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Optimizing Athletic Performance: The Impact of Sleep Monitoring

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Optimizing Athletic Performance: The Impact of Sleep Monitoring

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Resumo

O sono é fundamental para a recuperação física e mental, promovendo a reparação tecidular, o crescimento muscular, a síntese proteica e a libertação hormonal. No contexto desportivo, uma qualidade de sono deficiente pode prejudicar o desempenho atlético e a recuperação, aumentar o risco de lesões e contribuir para um estado de *overtraining*. Os atletas experienciam com frequência uma qualidade e quantidade de sono insuficientes, decorrentes de fatores como o stress competitivo, horários irregulares de treino e competição, consumo de cafeína, dores musculares, lesões e viagens frequentes.

Este estudo tem como objetivo realizar uma revisão da literatura para analisar criticamente a evidência atual sobre técnicas de monitorização do sono, avaliar a relação entre a qualidade do sono e o desempenho desportivo e fornecer orientações sobre higiene do sono e práticas de monitorização a profissionais de saúde, treinadores e atletas. Após um processo de pesquisa e seleção da literatura, foram incluídas 129 fontes para alcançar estes objetivos.

De um modo geral, a monitorização do sono demonstra ser uma ferramenta valiosa na avaliação e otimização dos padrões de sono dos atletas. Os resultados indicam que as equipas desportivas devem integrar instrumentos objetivos, como a actigrafia ou monitores de sono disponíveis para o consumidor validados, juntamente com questionários específicos para atletas ou o *Consensus Sleep Diary*, garantindo uma avaliação precisa a longo prazo. Além disso, o conjunto de estratégias para lidar com distúrbios do sono relacionados com atletas continuam a expandir-se e podem ser implementadas juntamente com as práticas habituais de higiene do sono. Apesar dos avanços tecnológicos nesta área, persistem desafios, incluindo protocolos de medição inconsistentes, escassez de dispositivos validados para atletas, algoritmos privados pouco transparentes e uma perceção limitada sobre potenciais efeitos adversos. Abordar estas limitações deve ser uma prioridade para investigações futuras.

Palavras chave: Sono, Qualidade do Sono, Actigrafia, Polissonografia, Desempenho Atlético, Recuperação de Função, Atletas

Abstract

Sleep plays a vital role in physical and mental recovery, promoting tissue repair, muscle growth, protein synthesis, and hormone regulation. In sports, poor sleep quality can hinder athletic performance and recovery, increase injury risk, and contribute to overtraining. Athletes frequently experience insufficient sleep due to competitive stress, irregular training and competition schedules, caffeine consumption, muscle pain, injuries, and frequent travel.

This study aims to conduct a literature review and critically analyze the current evidence on sleep monitoring techniques, assess the relationship between sleep quality and athletic performance, and provide healthcare professionals, coaches, and athletes with guidance on sleep hygiene and monitoring practices. Following a literature search and screening process, 129 sources were reviewed to meet these objectives.

Overall, sleep monitoring has proven to be a valuable tool for evaluating and optimizing athletes' sleep patterns. The findings indicate that athletic teams should integrate objective tools, such as actigraphy or validated consumer sleep trackers, with athlete-specific questionnaires or the Consensus Sleep Diary to ensure an accurate long-term assessment. Additionally, the range of strategies to address athlete-related sleep disturbances continues to expand and may be implemented alongside standard sleep hygiene practices. While technological advancements continue to improve sleep monitoring, challenges persist, including inconsistent measurement protocols, a lack of athlete validated devices, non-transparent proprietary algorithms, and limited awareness of potential adverse effects. Addressing these limitations should be a priority for future research.

Keywords: Sleep, Sleep Quality, Actigraphy, Polysomnography, Athletic Performance, Recovery of Function, Athletes

List of Abbreviations

AASM - American Academy of Sleep Medicine

AI - artificial intelligence

ASBQ - Athlete Sleep Behavior Questionnaire

ASSQ - Athlete Sleep Screening Questionnaire

BMI - body mass index

CSTs - consumer sleep trackers

ECG - electrocardiography

EEG - electroencephalography

EMG – electromyography

EOG - electrooculography

GABA - gamma-aminobutyric acid

GH - growth hormone

IGF-1 - insulin-like growth factor 1

ML - machine learning

NCAA - National Collegiate Athletic Association

NREM - non-rapid eye movement

NSF - National Sleep Foundation

PSG - polysomnography

PSQI - Pittsburgh Sleep Quality Index

REM - rapid eye movement

SE - sleep efficiency

SOL - sleep onset latency

TNFα - tumor necrosis factor alpha

TST - total sleep time

USD - United States dollar

WASO - wakefulness after sleep onset

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Introduction

Physiology of Sleep and its cycles

Sleep is a fundamental biological process essential for the recovery and optimal functioning of the human body, with humans spending approximately one-third of their lives engaged in this critical activity. According to the American Academy of Sleep Medicine (AASM), sleep is divided into four stages—N1, N2, N3, and REM—encompassing two main types: non-rapid eye movement (NREM) sleep and rapid eye movement (REM) sleep.[1] These stages alternate cyclically throughout the night, roughly every 90 minutes, with the duration of REM sleep increasing as the night progresses.

NREM sleep, which usually marks the onset of sleep, is further divided into three stages: N1, N2, and N3. Stages N1 and N2 are considered light sleep, characterized by moderate responsiveness to external stimuli, whereas stage N3—also known as deep or slow-wave sleep—is marked by minimal responsiveness and the lowest breathing and heart rates.[2, 3] During deep sleep (N3), the body engages in critical restorative activities, such as tissue repair, immune function enhancement, and the secretion of the majority of growth hormone (GH).[2, 4, 5] Conversely, REM sleep (stage R), where dreaming occurs, is primarily associated with cognitive functions, including memory consolidation, emotional regulation, and problem-solving skills.[6, 7] The dynamic transitions among these stages plays an essential role in physical restoration, mental health, and overall homeostasis. To allow these processes to occur effectively, the AASM [8] and the National Sleep Foundation (NSF) [9] recommend adults aged 18-64 years obtain 7–9 hours of sleep per day. Failing to meet these standards increases the risk of hypertension, major depressive disorder, and generalized anxiety disorder, as documented in several studies.[10]

Regulation of Sleep and the Circadian Rhythm

Sleep regulation involves intricate interactions between homeostatic (process S) and circadian (process C) mechanisms. The homeostatic process drives the need for sleep based on the duration of prior wakefulness; the longer an individual remains awake, the greater the accumulated sleep pressure. In contrast, the circadian rhythm governs the timing of sleep and wakefulness based on an approximately 24-hour cycle and can be shifted by environmental cues, particularly light.[2, 11] The interplay between these mechanisms ensures a balance between sleep duration and quality.

Neurotransmitters such as gamma-aminobutyric acid (GABA) and adenosine play vital roles in initiating and sustaining sleep. GABA acts as an inhibitory neurotransmitter, promoting relaxation and sleep onset, while adenosine—associated with process S—accumulates in the brain during wakefulness, signaling the need for sleep.[2] Additionally, the secretion of melatonin by the pineal gland regulates the circadian rhythm by signaling the onset of sleep in response to darkness.[11]

The NSF underscores the importance of sleep regularity and avoiding disruptions to the circadian rhythm.[12] Furthermore, substantial evidence indicates that adherence to regular schedules is associated with improved outcomes across multiple dimensions of health and performance, including sleep efficiency [13, 14], alertness, cardiovascular and metabolic health, inflammatory status, mental health, academic performance, cognitive function and overall mortality.[10, 12, 15]

How Exercise and the Athlete Lifestyle Influence Sleep

The relationship between sleep, recovery and performance is underscored by three critical components: total sleep duration, sleep quality and the alignment of sleep phases with the circadian cycle.[16] However, evidence indicates that athletes generally experience reduced sleep duration and poorer sleep quality compared to the benchmarks established by the AASM for healthy non-athletes.[17] Additionally, insomnia symptoms—such as prolonged sleep latency, increased sleep fragmentation, non-restorative sleep, and excessive daytime fatigue—have been reported by up to 70% of professional athletes[18], highlighting the prevalence of sleep challenges in this population.[19, 20] The scope of the issue has prompted the International Olympic Committee and the National Collegiate Athletic Association (NCAA) to address sleep disorders in recent consensus statements.[21, 22]

Athletes' sleep patterns are shaped by numerous external influences, including lifestyle choices, environmental factors, and stress. These effects are often amplified by the rigorous demands of training and competition, which place additional physical and mental strain on athletes.[23, 24] An analysis of sleep quality during the 2016 Rio Olympic Games identified significant sleep disturbances among athletes even before the competition began.[25] Increased psychological stress and anxiety are major contributors to these disturbances, with findings indicating that athletes experience prolonged sleep latency, frequent nighttime awakenings, and reduced sleep efficiency.[25, 26] Likewise, the timing of training and competition phases—such as pre-season training and competition nights—can disrupt sleep quantity and efficiency, leading to increased nighttime awakenings.[20, 27] Other contributing factors include the use of electronic devices before bedtime, training in high-temperature environments, and lingering muscle soreness after exercise.[17]

Although individual and team sport athletes differ in their training routines and competition schedules, the evidence is mixed regarding which type of sport is associated with poorer sleep, suggesting that additional variables may be involved.[20, 26, 28] Gender may also play a role; for instance, female athletes have been reported to obtain longer sleep durations and exhibit better objective sleep quality, yet they often report poorer subjective sleep perceptions—potentially due to hormonal fluctuations, anxiety, and other physiological factors.[4, 29]

Conversely, some research indicates that athletes tend to have more efficient sleep architecture, characterized by shorter total sleep duration but an increased proportion of deep sleep compared to non-athletes. Investigations into sleep patterns across varying fitness levels have demonstrated a positive relationship between physical fitness and both slow-wave sleep and NREM sleep.[30] This finding is consistent with other reviews of previous meta-analyses and randomized clinical trials, which suggest that exercise is associated with improvements in certain sleep outcomes.[31, 32] One exception is ultra-endurance competitions, which appear to increase the proportion of REM sleep, while not affecting N3 (deep sleep) stage.[17]

The relationship between exercise and sleep is nuanced. Although athletic training may enhance sleep efficiency, excessive training loads, demanding schedules, and physiological stressors can disrupt sleep. Moreover, athletes' perceptions of the effects of sleep deprivation vary; for instance, overreaching may have little impact on perceived sleep quality, even though it significantly affects its objective characteristics.[33] Interestingly, a recent study suggests that genetics may also contribute to these sleep variations, as both sleep duration and quality have strong genetic components, accounting for 46% and 44% of individual differences, respectively.[34]

Effects of Sleep Deprivation on Athletic Performance

Sleep deprivation adversely affects athletic performance by disrupting critical hormonal and immune functions. In sleep-deprived states, athletes typically exhibit elevated cortisol levels, diminished concentrations of testosterone and insulin-like growth factor 1 (IGF-1), and increased levels of inflammatory markers such as tumor necrosis factor alpha (TNF-α). In addition, heightened levels of muscle damage indicators, including creatine kinase and C-reactive protein, have been observed, potentially delaying recovery processes.[24, 35] Besides, inadequate sleep exacerbates the bidirectional relationship between pain and sleep disturbances, thereby perpetuating a cycle that impairs muscle repair and extends recovery times.[24] Interestingly, although sleep loss initially impairs growth hormone secretion, this deficiency appears to be offset by an increased daytime secretion of GH.[36]

In one study, 30 hours of sleep deprivation significantly reduced sprint performance, muscle glycogen storage, and pacing strategies while increasing perceived fatigue.[37] Moreover, sleep restriction has been associated with declines in sports-specific skills, submaximal strength, and anaerobic power.[36] At a physiological level, sleep deprivation may also negatively influence an athlete's willingness to collaborate with teammates, as sleep quality is a strong predictor of subsequent mood and affective experiences, with some evidence supporting a reciprocal association.[38]

A systematic review investigating the effects of acute sleep loss, defined as obtaining less than six hours of sleep within a 24-hour period, found that sleep deprivation particularly impairs tasks requiring both physical and cognitive skills. The review noted that these detrimental effects are more pronounced following total sleep deprivation and late sleep restriction (resulting from early awakening) compared with early sleep restriction (resulting from delayed sleep onset). Additionally, exercise performance in the afternoon appears more vulnerable to sleep loss than in the morning, with performance declining by approximately 0.4% per hour of wakefulness.[39]

Regarding injury risk, reduced sleep duration strengthens the link between stress and injury, increasing the overall risk.[40] A cross-sectional study found that runners with poorer sleep quality are more likely to report running-related injuries.[41] Similarly, sleep quality has been independently linked to a heightened risk of sports-related concussions.[42]

Collectively, these findings indicate that inadequate sleep undermines both recovery and performance. They highlight the necessity for individualized sleep monitoring and targeted interventions, ultimately being able to address the unique needs of athletes, and improve various performance metrics such as reaction times, shooting accuracy, and psychomotor vigilance.[43]

Objectives

The main objective of this study is to conduct a literature review on the effectiveness and impact of sleep monitoring on optimizing athlete performance and recovery. It seeks to analyze the available technologies, discuss their advantages and limitations, and understand how sleep assessment can be used to benefit both the athlete and the entire medical team responsible. By delving deeper into the relationship between sleep and sports performance, it is hoped to contribute to the implementation of strategies that promote healthy sleep habits among athletes, thereby enhancing both their results and overall well-being. In particular, the specific objectives of the work are to: compile and critically analyze the available scientific evidence on the various current monitoring techniques; evaluate the relationship between the quality and quantity of sleep, athletic performance, and injury risk; assist health professionals, coaches, and athletes in making informed decisions about the implementation of sleep monitoring and hygiene practices; identify gaps in the current literature and propose directions for future research.

