require activation before sleep.	• Beddit, • Sleep Score • Resmed+
Sleep questionnaires	• Inexpensive. • Can be used to identify sleep disorders and poor sleep hygiene.	• Data collected retrospectively increases the chance of false recall. • Can require expertise for follow-up.	• Athlete Sleep Screening Questionnaire (ASSQ) • Athlete Sleep Behavior Sleep diaries zQuestionnaire (ASBQ)
Sleep diaries	• Inexpensive. • Better precision for habitual sleep duration than questionnaires. • Can be customised. • Can be used to identify sleep disorders and poor sleep hygiene. • Many apps available.	• High compliance required. • Data collected retrospectively increases the chance of false recall.	• Consensus Sleep Diary • Pittsburgh Sleep Diary (PSD) • National Sleep Foundation (NSF) Diary

However, non-clinical EEG monitors (e.g., the Sleep Shepherd, Somfit, etc.) require further validation for sleep measurement in athletes.

Consumer wearable devices (CWDs), worn on the wrist, finger, or arm, use accelerometers and other sensors (e.g., photoplethysmography optical sensors) that measure physiological metrics (e.g., heart rate variability, body temperature). CWDs often include proprietary algorithms to calculate sleep duration, sleep architecture (i.e., sleep stages) and in some cases, the user's state of physiological recovery or readiness, communicated via an app. Several CWDs provide acceptable accuracy in detecting sleep-wake states, and wake after sleep onset (WASO) compared to PSG (Miller *et al.*, 2022). However, CWDs currently lack acceptable accuracy in sleep stage measurement, and the recovery/readiness scores require validation (Liang & Chapa-Martell, 2019; Miller *et al.*, 2022).

Most CWDs have been tested in short-term laboratory studies where participants had ample sleep opportunities. The reliability of CWDs in situations where athletes may experience frequent sleep interruptions (e.g., travel) is unknown. Data from most CWDs cannot be easily extracted due to proprietary algorithms, which manufacturers can change with firmware updates at any time. Therefore, CWDs are limited for bespoke sleep analysis and firmware updates could reduce longitudinal data fidelity. Also, caution should be used when working with individuals prone to obsessing over sleep metrics (i.e., orthosomnia) as attempting to achieve "perfect" sleep may exacerbate sleep issues (Baron *et al.*, 2017). Finally, further research is required to determine if the accuracy of cardiac metrics derived from photoplethysmography sensors are affected by skin tone and tattoos (Weiler *et al.*, 2017).

Non-contact devices 'nearables'

Non-contact devices (NCDs) are placed on or near the user's bed and use a combination of techniques, such as accelerometry, ballistocardiography vibration (for cardiorespiratory measures), light, sound, temperature, and motion sensors to estimate sleep. Smartphone-based apps are placed near the pillow and use the phone's inertial measurement unit and microphone to detect motion and sound, respectively. However, these lack validation and their placement near the pillow means they can easily be dislodged during sleep or be influenced by bedpartners.

Like commercial EEG devices, NCDs are in their infancy. The algorithms employed are not published, PSG validation studies are scarce, and they have not been extensively tested and established in the field where several factors (e.g., the presence of a bedpartner) influence their performance and usability. Finally, many NCDs are impractical when athletes routinely sleep in different locations.

Sleep questionnaires

Questionnaires capture quantitative (e.g., sleep duration) and qualitative (e.g., perceived sleep quality) sleep variables and are often used as a first diagnostic test for sleep disorders. Athlete specific questionnaires, such as the Athlete Sleep Screening Questionnaire (ASSQ) and the Athlete Sleep Behavior Questionnaire (ASBQ) have been developed to measure sleep indices and identify sleep disorders in athletes (Bender *et al.*, 2018; Driller *et al.*, 2018). However, they are not suited for continuous daily monitoring and retrospective information should be contextualised with the athlete's recent circumstances (e.g., travel, injury etc.).

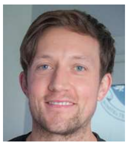
Sleep diaries

A sleep diary is a self-reported daily record of sleep information that typically provides a more accurate estimation of sleep duration than a single questionnaire (Carney *et al.*, 2012). Although sleep diaries vary in the quantity of information required, they usually include bedtime, number of awakenings, wake time, and perceived sleep quality. A longstanding limitation of sleep diaries for practitioners and researchers has been a lack of standardisation, which lead to the development of the Consensus Sleep Diary (Carney *et al.*, 2012).

Electronic sleep diaries are available as mobile device apps and offer benefits over paper diaries (see Tonetti *et al.*, 2016). Regardless of method (paper or electronic), sleep diaries should be completed soon after waking for at least a week, as data collected retrospectively increases the chance of false recall or forgetfulness (Tonetti *et al.*, 2016). To verify data fidelity, sleep diaries are often used alongside actigraphy and vice versa.

Conclusions and Recommendations

The sleep monitoring methods summarised above can provide useful information on sleep patterns. Sleep monitoring methods should be selected according to the aims of data collection (e.g., screening), resources (financial, personnel etc.), and athlete preferences. Where possible, practitioners should select methods that have been validated against PSG (see Table 1). ■



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