Methods

This literature review was conducted in two complementary stages to ensure broad coverage of the topic. In the first stage, a systematic search was performed using the PubMed database. The main terms employed were “sleep”, “sleep monitoring”, “polysomnography”, “actigraphy” and “sleep quality”. These were combined with “recovery of function”, “injury prevention”, “perceived fatigue” as well as additional terms such as “athletes”, “sports”, “athletic performance” or “physical fitness” either individually or in various combinations. Results were filtered, for articles written in English, with full-text access available and a publishing date between 2014 and 2024. This process yielded 169 articles, which were imported into EndNote. A preliminary screening of titles and abstracts, followed by a full review of those deemed relevant, resulted in 45 articles being selected for the initial review.

In a second stage, an additional 84 sources were identified and imported into EndNote to further enrich the review and capture emerging themes. These sources were obtained from suggestions and the reference lists from previously included papers, targeted search queries on both Google Scholar and PubMed, and the "Recommended Articles" and "Similar Content" features available on PubMed and publisher’s websites (e.g., Elsevier, Nature, Wiley, and Springer). This extended search included book chapters, reports and guidelines. In total, 129 sources were ultimately included in the review. A flowchart summarizing the review methodology is provided in Figure 1.

Results

The selected articles cover a wide range of study designs and methodologies related to sleep monitoring in athletes. These include the validation of emerging sleep-monitoring technologies, the evaluation of commercial sleep trackers, and investigations into the relationship between sleep quality, athletic performance, and injury risk. Table I summarizes the 129 reviewed sources, detailing authors, publication year, study type, methodology, and key findings. Additionally, Tables II to V present core insights, including commonly measured sleep parameters, frequently used questionnaires, primary monitoring tools, and general sleep hygiene recommendations. A proposed protocol for sleep monitoring and intervention is presented in Figure 3.

According to the reviewed articles, athlete sleep assessment should rely on a combination of objective tools and subjective instruments. Actigraphy, Likert scales, and sleep diaries are among the most commonly used methods in scientific literature. Several validated questionnaires have demonstrated strong psychometric properties. For example, the PSQI shows high internal consistency and specificity for distinguishing poor sleepers, with a one-week timeframe yielding better reliability and validity in athletes. The ASSQ demonstrates 81% sensitivity and 93% specificity in identifying athletes requiring clinical intervention, while the ASBQ exhibits moderate internal consistency (Cronbach's alpha = 0.73) and high test-retest reliability (ICC = 0.88). However, limitations persist, as sleep diaries often show discrepancies with actigraphy, and further refinement is needed to optimize consistency and validate certain questionnaires across diverse athletic populations.

Among objective tools, actigraphy has shown good agreement with polysomnography in elite athletes, though higher sensitivity thresholds improve performance. Despite some actigraphy devices exceeding 90% sensitivity, software validation gaps remain. Among consumer sleep trackers (CSTs), only the Fitbit HR Charge (validated in semi-professional soccer players, though it overestimates total sleep time) and the Fitbit Alta HR (validated in college athletes, showing strong correlation for total sleep time) have undergone athlete-specific validation. Other devices, such as the Huawei Band 6, WHOOP 4.0, and Oura Ring Gen 3, have been used in athlete studies but lack formal validation for this population. Emerging multi-signal approaches, textile-integrated devices, and artificial intelligence show promise in enhancing sleep assessment. However, inconsistencies in device accuracy, proprietary algorithms, and variable definitions of sleep parameters and validation criteria hinder cross-study comparability.

Several reviewed studies have linked sleep monitoring to performance optimization. Monitoring helped identify poor sleep in Olympic athletes and high rates of insomnia and sleep apnea in over half of NCAA athletes. It also highlighted risk factors, including irregular sleep patterns, late caffeine intake, which are associated with reduced sleep efficiency and prolonged sleep latency. Furthermore, monitoring enables personalized strategies, such as sleep extension and daytime napping, which have been linked to improved reaction time, sprint performance, and reduced injury risk. Bright light therapy has been shown to delay sleep-wake cycles and enhance reaction times in swimmers, while mindfulness interventions help mitigate pre-competition insomnia. Conversely, sleep deprivation impairs muscle glycogen recovery and pacing strategies while increasing injury risk—moderate-to-severe insomnia, for example, triples concussion risk, and each additional hour awake reduces performance by approximately

0.4%. These findings emphasize the important role of sleep monitoring in enhancing athletic performance, recovery, and overall well-being.

Discussion

Evaluated Parameters and Common Techniques for Monitoring Sleep in Athletes

Since the recognition of sleep's critical role in athletic performance and well-being, tracking sleep has emerged as a valuable approach to measure, quantify, and enhance its patterns. Sleep monitoring techniques are broadly classified into two categories based on the nature of the data collected: objective and subjective tools.

Objective tools employ various sensors to collect quantitative, impartial data on sleep. This raw data is subsequently analyzed to determine sleep duration and quality. Prominent examples include polysomnography—widely regarded as the gold standard for diagnosing sleep disturbances—and actigraphy.[25, 44, 45]

In contrast, subjective tools—such as questionnaires and sleep diaries—rely on self-reported data to identify issues that may warrant further intervention.[46] Instruments like the Pittsburgh Sleep Quality Index (PSQI), Likert scales, and the Epworth Sleepiness Scale are regularly used to capture an athlete's perception of sleep quality and document potential external factors influencing sleep.[25, 44, 45]

Sleep quality, a central concept in sleep medicine, is quantified using several parameters, including total sleep time (TST), sleep onset latency (SOL), sleep efficiency (SE), wakefulness after sleep onset (WASO), and disruptive events such as spontaneous arousals or apneas.[46] Parameters indicative of restorative sleep have been identified across all age groups, with the National Sleep Foundation's recommendations widely regarded as the standard.[23] An overview of these commonly measured parameters, including their definitions and recommended values, is provided in Table II; these parameters can be derived either from questionnaire data or calculated from objective measurements.

A systematic review of Olympic athletes' sleep found that they typically exhibit a TST of approximately 6 hours and 10 minutes, a SE of 84%, a SOL of 28 minutes, and a WASO of 49 minutes.[25] These values fall outside the recommended ranges for restorative sleep, stressing the widespread issue of inadequate sleep quality in this population.

Polysomnography

Polysomnography (PSG) is a well-rounded sleep-recording procedure that integrates multiple sensing technologies, including electroencephalography (EEG), electrocardiography (ECG), electrooculography (EOG), and electromyography (EMG), along with recordings of airflow, respiratory effort, oxygen saturation, and synchronized video.[1] By leveraging the collected data, PSG provides detailed sleep stage classification and facilitates the detection of sleep disorders such as sleep apnea.[47, 48] Traditionally, PSG requires participants to sleep in a laboratory setting. An illustration of a PSG procedure and its evaluation is provided in Figure 2.

The differentiation of sleep stages through PSG relies primarily on brain wave patterns and physiological markers, for which the AASM has published a manual establishing international standards.[1] Wakefulness is characterized by high muscle tone, eye movements, and an activated cerebral cortex, whereas non-REM sleep is marked by moderate muscle tone, absence of eye movements, and synchronous EEG activity—often featuring distinctive waveforms such as sleep spindles, K-complexes, and high-voltage slow waves.[1, 49] In contrast, REM sleep is typified by low muscle tone, rapid eye movements, and an active cerebral cortex exhibiting a prominent theta rhythm.[6, 7, 49] This phase may also include episodes of muscle twitches (phasic REM sleep), cardiorespiratory irregularities, and a suspension of internal heat production.[7, 49]

Just like most objective techniques, for the sake of storage-efficiency, PSG records data in segments known as epochs—configurable time intervals typically ranging from 10 seconds to 1 minute. The AASM recommends the use of 30-second epochs for PSG [1], which are assigned a corresponding sleep stage each by an expert scorer. However, this process may introduce reliability issues (with average inter-scorer reliability reported at approximately 83%) and requires 1–2 hours to score a single night of clinical PSG recording.[50]

Despite its status as the gold standard for sleep assessment, the high cost (several thousand USD per session), intrusiveness, and complexity of PSG limit its routine use outside of clinical or research settings.[47, 51, 52] Although level 2 PSG, which offers comparable diagnostic reliability and can be performed at home, appears promising, its cost-effectiveness remains uncertain due to the necessary equipment and technical expertise.[52] A 2019 study evaluating a portable PSG system—the SOMNOwatch plus EEG—concluded that while it does not replace in-lab polysomnography, it may serve as a valuable adjunct for assessing sleep architecture and stages in athletes when actigraphy alone is insufficient.[53]

Activity Monitoring – Actigraphy

The recording of body activity to assess the sleep-wake cycle is known as actigraphy.[54] Typically, actigraphs are portable, wrist-worn devices that incorporate motion sensors—primarily micro-electro-mechanical system accelerometers and gyroscopes—to capture limb movements and other sleep-related mechanical signals such as posture, motion, and acceleration. By analyzing periods of activity and inactivity, specialized algorithms can infer sleep–wake patterns and derive various sleep parameters.[47, 54, 55] Although enhancements in algorithmic processing can improve detection accuracy, the inherent limitations of a reduced sensor suite cannot be fully compensated by these adjustments alone.[47]

Modern actigraphs have evolved to integrate additional sensors that measure body temperature, heart rate, respiratory rate, and even galvanic skin response.[54] Beyond the conventional wrist and ankle placements, devices may also be positioned on the chest to more accurately capture torso motion and the mechanical signals related to respiration and cardiac activity.[47] Since the precision of actigraphy is influenced by its sampling frequency, an epoch duration of 10 seconds is generally recommended for sleep tracking.[54] Research-grade examples, such as the Philips Respironics ActiWatch 2 and the ActiGraph wGT3X-BT, typically cost around 1000 USD per unit, excluding software expenses.

Despite these advantages, actigraphy exhibits limited specificity. Periods of stillness may be misclassified as sleep, potentially leading to an overestimation of total sleep time and sleep efficiency, while underestimating sleep in individuals with movement disorders.[56] Additionally, actigraphy lacks the physiological signal data required for accurate sleep stage identification.[51]

Compared to the gold-standard PSG, actigraphy demonstrates high accuracy (approximately 90%) in detecting total sleep time.[57] Yet, its ability to precisely identify sleep onset and wakefulness is less reliable, with an accuracy of only around 55% for sleep stage detection.[25, 57] Although combining actigraphy with sleep diaries may enhance overall accuracy, inconsistent methodologies and variable algorithms complicate standardization efforts.[18, 45] Likewise, when using activity monitors to measure the sleep of elite athletes, it is advisable to select thresholds with high sensitivity to sleep (i.e., 80) to achieve the best balance of agreement, sensitivity, and specificity.[58]

Despite its shortcomings, actigraphy is considered valid for measuring the sleep of elite athletes.[58] In fact, several reviews point to actigraphy being the most used tool to measure sleep quality in sports sleep research, surpassing PSG by a good margin.[25, 44, 45] Its popularity is largely driven by its cost-effectiveness, less invasiveness and capability for continuous recording over extended periods, compared to PSG. This advantage is particularly valuable in sports sleep research, where variations in sleep quality and quantity occur during different training and competition phases.

A meta-analysis by the AASM further established the utility of actigraphy by confirming its suitability for assessing total sleep time and sleep onset latency in both children and adults across a wide range of sleep disorders, thereby supporting its use in clinical decision-making.[59]

Commercial Sleep Trackers (CSTs)

With the growing popularity of measuring and improving personal health, sleep monitoring has emerged as a profitable industry, resulting in the widespread adoption of commercial sleep trackers (CSTs).[60] These devices provide the general public with accessible sleep-wake tracking by reducing both the expertise and cost required. Although CSTs are not as clinically validated as research-grade actigraphy and PSG, they leverage advanced sensors and algorithms to estimate sleep parameters.

Some CSTs utilize technologies similar to those found in professional devices but often serve multiple purposes beyond sleep measurement [61] , which can compromise their precision and validation. In contrast, clinically validated actigraphs—despite being more expensive—are developed exclusively for precise sleep tracking.[54] In literature, CSTs are generally categorized into two primary types: wearables and nearables.

Wearables

Wearables, as the name suggests, are devices worn in direct contact with the user. Typically priced at an average of approximately 386 USD [62], these devices often take the form of smartwatches, wristbands, or rings and incorporate sensors such as photoplethysmography and accelerometers to collect biometric data. These monitor metrics such as cardiac activity (e.g., heart rate and heart rate variability), skin temperature, breathing rate and body movements. Sleep patterns are then assessed using algorithms that analyze the data, providing insights into sleep quality and duration.[62] Wearable CSTs have gained popularity for their cost-effectiveness, user-friendliness, and ability to track long-term sleep trends.[63] Despite their ability to predict sleep stages—particularly deep sleep[18]—most wearables tend to overestimate sleep by misclassifying wake stages. This misclassification results in a substantial negative proportional bias when estimating sleep efficiency, especially in individuals with inherently low sleep efficiency.[62] Some popular examples include the Apple Watch, WHOOP and Oura Ring.

Nearables and Smartphone Applications (Airables)

Nearables devices (a portmanteau of "nonwearable"), are typically placed under or over the mattress or in close proximity to the user. With an average price of 123 USD [62], nearables employ a diverse range of technologies, including piezoelectric sensors, video cameras, infrared thermometers, and echo-based radiofrequency waves.[54] Like wearables, by tracking various physiological changes during sleep, nearables can infer sleep parameters through algorithmic analysis.[62, 64] Their accuracy, however, can be affected by factors such as postural differences, variability in body mass index (BMI), and pre-existing clinical conditions.[50] Additionally, movement during sleep onset and general restlessness may interfere with sensor performance, leading to overestimations of SOL and WASO.[62, 65] Furthermore, since nearables struggle to precisely track respiratory patterns and subtle movements, they tend to exhibit the lowest sensitivity in distinguishing between deep and light sleep stages compared to other CSTs.[62] One clinically validated example is the Beddit 3.5 bed sensor by Apple, which has demonstrated high reliability when compared to PSG and has even outperformed wristband actigraphy and self-reported measures.[65]

Airables, a specific subcategory of nearables, are smartphone applications that utilize the sensors already integrated into the user's device. These applications are notable for their accessibility and low cost—some are available free of charge, while others may require a subscription fee of approximately US $53—and they do not require additional hardware.[54, 62] Airables leverage a variety of smartphone sensors (e.g., microphones, ultrasound transducers, accelerometers), and their performance is heavily dependent on the specific sensor configurations and algorithms employed.[54] Examples include "Pillow," an accelerometer-based application; "SleepScore," which uses a sonar biomotion sensor to direct ultrasonic signals from the smartphone's speaker toward the user's chest to track thoracic respiratory effort; and "SleepRoutine," a microphone-based application that analyzes sounds generated by breathing and body movements.[62, 66] It is important to exercise caution with these applications, as many sleep detection apps are developed by amateur programmers, and their rapid production often outpaces the validation processes required to establish their suitability for clinical or research applications.[54] For perspective, there were 311 million health application users in 2023.[67]

Comparing Various Commercial Sleep Trackers

While not without limitations, consumer sleep-tracking devices have demonstrated relatively high sensitivity and agreement when estimating sleep patterns compared to the gold-standard PSG.[63] Some CST models, despite being less expensive than research-grade actigraphy devices, perform comparably—or even surpass them—in overall sleep–wake classification. However, these devices often encounter challenges with detailed sleep stage analysis.[64, 68] Furthermore, CSTs exhibit lower specificity relative to PSG; while they effectively detect sleep, they are less precise in identifying wake periods. They frequently struggle with complex metrics, such as WASO, often overestimating its duration, which renders them less suitable for clinical diagnostics.[65]

Numerous studies have compared the efficacy of various CSTs. Among wearables, several Fitbit models—including the Alta HR [64], Inspire HR and Versa 2 [68], Fitbit Sense 2 [62], and Fitbit Charge 4 [63]—as well as the Oura Ring (Gen 2 [68]; Gen 3 [62, 69]) and WHOOP [63] have demonstrated relatively high sensitivity and agreement when estimating sleep patterns compared to PSG or research-grade actigraphy. In the category of nearables, devices such as the Withings Sleep Tracking Mat [68], ResMed S+ [70] and SleepRoutine [62] have shown favorable performance when compared to PSG. Moreover, a 2019 review reported that among nearables, the Withings Sleep device received the highest customer ratings, and the Sleep as Android Unlock application was considered the best mobile application for sleep detection.[54]

In general, studies comparing various CSTs tend to favor wearables. One plausible explanation is that devices in direct contact with the user yield more precise results; their sensors, being positioned closer to the body, capture more accurate measurements than those of contactless alternatives.[62, 64, 71] In addition, nearable devices—which depend heavily on proper positioning—may be influenced by external factors such as the presence of a bed partner or pet and tend to be less accurate in non-healthy populations.[70]

For a wearable sleep device to be appropriate for monitoring sleep in athletes, it must accurately detect sleep periods and provide precise measurements of TST.[72] In general, this can be achieved, provided that the start and end times of detected sleep periods are reviewed daily by the athlete and/or practitioner, and any errors in these timepoints are promptly corrected.[72] However, the available literature on CSTs in athletes is limited. Among the few athlete-specific validated examples are the Fitbit HR Charge and the Fitbit Alta HR. The Fitbit HR Charge was found to detect 80% of nighttime sleep periods lasting 7–9 hours, but only 30% of daytime sleep periods lasting 1–2 hours and it significantly overestimated TST compared with PSG.[72] The Fitbit Alta HR was deemed acceptable, as it exhibited a strong correlation with an EEG-based device for TST, sleep onset and initial REM sleep, a moderate correlation for stage N3 sleep, and a weak correlation in SOL.[73] Other CSTs that, while not formally validated for athletes, have been employed in sports sleep studies include the Huawei Band 6 [74], the WHOOP 4.0 band [75] and the Oura Ring Gen 3.[76] A key challenge in this field is the lack of standardized criteria for determining acceptable agreement with PSG. As a result, one research team may deem a device valid, while another, using different criteria, may reach the opposite conclusion.[77]

Several overarching issues must be addressed across all CSTs, including limited access to raw data and to the characteristics of proprietary algorithms used to compute sleep parameters.[72] Additionally, non-validated CSTs integrated with mobile applications may display erroneous information or advice, potentially resulting in adverse outcomes.

In short, further research is necessary to validate the performance of these devices—especially in athletes—in order to deepen our understanding of their features and assess their efficacy in diagnosing sleep disorders and related comorbidities.[78]

Subjective Methods

Questionnaires

A variety of subjective instruments are currently available for diverse populations and objectives, ranging from diagnosing sleep disorders (e.g., the Athens Insomnia Scale [79], SLEEP-50 [80]) to assessing individual chronotypes (e.g., the Hörne and Ostberg Chronotype Questionnaire [81]) and evaluating daytime sleepiness (e.g., the Epworth Sleepiness Scale [82]). Among these, the Pittsburgh Sleep Quality Index [83] remains one of the most widely used due to its extensive validation history of sleep quality components estimation, even in athletic populations.[84] Despite the large array of available questionaries, many studies opt to employ Likert scales to assess sleep quality through straightforward questions (e.g., "How would you evaluate the quality of your sleep in the past few days?").[25, 44, 45]

Given the limitations of many subjective questionnaires when applied to athletes, athlete-specific instruments—such as the Athlete Sleep Screening Questionnaire (ASSQ) [85] and the Athlete Sleep Behavior Questionnaire (ASBQ) [86]—have recently been developed and validated specifically for use in athletic contexts.[87, 88] These tools assess sleep behaviors and habits while accounting for sport-specific factors, including travel fatigue, competition-related stress, and training schedules. Consequently, they provide a valuable alternative for identifying the sleep patterns and behaviors of elite athletes, offering greater relevance than traditional methods.

However, questionnaires have inherent limitations, including extended recall periods and scoring complexity, which may reduce their effectiveness in discriminating between good and poor sleepers.[46] Furthermore, when employing non–athlete-specific questionnaires such as the PSQI, results should be interpreted with careful consideration of the unique demands and schedules inherent to athletic populations.[89]

Overall, a wide range of self-report questionnaires has been developed and utilized in sports settings, each providing unique insights into various aspects of sleep health. Table III presents an overview of some of the most commonly used questionnaires, outlining their characteristics and recommended use in athletic populations.

Sleep Diaries

In addition to questionnaires, the sleep diary [46, 90] is another valuable tool that enables clinicians and researchers to monitor sleep timing and variability over multiple nights. Commonly used for daily self-monitoring of sleep patterns—by recording bedtimes, wake times, and perceived sleep quality—sleep diaries help reduce recall bias relative to retrospective questionnaires, although consistent use can be challenging for some individuals. They are often combined with objective measures, such as actigraphy, to provide a more valid sleep assessment, since sleep parameters may be overestimated by athletes.[91] When possible, employing a validated format—such as the Consensus Sleep Diary [92]—in conjunction with corroborated cutoff values [90] can ease the inference of various sleep parameters and help differentiate individuals with insomnia from normal sleepers.

To guarantee optimal use of subjective sleep evaluations, further validation studies focusing on athletic populations and language adaptation are recommended. Such efforts would expand the reliability and accuracy of these tools across varied contexts and populations, improving their utility in both research and clinical practice.

Advances in Sleep Monitoring Technologies

Sleep monitoring represents a rapidly expanding market, with nearable technology gaining increasing traction each year.[60] The number of commercially available devices is expected to continue rising, as industry experts and stakeholders anticipate that smartwatches, fitness trackers, and smart rings will drive the highest business potential within the digital health industry.[93] Likewise, the use of health applications is projected to grow, spurred by rising smartphone penetration, which is predicted to reach 92% by 2030.[67, 94]

Artificial Intelligence (AI) and Sleep-Tracking Algorithms

Artificial Intelligence (AI) has emerged as a central topic in the digital health area.[93] The arrival of AI and Machine Learning (ML) offers a wide array of potential benefits for sleep science. First, AI can improve tools by refining data analysis accuracy, supporting sleep disorder diagnoses, and providing a fast, cost-effective, and objective alternative to manual sleep stage scoring.[50, 60] In fact, AI is already demonstrating promise in sleep stage analysis [66] and apnea detection [95, 96], yet its clinical application remains limited due to biases and inconsistencies in validation studies. A recent review found that even top-performing deep learning algorithms still underperform compared to simpler heuristic models and legacy models.[97] Despite these advancements, the role of physicians in verifying predicted hypnograms remains essential, with AI serving as a supplementary tool rather than a replacement.[98]

Beyond diagnostics, AI could also offer personalized sleep recommendations. By integrating with smart-home systems, AI may dynamically adjust environmental factors like lighting and temperature to optimize sleep conditions.[50, 60] Additionally, newer algorithms—distinct from traditional ML models—are designed to operate without pre-deployment training and can run directly on devices, ensuring user privacy. A notable example is a recent study that introduced a validated, device-agnostic heart rate (HR)-based algorithm for sleep detection, providing an alternative to traditional actigraphy and privately-owned algorithms.[99]

Novel Sensor Technology

Advancements in sensor technology—particularly in wireless modalities such as infrared, microwave, conductive fabrics, and bioelectric signal sensors— are expected to improve the accuracy of sleep-tracking devices.[47] Continuous miniaturization and the development of less invasive alternatives to traditional PSG electrodes are underway. For example, wearable EEG monitoring enables the measurement of neural activity via skin-surface electrodes, yielding results comparable to conventional PSG. Innovations in this area range from headbands and ear electrodes to implantable devices.[47, 50, 100] Moreover, flexible sensors are becoming more comfortable and durable through innovative materials like self-healing polymers and microfluidic designs that allow for an extended lifespan and advanced functionalities like sweat analysis or drug delivery.[101]

These innovations suggest a future where sleep evaluation for athletes can be both highly accurate and minimally invasive. Until then, challenges persist in minimizing technologies' harmful effects on athletes and achieving the precision of PSG, particularly for detailed sleep staging and disorder diagnosis.

Key Factors in Monitoring Method Selection

When selecting which tools to use, it is crucial to carefully consider their limitations. Subjective tools, which rely on personal interpretation and memory recall, can lack precision and often show only modest correlations with objective measures. For instance, a recent study using at-home EEG monitoring found that objective sleep metrics—such as SE and TST—explained only about 20% of the variance in subjective sleep ratings. This indicates that while subjective assessments capture additional factors (like mood and personality), they may not fully reflect measurable sleep parameters.[102] In contrast, objective tools, although less influenced by individual bias, may fail to capture behavioral insights and can be affected by systematic errors, algorithm variability, intrusiveness, and high cost. Since each type of tool collects distinct data with unique strengths and limitations, combining both subjective and objective, athlete-validated approaches can provide the most and accurate results.[25, 45] A summary of the advantages and limitations of each discussed tool is provided in Table IV.

Before selecting a specific tool, clinicians, as advised by AASM recommendations, should be well-versed in several critical operational aspects of the devices. These aspects include understanding Food and Drug Administration (FDA) classifications, knowing how products define sleep metrics, assessing suitability for specific populations, addressing data integrity concerns, recognizing sensor types and their applications, evaluating their algorithms, and scrutinizing the transparency of the validation methods used to support product claims.[103] The NCAA further advises that any CST used must comply with Health Information Portability and Accountability Act (HIPAA) and Family Educational Rights and Privacy Act (FERPA) laws.[21] In a similar vein, researchers have proposed a matrix to guide consumers in evaluating health and performance technologies, focusing on two key dimensions: strength of evidence and effectiveness, considering factors such as rigor of evaluation, causality, and the desirability of outcomes.[104]

Diminishing the Detrimental Effects of Sleep Tracking

Prior to initiating any monitoring protocol, it is advisable to educate athletes about what constitutes healthy sleep and its importance for recovery and performance.[21] Athletes should be informed that most devices may lack precision and are better suited for tracking trends and setting personal goals over time. Such education can increase cooperation and help reduce sleep-related anxiety throughout the monitoring process.[56] Clinicians should also be aware of potential anxiety stemming from an obsessive preoccupation with sleep tracker data and the relentless pursuit of ideal sleep—a phenomenon recently termed "orthosomnia." Particular caution is warranted for athletes with perfectionist personality traits, as they may be more susceptible to insomnia and other anxieties, including nomophobia—the fear of being without a mobile device or internet connectivity—which is increasingly prevalent.[18] Intriguingly, a recent study analyzing the effects of a two-week sleep self-tracking intervention using two commercial smartphone applications, found that while the CST use did not exacerbate sleep nor promoted orthosomnia, it did not yield the anticipated beneficial effects.[105]

Suggested Monitoring Protocol

Monitoring should generally extend for at least one to two weeks to allow for the recognition of sleep patterns and the calibration of certain tools.[106] After this period, data should be reviewed to identify disorders and deviations from recommended healthy values, and findings should be compared with the subjective sleep experience.[56] In addition, it is important to handle athletes' sleep data with discretion and in accordance with the privacy rights and laws governing personal health information in the relevant jurisdiction.

Once the data has been stored and properly evaluated, athletes can be advised accordingly. If an athlete reports satisfaction with their sleep and objective parameters fall within recommended ranges, current sleep habits may be maintained.[106] However, if the data suggest a clinical sleep disturbance, or if an athlete experiences high levels of daytime sleepiness despite adequate sleep opportunities, referral to a sleep clinic or physician is recommended.[106] These athletes should be treated with evidence-based treatments, such as positive airway pressure and oral appliances for sleep apnea, cognitive behavioral therapy for insomnia, and melatonin for circadian rhythm disturbances. Clinicians must carefully weigh the use of sedating medications, which may impair performance, against the risk of certain treatments not complying with anti-doping regulations.[104] Additionally, when access to in-person treatment is limited, online cognitive behavioral therapy for insomnia offers a viable alternative.[107] Finally, athletes who do not meet the criteria for a formal clinical sleep disturbance but remain subjectively dissatisfied with their sleep, or whose objective parameters deviate from recommended values, should be prioritized for interventions aimed at improving sleep.[106] A proposed protocol for monitoring and sleep intervention is presented in Figure 3.

Optimal approach to Implementing Sleep Interventions in Athletes

Given that motivation is a critical factor for achieving behavioral change, it is imperative to clearly explain the importance of sleep and the rationale behind each proposed intervention before implementation.[106] Establishing a pre- and post-assessment protocol for relevant performance metrics (e.g., sprint times) can also enable teams to evaluate the efficacy of newly adopted sleep improvement strategies. Post-assessment is typically recommended 2–4 weeks after the initiation of the improved sleep regimen.[107] During this period, regular reviews of sleep hygiene practices and monitoring of how sleep data respond to behavioral modifications can yield further insights into potential sleep disorders or environmental disturbances—for example, frequent awakenings caused by external factors such as pets.[56]

The first step should be to prevent disturbances by prioritizing supervision and increasing awareness during periods of increased exposure to sleep aggravators, like early morning training, large increases in training load, exposure to hypoxia and jet lag.[27] When prevention is not feasible, focus may be directed to the two primary mechanisms that underpin sport-related insomnia symptoms and offer potential targets for intervention: pre-sleep cognitive/psychophysiological arousal and sleep restriction.[20] Interventions such as sleep hygiene education and mindfulness are particularly well suited to address cognitive arousal, whereas strategies focused on sleep extension and napping are more beneficial when a loss of sleep duration is documented.[106] Additionally, when disturbances are identified amongst several athletes, it is advisable to implement broad adjustments such as optimizing training schedules, travel arrangements, and recovery protocols to improve overall health, well-being, and performance.[28] A list of general sleep hygiene recommendations is provided in Table V.

Mitigating Sleep Restriction

Maintaining regular sleep patterns is essential; however, when sleep deficiency accumulates, it should be addressed by extending sleep duration on non-working days by one to two hours.[12] An alternative strategy is to intentionally extend sleep prior to anticipated disruptions, such as long travel days before major competitions—a practice that has been associated with improved motor performance in athletes.[43] For athletes who typically obtain approximately seven hours of sleep per night, extending sleep to 9–10 hours is generally recommended.[43, 106] This extension should be implemented gradually—increments of 15–30 minutes every few nights—until the athlete consistently feels well-rested and alert during the day.[107]

Napping is another viable option. Defined as a sleep period lasting less than half of the typical nightly duration, naps often occur in response to the post-lunch dip in the circadian rhythm.[108] Daytime napping has been shown to enhance alertness and athletic performance—evidenced by improvements in tests such as the 5-meter shuttle run [109]—in both partially sleep-deprived and well-rested individuals. Although longer naps (approximately 90 minutes) may confer more significant benefits, it is crucial to allow sufficient time (approximately 30 minutes) for the return to full alertness post-nap.[106-108, 110]

To minimize the impact of travel on sleep, it is important to consider the time required for adjustment to a new time zone; humans generally adapt at a rate of approximately one hour per day. Strategies to facilitate this adjustment include gradually shifting the circadian clock prior to departure or during the flight, and minimizing other travel-related stressors such as dehydration, acoustic disturbances, and disruptions in dietary patterns.[107] When sleep deprivation is unavoidable, it is generally more advantageous to initiate sleep restriction earlier rather than delaying it—for instance, by traveling the night before and staying overnight at the destination. Additionally, following a period of sleep loss, engaging in exercise as promptly as possible can help mitigate performance decrements.[39]

Enhancing Sleep Quality and Reducing Performance Anxiety

Performance anxiety is a significant factor that can adversely affect an athlete's sleep quality. Effective strategies to reduce anxiety include proper practice for sport-specific tasks and mindfulness.[111] A systematic review of sleep interventions reported that while mindfulness can improve sleep quality, it may take extended periods (5 to 12 months) to see benefits, as it requires practice to master.[106] Another set of interventional approaches able to prevent and manage anxiety include relaxation techniques, yoga, deep breathing exercises, anti-anxiety medications, and cognitive restructuring.[111, 112] Moreover, interventions aimed at rapidly reinstating the dominance of automatic processing—such as providing positive feedback and coaching—may be beneficial when athletes experience a shift toward a more deliberative cognitive mode.[111] Combining multiple strategies may yield the best outcomes.

Caffeine and Dietary Habits

Caffeine consumption is widespread among athletes due to its performance-enhancing effects, with prevalence estimated at 76% as of 2015.[113] However, ingestion of caffeine at doses exceeding 2 mg per kilogram of body weight prior to evening competitions has been shown to adversely affect various aspects of sleep.[114, 115] To prevent reductions in TST, it is recommended that coffee be consumed at least 8.8 hours before bedtime. Similarly, a standard dose of pre-workout supplements (217.5 mg of caffeine) should be taken no later than 13.2 hours before going to sleep.[115]

A recent review indicated that incorporating tryptophan-rich proteins, consuming high glycemic index carbohydrates in the evening, and maintaining consistent probiotic supplementation can benefit sleep patterns.[114] Although some dietary supplements, such as tart cherry juice [17] and beetroot juice [114], show promise in promoting sleep, further research is needed to confirm their efficacy. Additionally, alcohol consumption should be limited to avoid negative effects on sleep quality.[107]

Use of Artificial Light Therapy

Artificial Light Therapy is being used to influence athletes' circadian rhythm. During the Olympic Games acclimatization period, daily sessions of artificial light therapy (30–45 minutes) combined with sleep hygiene recommendations were shown to effectively delay swimmers' sleep–wake cycles and improve reaction times.[116] In a similar study, exposure to a well-lit environment and the use of specialized light therapy glasses reduced total wake time and SOL while increasing TST, culminating in enhanced block reaction times.[117]

Another research team combined exposure to bright light at night with the administration of 8 mg of ramelteon—taken twice during the flight and again before bedtime upon arrival—to mitigate insomnia. The experimental group exhibited shorter SOL and higher SE compared to the control group, indicating improvements in sleep parameters.[118] However, there is evidence that, similar to blocking blue light from devices [119], this method primarily improves subjective sleep, and the use of glasses can be inconvenient, limiting athlete adherence.[120] Furthermore, the short-term use of ramelteon should be approached with caution, as its clinical impact on insomnia is minimal and it may contribute to increased daytime sleepiness.

The aforementioned recommendations should be implemented as part of a holistic set of sleep-promoting behaviors, as their effectiveness is often limited when applied in isolation. Also, although some interventions may lead to immediate improvements in sleep quality, their long-term benefits frequently diminish without sustained adherence.[17]

Conclusion

The present review demonstrates that sleep monitoring has evolved significantly from its early days of simple questionnaires, sleep diaries, and occasional polysomnography to diagnose disturbances, to becoming a rapidly expanding multi-million-dollar industry. Today, a wide range of consumer-targeted tools—often developed by amateur programmers and easily accessible via smartphone downloads—are available. While these tools can serve as powerful allies in enhancing athletic performance, validated consumer sleep technologies for athletes remain exceedingly scarce. This scarcity raises concerns about potential misinformation, inaccurate readings, data mismanagement, and increased anxiety. Consequently, athletic teams are advised to use validated objective tools, such as actigraphy or established CSTs, alongside athlete-specific questionnaires (e.g., the Athlete Sleep Screening Questionnaire) or the Consensus Sleep Diary, to ensure an accurate evaluation of an athlete's sleep.

Recent advancements, including the miniaturization of critical PSG components like EEG and the rapid development of AI and ML, suggest that progress in sleep analysis technology will continue. However, given that these technologies are still in their early stages, those responsible for athlete care are advised to adhere to AASM recommendations when selecting and evaluating new tools. Additionally, the range of strategies to address athlete-related sleep disturbances continues to expand and may be implemented alongside standard sleep hygiene practices. Therefore, it is also vital to validate and tailor these strategies for high-stress environments, such as the Olympic Games and daily training regimens, to ensure their effectiveness.

In conclusion, this review reaffirms the critical importance of sleep and its assessment for the overall health and success of athletes. Future research should focus on standardizing measurement protocols, validating consumer-grade devices, increasing transparency of proprietary algorithms, and raising awareness of potential adverse effects, while also developing athlete-specific tools to support long-term well-being and peak performance duration.

Appendix

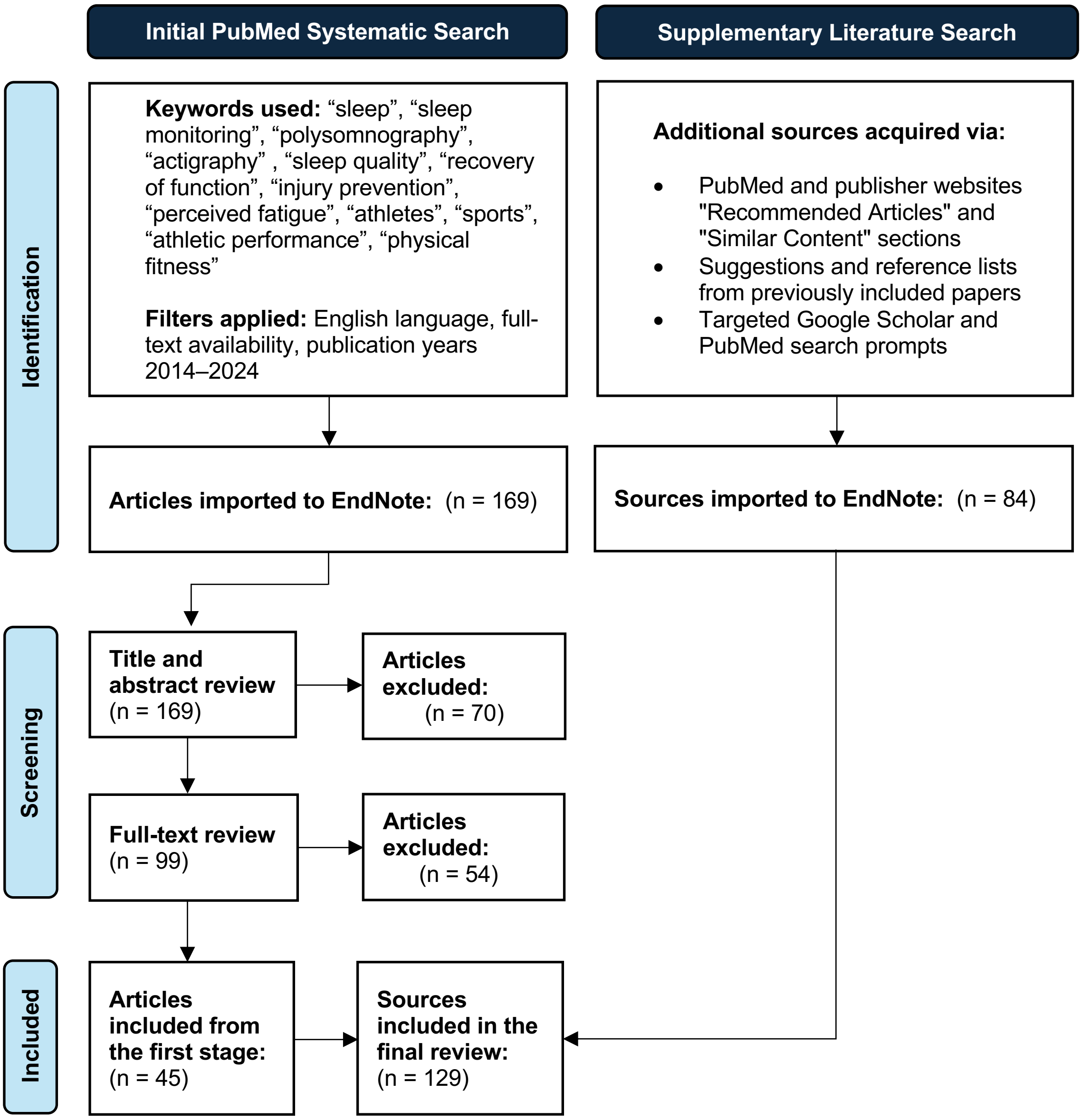

Figure 1. Flowchart summarizing the review methodology.

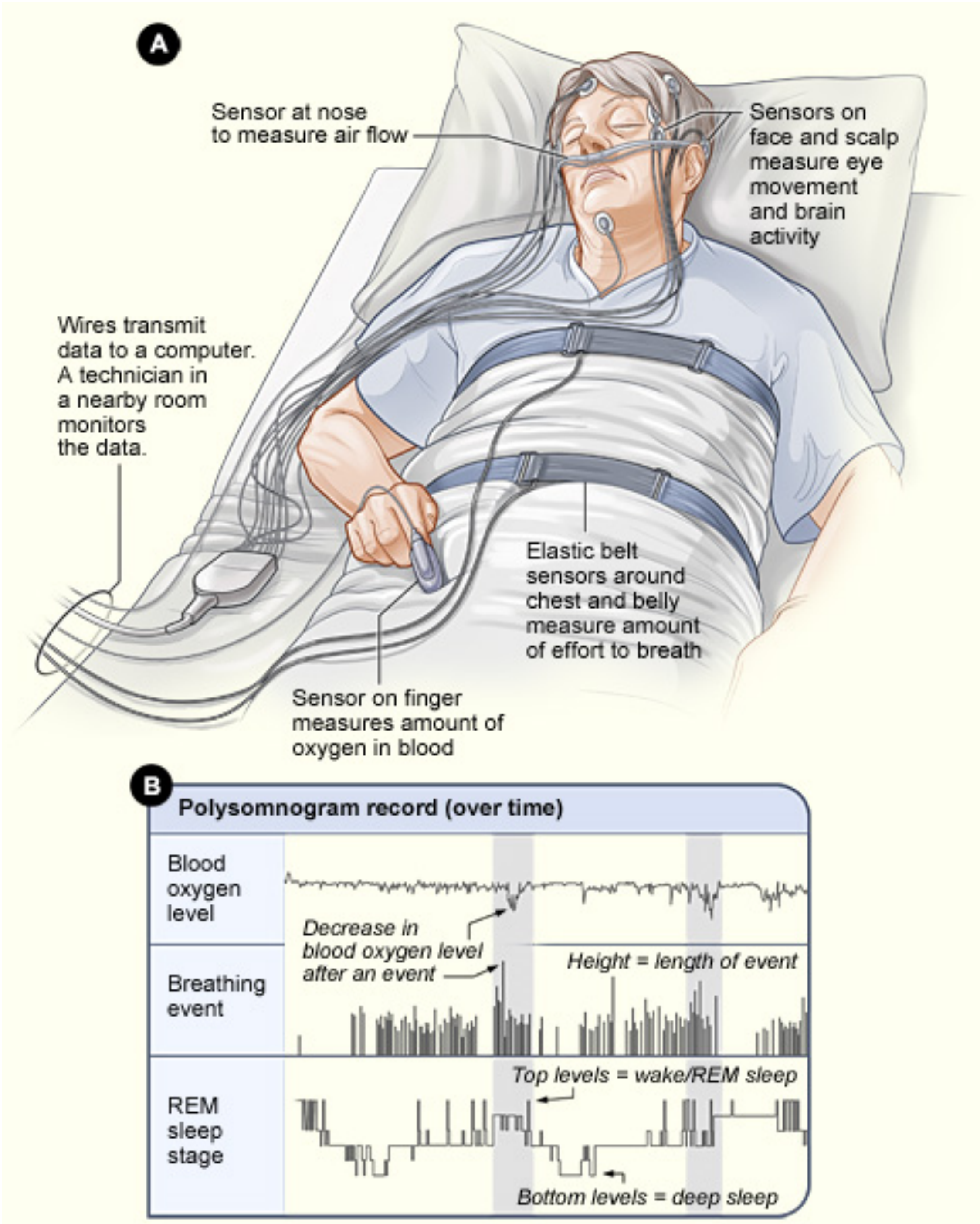

Figure 2. Illustration of a polysomnography procedure and its evaluation. Source: National Heart Lung and Blood Institute (NIH), Public domain, via Wikimedia Commons. The figure was taken from Wikimedia Commons-Sleep Studies. https://commons.wikimedia.org/wiki/File:Sleep_studies.jpg (accessed on 8 February 2025).

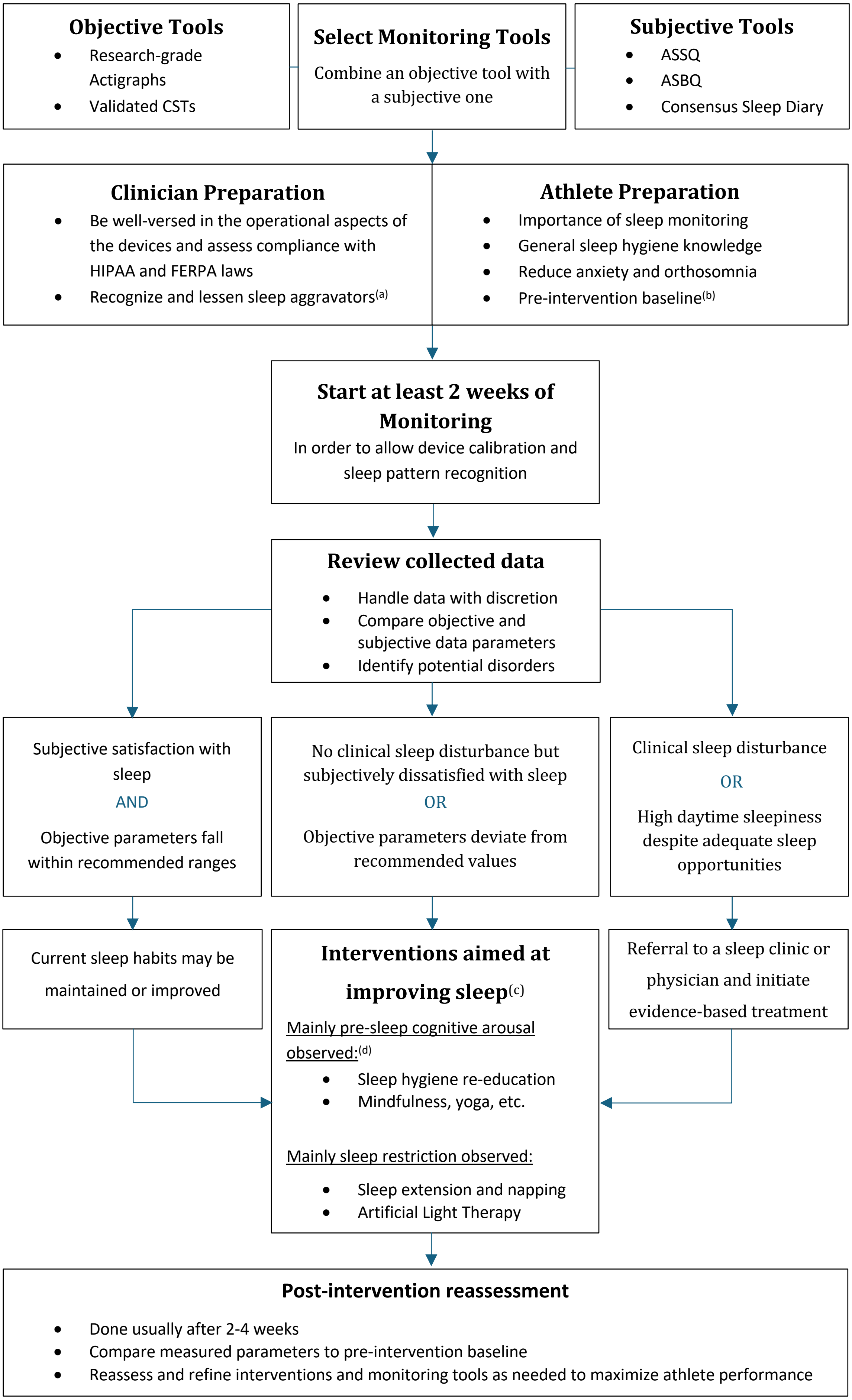
Objective Tools
Research-grade Actigraphs
Validated CSTs
Select Monitoring Tools
Combine an objective tool with a subjective one
Subjective Tools
ASSQ
ASBQ
Consensus Sleep Diary
Clinician Preparation
Be well-versed in the operational aspects of the devices and assess compliance with HIPAA and FERPA laws
Recognize and lessen sleep aggravators[(a)]
Athlete Preparation
Importance of sleep monitoring
General sleep hygiene knowledge
Reduce anxiety and orthosomnia
Pre-intervention baseline[(b)]
Start at least 2 weeks of Monitoring
In order to allow device calibration and sleep pattern recognition
Review collected data
Handle data with discretion
Compare objective and subjective data parameters
Identify potential disorders
Subjective satisfaction with sleep
AND
Objective parameters fall within recommended ranges
No clinical sleep disturbance but subjectively dissatisfied with sleep
OR
Objective parameters deviate from recommended values
Clinical sleep disturbance
OR
High daytime sleepiness despite adequate sleep opportunities
Current sleep habits may be maintained or improved
Interventions aimed at improving sleep[(c)]
Mainly pre-sleep cognitive arousal observed:[(d)]
Sleep hygiene re-education
Mindfulness, yoga, etc.
Mainly sleep restriction observed:
Sleep extension and napping
Artificial Light Therapy
Referral to a sleep clinic or physician and initiate evidence-based treatment
Post-intervention reassessment
Done usually after 2-4 weeks
Compare measured parameters to pre-intervention baseline
Reassess and refine interventions and monitoring tools as needed to maximize athlete performance

Figure 3. Proposed protocol for monitoring and sleep intervention in athletes. (a) Frequent athlete related sleep aggravators are early morning training, large increases in training load, exposure to hypoxia and jet lag, all of which should be mitigated; (b) Utilize sport-specific performance metrics (e.g., sprint time for track and field athletes) to ensure relevance; (c) When disturbances are identified amongst several athletes, it is advisable to implement broad adjustments such as optimizing training schedules and refining travel arrangements; (d) Performance anxiety may be a significant factor. Abbreviations: ASSQ - Athlete Sleep Screening Questionnaire; ASBQ - Athlete Sleep Behavior Questionnaire; CSTs - Consumer Sleep Trackers; AASM - American Academy of Sleep Medicine; HIPAA - Health Information Portability and Accountability Act; FERPA - Family Educational Rights and Privacy Act.

Table I - Summary of the 129 papers included in this review, listing the authors, year of publication, study type, methods used and key findings.

Authors	Year	Title	Study Type	Methodology	Main Findings
Troester MM, Quan SF, Berry RB.	2023	The AASM Manual for the Scoring of Sleep and Associated Events: Rules, Terminology and Technical Specifications.	Consensus Guideline	Manual by expert consensus	Guide users through the technical aspects of conducting routine polysomnography (PSG) testing as well as the analytic scoring and interpretation of PSG results.
Morris CJ, Aeschbach D, Scheer FA.	2012	Circadian system, sleep and endocrinology.	Narrative Review	N/A	Relationship between the circadian system, sleep, and endocrinology, highlighting how the circadian rhythm influences sleep patterns and the regulation of hormones in the body.
Carskadon MA, Dement WC.	2011	Monitoring and staging human sleep.	Book chapter	N/A	Outlines the characteristics of normal human sleep, including the cyclical nature of NREM and REM sleep, age-related changes, and factors influencing sleep patterns, providing a baseline for understanding sleep disorders.
Power CJ, Fox JL, Elliott-Sale KJ, Bender AM, Dalbo VJ, Scanlan AT.	2024	Waking Up to the Issue! Research Inattention and Sex-Related Differences Warrant More Sleep Studies in Female Athletes.	Narrative Review	N/A	Highlights the need for more female-specific sleep data in athletic populations, identifying sex differences in sleep patterns, sleep disorders, and factors such as the menstrual cycle that impact sleep in female athletes.
Irwin MR, Opp MR.	2017	Sleep Health: Reciprocal Regulation of Sleep and Innate Immunity.	Narrative Review	N/A	Emphasizes how sleep disturbances, particularly insomnia, contribute to inflammation and depressive symptoms, while also discussing potential interventions targeting insomnia to reverse inflammation and improve sleep health.
Blumberg MS, Lesku JA, Libourel PA, Schmidt MH, Rattenborg NC	2020	What Is REM Sleep?	Narrative Review	N/A	Advocates for a broader, more biologically grounded approach to studying REM sleep, emphasizing the diverse expression of its components across species and developmental stages.
Peever J, Fuller PM.	2017	The Biology of REM Sleep.	Narrative Review	N/A	Highlights key developments in understanding REM sleep, including its neural control, potential functions like memory consolidation, and its role in disorders such as REM sleep behavior disorder and narcolepsy.
Watson NF, Badr MS, Belenky G, et al.	2015	Recommended Amount of Sleep for a Healthy Adult: A Joint Consensus Statement of the American Academy of Sleep Medicine and Sleep Research Society.	Consensus Statement	A panel of 15 experts reviewed 5314 scientific articles using the RAND Appropriateness Method.	The recommended sleep duration range to promote optimal health in adults aged 18 to 60, based on evidence from multiple health categories, is 7 or more hours per night.
Hirshkowitz M, Whiton K, Albert SM, et al	2015	National Sleep Foundation's sleep time duration recommendations: methodology and results summary.	Consensus Statement	An 18-member expert panel used the RAND/UCLA Appropriateness Method to evaluate scientific literature and determine sleep duration recommendations across the lifespan.	The panel provided age-specific sleep duration guidelines, highlighting variations across the lifespan and potential health risks of deviating significantly from recommended ranges.
Zheng NS, Annis J, Master H, et al.	2024	Sleep patterns and risk of chronic disease as measured by long-term monitoring with commercial wearable devices in the All of Us Research Program.	Observational Study	Objectively measured longitudinal sleep data from commercial wearable devices were linked to electronic health records to analyze associations between sleep patterns and chronic disease incidence in 6785 participants.	Variations in sleep stages, duration, and regularity were linked to risks of atrial fibrillation, obesity, hypertension, hyperlipidemia, major depressive disorder, and generalized anxiety disorder.

Beersma DGM, Gordijn MCM.	2007	Circadian control of the sleep–wake cycle.	Narrative Review	N/A	The circadian clock regulates sleep timing, but its interaction with sleep processes remains incompletely understood, especially regarding societal impacts on well-being and performance. Provides a description of process C and S.
Sletten TL, Weaver MD, Foster RG, et al.	2023	The importance of sleep regularity: a consensus statement of the National Sleep Foundation sleep timing and variability panel.	Consensus Statement	A panel of experts conducted a systematic literature review and used a modified Delphi RAND/UCLA method for consensus voting.	Regular sleep timing is crucial for health and performance, and catch-up sleep on non-work days may help mitigate insufficient sleep during workdays.
Teece A, Beaven CM, Suppiah H, Argus CK, Gill N, Driller MW.	2024	Routine, Routine, Routine: Sleep Regularity and its Association with Sleep Metrics in Professional Rugby Union Athletes.	Observational cohort study	Sleep monitoring with wrist actigraphy for 3 weeks, daily wellness questionnaire, and calculation of the sleep regularity index (SRI).	Athletes with more regular sleep patterns (lower SRI) had significantly longer sleep duration (7:42 vs. 7:18 hours), with trends toward better sleep efficiency and fewer wake episodes. Minimizing sleep onset and offset variability may improve sleep quality in elite athletes.
Halson SL, Johnston RD, Piromalli L, Lalor BJ, Cormack S, Roach GD, et al.	2022	Sleep Regularity and Predictors of Sleep Efficiency and Sleep Duration in Elite Team Sport Athletes.	Observational cohort study	Sleep monitored for 7–43 days using activity monitoring and sleep diaries, with sleep regularity index (SRI) calculated to assess variability in sleep onset and offset. Multiple linear regression models were used to assess contributors to sleep efficiency and total sleep time.	Regular sleepers had better sleep efficiency, less variability in sleep duration, and more consistent sleep onset/offset times. Key contributors to sleep efficiency were earlier bedtimes and less variability in sleep onset, while later sleep offset contributed most to total sleep time.
Windred DP, Burns AC, Lane JM, Saxena R, Rutter MK, Cain SW, et al.	2023	Sleep regularity is a stronger predictor of mortality risk than sleep duration: A prospective cohort study.	Prospective cohort study	The study analyzed data from 60,977 UK Biobank participants who wore accelerometers for 7 days to measure sleep regularity (via Sleep Regularity Index - SRI). Mortality data were collected up to 7.8 years later, with 1859 deaths recorded.	Higher sleep regularity was associated with a 20%-48% lower risk of all-cause mortality, a 16%-39% lower risk of cancer mortality, and a 22%-57% lower risk of cardiometabolic mortality. Sleep regularity was a stronger predictor of mortality risk than sleep duration.
Mason L, Connolly J, Devenney LE, Lacey K, O'Donovan J, Doherty R.	2023	Sleep, Nutrition, and Injury Risk in Adolescent Athletes: A Narrative Review.	Narrative Review	N/A	Adolescent athletes often experience inadequate sleep, which, along with nutritional factors, may increase injury risk and impair recovery.
Vlahoyiannis A, Aphamis G, Bogdanis GC, Sakkas GK, Andreou E, Giannaki CD.	2021	Deconstructing athletes' sleep: A systematic review of the influence of age, sex, athletic expertise, sport type, and season on sleep characteristics.	Systematic Review	PubMed and Scopus were searched for studies using objective sleep evaluation tools, with quality assessed via a modified Newcastle-Ottawa Scale. 81 studies were included.	Athletes generally have short sleep duration and low sleep efficiency, with young athletes and heavy training periods showing the most significant sleep issues.
Trabelsi K, BaHammam AS, Chtourou H, Jahrami H, Vitiello MV.	2023	The good, the bad, and the ugly of consumer sleep technologies use among athletes: A call for action.	Narrative Review	N/A	Excessive use of CSTs may contribute to insomnia in athletes through orthosomnia and nomophobia, highlighting the need for scientifically validated CSTs and personalized interventions.
Swinbourne R, Gill N, Vaile J, Smart D.	2016	Prevalence of poor sleep quality, sleepiness and obstructive sleep apnoea risk factors in athletes.	Observational Study	175 elite athletes completed sleep-related questionnaires and an OSA risk factor screen.	Half of the athletes were poor sleepers, with high levels of daytime sleepiness and potential OSA risk, emphasizing the need for sleep education and intervention.
Gupta L, Morgan K, Gilchrist S.	2017	Does Elite Sport Degrade Sleep Quality? A Systematic Review.	Systematic Review	Systematic search of four databases identified 37 studies on elite athletes' sleep patterns and insomnia symptoms.	Elite athletes have a high prevalence of insomnia symptoms, with training, travel, and competition identified as key risk factors affecting sleep quality.
Kroshus E, Wagner J, Wyrick D, Athey A, Bell L, Benjamin HJ, et al.	2019	Wake up call for collegiate athlete sleep: narrative review and consensus recommendations from the NCAA Interassociation Task Force on Sleep and Wellness.	Narrative Review with Delphi consensus	Literature review and Delphi consensus from the NCAA Sleep Summit on collegiate athlete sleep, focusing on patterns, functioning, assessment, and interventions.	Identified sleep as crucial but often neglected due to academic, athletic, and social pressures. Provided five consensus recommendations to improve sleep management in collegiate athletics.

Reardon CL, Hainline B, Aron CM, Baron D, Baum AL, Bindra A, et al.	2019	Mental health in elite athletes: International Olympic Committee consensus statement (2019).	Consensus statement with systematic review	Systematic literature review (14,689 articles screened), expert consensus meeting (2.5-day discussion), and drafting of a consensus statement with updated reviews.	Over half of NCAA athletes get insufficient sleep, with high rates of insomnia and sleep apnea, especially in heavier athletes. Melatonin is effective for insomnia and circadian disturbances, while positive airway pressure is recommended for sleep apnea.
Ohayon M, Wickwire EM, Hirshkowitz M, Albert SM, Avidan A, Daly FJ, et al.	2017	National Sleep Foundation's sleep quality recommendations: first report.	Consensus Statement	Systematic literature review of 277 studies followed by a modified Delphi RAND/UCLA Appropriateness Method with three voting rounds.	Experts agreed on key sleep continuity variables as indicators of good sleep quality but found less consensus on sleep architecture and nap-related factors.
Chennaoui M, Vanneau T, Trignol A, Arnal P, Gomez-Merino D, Baudot C, et al.	2021	How does sleep help recovery from exercise-induced muscle injuries?	Narrative Review	N/A	Sleep plays a crucial role in muscle recovery by regulating hormonal and immune responses, and sleep extension may enhance injury recovery through increased IGF-I and inflammation control.
de Mello MT, Stieler E, Grade I, Filho AFC, Mendes G, Ituassu N, et al.	2024	The Sleep Parameters of Olympic Athletes: Characteristics and Assessment Instruments.	Systematic Review	Review of 11 studies analyzing sleep parameters in Olympic athletes using objective assessments.	Olympic athletes have poor total sleep time, sleep efficiency, and high wake after sleep onset, with frequent sleep complaints; actigraphy is the most used assessment method.
Juliff LE, Halson SL, Peiffer JJ.	2015	Understanding sleep disturbance in athletes prior to important competitions.	Cross-sectional study	Questionnaires assessing sleep complaints in 283 elite Australian athletes before competitions.	64% of athletes reported worse sleep before competitions, mainly due to difficulty falling asleep caused by pre-competition thoughts and nervousness; team sport athletes had fewer sleep strategies than individual athletes.
Roberts SSH, Teo WP, Warmington SA.	2019	Effects of training and competition on the sleep of elite athletes: a systematic review and meta-analysis.	Systematic review	Systematic search of studies reporting total sleep time (TST) and sleep efficiency (SE) in elite athletes.	Athletes often fail to meet sleep recommendations, with competition nights leading to reduced TST (by 60 min) and SE (by 1%). Factors impairing sleep include early training, increased training load, travel, jet lag, and altitude.
Driller MW, Suppiah H, Rogerson D, Ruddock A, James L, Virgile A.	2022	Investigating the sleep habits in individual and team-sport athletes using the Athlete Sleep Behavior Questionnaire and the Pittsburgh Sleep Quality Index.	Cross-sectional study	407 elite athletes (individual and team-sport) completed ASBQ and PSQI.	Team-sport athletes had worse pre-sleep behaviors and poorer sleep characteristics than individual-sport athletes, despite similar PSQI scores. Individual-sport athletes had longer total sleep time and higher sleep efficiency.
Silva A, Narciso FV, Rosa JP, Rodrigues DF, Cruz AÂ DS, Tufik S, et al.	2019	Gender differences in sleep patterns and sleep complaints of elite athletes.	Observational cross-sectional study	146 Brazilian Olympic athletes (86 male, 60 female) were assessed with polysomnography (PSG) and a clinical consultation about sleep complaints, without training or competitions during the week of evaluation.	53% had sleep complaints (most common: insufficient sleep/waking up tired, snoring, insomnia). Men had higher sleep latency, wake after sleep onset, and lower sleep efficiency and slow-wave sleep compared to women. 36% had a sleep disorder, with worse sleep quality in men.
Dickinson RK, Hanrahan SJ.	2009	An investigation of subjective sleep and fatigue measures for use with elite athletes.	Validation study	59 elite Australian athletes completed sleep and fatigue scales; subsets completed retests and interviews.	The Athens Insomnia Scale, Fatigue Severity Scale, and SLEEP-50 subscales showed good reliability and validity for athletes, though improvements were suggested. Athletes reported few sleep issues but moderate fatigue.
Kelley GA, Kelley KS.	2017	Exercise and sleep: a systematic review of previous meta-analyses.	Systematic review of meta-analysis	Review of 3 meta-analyses on randomized controlled exercise interventions for sleep outcomes in adults.	Exercise significantly improves sleep quality, sleep latency, and apnea-hypopnea index, though evidence quality is low. A larger, high-quality meta-analysis is needed.
Huang HH, Stubbs B, Chen LJ, Ku PW, Hsu TY, Lin CW, et al.	2023	The effect of physical activity on sleep disturbance in various populations: a scoping review of randomized clinical trials.	Scoping review of RCTs	Systematic search (PubMed, Web of Science, Cochrane, Embase) for RCTs on physical activity (PA) and sleep, with thematic analysis of 21 trials (N = 3677).	PA improves sleep across various populations, with self-tolerated PA being safe for elderly and comorbid individuals. Addressing sleep environment may enhance intervention effectiveness.
Murphy C, Svansdottir SA, Dupuy O, Louis J.	2024	Does overreaching from endurance-based training impair sleep: A systematic review and meta-analysis.	Systematic review and meta-analysis	Reviewed 14 studies on endurance-based overreaching and its effects on sleep, using PRISMA guidelines.	Overreaching reduces objective sleep efficiency but does not affect perceived sleep quality. More high-quality studies are needed.

Kocevska D, Barclay NL, Bramer WM, Gehrman PR, Van Someren EJW.	2021	Heritability of sleep duration and quality: A systematic review and meta-analysis.	Meta-analysis	A systematic literature search was conducted across five databases, yielding 23 papers (19 independent samples) on sleep duration and 13 papers (10 independent samples) on sleep quality. The studies included a total of 45,328 twins for sleep duration and 39,020 twins for sleep quality. Heritability estimates for sleep characteristics were meta-analyzed.	The study found that 46% of the variability in sleep duration and 44% of the variability in sleep quality is genetically determined. Heritability estimates varied by age (from 17% in infancy to 69% in adolescence) and reporter type (8% for parent-report vs. 38–52% for self-report). Variability was mainly due to unique environmental factors, with shared environment affecting childhood sleep duration.
Dattilo M, Antunes HK, Medeiros A, Mônico Neto M, Souza HS, Tufik S, et al.	2011	Sleep and muscle recovery: endocrinological and molecular basis for a new and promising hypothesis.	Hypothesis-driven review	N/A	Sleep deprivation creates a catabolic environment, impairing muscle repair and promoting muscle loss.
Fullagar HH, Skorski S, Duffield R, Hammes D, Coutts AJ, Meyer T	2015	Sleep and athletic performance: the effects of sleep loss on exercise performance, and physiological and cognitive responses to exercise.	Narrative Review	N/A	Sleep loss may impair sport-specific performance, autonomic balance, immune function, and cognitive accuracy, but effects on maximal effort performance remain unclear.
Skein M, Duffield R, Edge J, Short MJ, Mündel T.	2011	Intermittent-sprint performance and muscle glycogen after 30 h of sleep deprivation.	Experimental trial with repeated measures	Athletes underwent two experimental trials (sleep deprivation vs. control) to assess performance and muscle glycogen levels during intermittent-sprint exercise.	Sleep deprivation led to slower sprint times, reduced muscle glycogen, and diminished voluntary force and pacing strategies, indicating negative impacts on performance.
Hickman R, D'Oliveira TC, Davies A, Shergill S.	2024	Monitoring Daily Sleep, Mood, and Affect Using Digital Technologies and Wearables: A Systematic Review.	Systematic review and meta-analysis	Reviewed 121 studies using ambulatory monitoring and wearables to assess sleep-affect associations across various populations (e.g., affective disorders, shift workers).	Sleep disturbances were found to influence affective experiences, with subjective sleep quality being a stronger predictor of mood than objective measures. Bidirectional relationships were observed, but the strength of these associations varied by sleep indices, affective dimensions, and diagnostic status.
Craven J, McCartney D, Desbrow B, Sabapathy S, Bellinger P, Roberts L, et al.	2022	Effects of Acute Sleep Loss on Physical Performance: A Systematic and Meta-Analytical Review.	Systematic review and meta-analysis	Analyzed 69 studies assessing exercise performance under normal sleep (>6h) vs. sleep loss (≤6h). Meta-regressions explored sleep-loss protocols, exercise timing, and body limb strength.	Sleep loss negatively impacted all exercise categories, with stronger effects from deprivation and late restriction. Every additional hour awake reduced performance by ~0.4%. PM exercise was consistently impaired, whereas AM performance was less affected. Prioritizing morning exercise may help mitigate performance declines due to sleep loss.
Lathlean TJH, Newstead SV, Gastin PB.	2022	Elite Junior Australian Football Players With Impaired Wellness Are at Increased Injury Risk at High Loads.	Observational cohort study	Data from 280 players across 2014; internal load via session RPE; wellness (sleep, fatigue, soreness, stress, mood) tracked; training load variables analyzed; injury defined as missed session/match; logistic GEE used for associations.	Injury risk is nonlinearly linked to training load, with wellness factors (stress, soreness, sleep) influencing this relationship.
Mousavi SH, Hijmans JM, Minoonejad H, Rajabi R, Zwerver J.	2021	Factors Associated With Lower Limb Injuries in Recreational Runners: A Cross-Sectional Survey Including Mental Aspects and Sleep Quality.	Cross-sectional survey	Internet-based questionnaire on personal/training characteristics, mental aspects, sleep, health, and injuries in 804 recreational runners; logistic regression used for associations.	54% reported running-related injuries (RRIs), most commonly patellofemoral pain syndrome (20%). Obsessive passion, motivation, poor sleep, overweight, pes planus, running >20 km/week, and hard surfaces increased RRI risk. Mental aspects and sleep quality explained 15% of RRI variance.

Raikes AC, Athey A, Alfonso-Miller P, Killgore WDS, Grandner MA.	2019	Insomnia and daytime sleepiness: risk factors for sports-related concussion.	Cross-sectional survey	190 NCAA Division-1 athletes completed the Insomnia Severity Index and NHANES Sleep module; univariate and multivariate logistic regression assessed concussion risk.	Moderate-to-severe insomnia (RR = 3.13) and frequent daytime sleepiness (RR = 2.86) significantly increased concussion risk, even after adjusting for sport participation.
Vitale KC, Owens R, Hopkins SR, Malhotra A.	2019	Sleep Hygiene for Optimizing Recovery in Athletes: Review and Recommendations.	Systematic review	Reviewed 40 studies on sleep deprivation and extension in athletes from 1980–2018 using PubMed/Medline. Included endurance, strength, and mixed-sport athletes; excluded non-athletes and animal studies.	Sleep deprivation negatively impacts reaction time, accuracy, strength, endurance, and cognitive function. Sleep extension improves reaction time, mood, sprint performance, and accuracy in various sports. "Banking sleep" before sleep deprivation may mitigate performance declines.
Simim MAM, Souza HS, Cardoso Filho CA, Gianoni R, Bezerra RR, Affonso HO, et al.	2020	Sleep quality monitoring in individual sports athletes: parameters and definitions by systematic review.	Systematic Review	Systematic searches in PubMed, Scopus, and Web of Science were conducted, yielding 75 eligible studies following PRISMA guidelines.	Actigraphy, Likert scales, and sleep diaries are the most used instruments for monitoring sleep quality in athletes, but inconsistent definitions of sleep parameters hinder the clarity of the sleep-performance relationship.
Claudino Claudino JG, T JG, de Sá Souza H, Simim M, Fowler P, de Alcantara Borba D, et al. al.	2019	Which parameters to use for sleep quality monitoring in team sport athletes? A systematic review and meta-analysis.	Systematic review and meta-analysis	Systematic searches in PubMed, Scopus, SPORTDiscus, and Web of Science identified 30 instruments, with 15 parameters included in a meta-analysis using a random-effects model.	Sleep efficiency (actigraphy), Pittsburgh Sleep Quality Index, Likert scales, Liverpool Jet-Lag Questionnaire, and RESTQ are recommended for monitoring sleep quality in team sport athletes.
Fabbri M, Beracci A, Martoni M, Meneo D, Tonetti L, Natale V.	2021	Measuring Subjective Sleep Quality: A Review.	Systematic Review	Systematic search (2008–2020) in PubMed and Scopus, analyzing 49 articles on sleep quality questionnaires.	Various self-report tools (PSQI, AIS, ISI, MSQ, JSS, LSEQ, SLEEP-50, ESS) show good psychometric properties, but inconsistencies in factorial structures challenge their clinical utility. Reliable cut-offs and clearer factor models are needed.
Yin J, Xu J, Ren TL.	2023	Recent Progress in Long-Term Sleep Monitoring Technology.	Narrative Review	N/A	Traditional sleep monitoring (e.g., polysomnography) is well-established, but there is a growing need for wearable and non-contact devices for continuous at-home monitoring. Multi-signal approaches (bioelectrical, biomechanical, and biochemical) offer better sleep assessment. Future research should focus on improving accuracy and accessibility.
de Gans CJ, Burger P, van den Ende ES, Hermanides J, Nanayakkara PWB, Gemke R, et al.	2024	Sleep assessment using EEG-based wearables - A systematic review.	Systematic Review	Systematic search in OVID MEDLINE, Embase, and CINAHL; machine learning-assisted screening; 60 papers reviewed.	EEG-based wearables are promising alternatives to PSG for sleep monitoring, with high accuracy in sleep staging and good feasibility. User-friendliness, comfort, and cost should be considered when selecting a device.
Carskadon M, Dement W.	1989	Normal Human Sleep: An Overview.	Narrative Review	N/A	Sleep cycles between NREM and REM in ~90-minute intervals, with deeper NREM (N3) dominating early sleep and REM increasing later. Newborns have more REM, which declines with age. Slow-wave sleep decreases significantly in adolescence and continues declining into old age, especially in men. Sleep is influenced by homeostatic load, circadian phase, temperature, drugs, and disorders.
Perez-Pozuelo I, Zhai B, Palotti J, Mall R, Aupetit M, Garcia-Gomez JM, et al.	2020	The future of sleep health: a data-driven revolution in sleep science and medicine.	Narrative Review	N/A	Advances in multi-modal sensors enable large-scale sleep monitoring with applications in research and wellness. Challenges include performance evaluation, data processing, integration, and interpretation. AI-driven approaches offer potential but require validation for clinical and consumer use.

Yuan H, Hill EA, Kyle SD, Doherty A.	2024	A systematic review of the performance of actigraphy in measuring sleep stages.	Systematic Review	Narrative synthesis of eight studies comparing actigraphy with polysomnography for sleep staging.	Actigraphy shows some ability to classify sleep stages, but accuracy is limited and heterogeneous across studies. Quantitative synthesis was not feasible.
Ontario Health	2024	Level 2 Polysomnography for the Diagnosis of Sleep Disorders: A Health Technology Assessment.	Systematic Review	Systematic literature searches, diagnostic accuracy and economic evaluations (using QUADAS-2 and GRADE) along with stakeholder consultations were conducted.	Level 2 polysomnography shows promising diagnostic accuracy compared to level 1 and may offer cost savings for adults, with patients favoring at-home testing for comfort and convenience, though cost-effectiveness remains uncertain.
Hof Zum Berge A, Kellmann M, Kallweit U, Mir S, Gieselmann A, Meyer T, et al.	2020	Portable PSG for sleep stage monitoring in sports: Assessment of SOMNOwatch plus EEG.	Validation study	25 participants underwent two nights of simultaneous PSG and SOMNOwatch plus EEG recordings; sleep parameters were compared using paired t-tests and Bland-Altman plots.	SOMNOwatch plus EEG demonstrated good agreement with PSG for sleep staging and key parameters, making it a viable tool for sports research, though not a full replacement for PSG in clinical settings.
Ibáñez V, Silva J, Navarro E, Cauli O.	2019	Sleep assessment devices: types, market analysis, and a critical view on accuracy and validation.	Systematic literature review and market analysis	Reviewed 132 studies on sleep assessment devices, focusing on validation studies' sensitivity and specificity; conducted a market analysis from 2017 to 2019 monitoring top-selling devices.	Technological advancements have improved sensor accuracy, with some actigraphs achieving >90% sensitivity; however, many devices, especially software, lack proper validation for clinical use.
Berry RB, Wagner MH.	2015	Sleep Medicine Pearls (Third Edition). Introduction.	Book chapter	N/A	A practical and concise resource for sleep medicine clinicians, fellows, and those studying for board exams, offering key insights into the evaluation and management of sleep disorders.
Thomas SJ, Gamble K.	2025	Actigraphy in the evaluation of sleep disorders.	Review	N/A	Actigraphy is a valid, noninvasive method for measuring sleep-wake cycles in various sleep disorders, offering greater external validity than polysomnography for certain parameters. It complements self-reported data and is useful in monitoring treatment responses. Consumer wearable devices are also discussed.
Ancoli-Israel S, Martin JL, Blackwell T, Buenaver L, Liu L, Meltzer LJ, et al.	2015	The SBSM Guide to Actigraphy Monitoring: Clinical and Research Applications.	Consensus Guideline	Scoring and instructional manual was commissioned by the Society of Behavioral Sleep Medicine (SBSM) primarily to assist clinicians, but in addition to inform researchers in the use of actigraphy.	Actigraphy is a valuable tool for long-term, at-home sleep monitoring, particularly for circadian rhythm and insomnia disorders. It's not a substitute for polysomnography but complements it for extended sleep data collection. Its accuracy has improved, with advances in technology and software, and it's now used in both clinical and research settings. Actigraphy is also reimbursed in clinical settings through the CMS.
Sargent C, Lastella M, Halson SL, Roach GD.	2016	The validity of activity monitors for measuring sleep in elite athletes.	Validation study	16 endurance-trained cyclists participated in a 6-week training camp, where sleep was recorded with both polysomnography and activity monitors over 122 nights. Epoch-for-epoch comparisons were made to calculate agreement, sensitivity, and specificity.	Activity monitors showed good agreement with polysomnography in detecting sleep and wake states in elite athletes, but the accuracy varied based on the chosen sleep-wake threshold. The default threshold led to underestimation of sleep and overestimation of wake, while higher sensitivity thresholds produced better results.
Smith MT, McCrae CS, Cheung J, Martin JL, Harrod CG, Heald JL, et al.	2018	Use of Actigraphy for the Evaluation of Sleep Disorders and Circadian Rhythm Sleep-Wake Disorders: An American Academy of Sleep Medicine Systematic Review, Meta-Analysis, and GRADE Assessment.	Systematic review and guideline development	Systematic review of 81 studies comparing actigraphy, sleep logs, and/or polysomnography.	Actigraphy provides consistent objective data distinct from patient-reported sleep logs for insomnia, circadian rhythm disorders, sleep-disordered breathing, and hypersomnolence but is not reliable for periodic limb movements.

Faizullabhoy M, Wani G.	2024	Sleep Tech Devices Market — By Product, By Application, By Distribution Channel — Global Forecast, 2024–2032.	Report	N/A	The global sleep tech devices market was valued at $21.1 billion in 2023 and is expected to grow at a CAGR of 18.3% (2024-2032), reaching $95.2 billion by 2032. Growth drivers include rising awareness, technological advancements, and increasing prevalence of sleep disorders
Olsen RJ, Hasan SS, Woo JJ, Nawabi DH, Ramkumar PN.	2025	The Fundamentals and Applications of Wearable Sensor Devices in Sports Medicine: A Scoping Review.	Systematic Review	Systematic search of PubMed and EMBASE for studies using wearable sensor devices (WSDs) in sports medicine, extracting data on demographics, sensor specifications, and applications.	WSDs include accelerometers, GPS trackers, force sensors, and inertial measurement units, used for monitoring biomechanics, workload, injury prevention, and rehabilitation. They enable real-time, quantitative performance tracking to aid training, injury risk assessment, and return-to-play decisions.
Lee T, Cho Y, Cha KS, Jung J, Cho J, Kim H, et al.	2023	Accuracy of 11 Wearable, Nearable, and Airable Consumer Sleep Trackers: Prospective Multicenter Validation Study.	Validation study	Comparison of 11 consumer sleep trackers (CSTs) with polysomnography in a multicenter study involving 75 participants and 3890 hours of sleep recordings.	CSTs varied in accuracy, with some showing substantial agreement with polysomnography. Wearables (e.g., Google Pixel Watch, Fitbit Sense 2) performed better for deep sleep, while nearables and airables had biases in different sleep measures. CSTs may be useful for personal sleep monitoring but have limitations in clinical accuracy.
Schyvens AM, Van Oost NC, Aerts JM, Masci F, Peters B, Neven A, et al.	2024	Accuracy of Fitbit Charge 4, Garmin Vivosmart 4, and WHOOP Versus Polysomnography: Systematic Review.	Systematic Review	PRISMA-based review of 8 studies evaluating Fitbit Charge 4, Garmin Vivosmart 4, and WHOOP against PSG or ambulatory EEG.	WHOOP had the least disagreement for total sleep time but overestimated REM sleep. Fitbit Charge 4 showed the highest sensitivity for deep and REM sleep. All devices showed moderate accuracy but require further improvement in sleep stage classification. More research with standardized protocols is needed.
Chinoy ED, Cuellar JA, Huwa KE, Jameson JT, Watson CH, Bessman SC, et al.	2021	Performance of seven consumer sleep-tracking devices compared with polysomnography.	Validation study	34 adults underwent PSG for 3 nights, including disrupted sleep, while wearing 4 wearable and 3 nonwearable consumer sleep trackers, plus actigraphy.	Most devices (except Garmin) matched or outperformed actigraphy in sleep/wake detection. Sensitivity was high (≥0.93), but specificity was low-to-medium (0.18-0.54). Sleep stage classification was inconsistent, and performance declined with disrupted sleep. Broader validation in different populations is needed.
Hsiou DA, Gao C, Matlock RC, Scullin MK.	2022	Validation of a nonwearable device in healthy adults with normal and short sleep durations.	Validation study	35 adults underwent PSG under normal and restricted sleep conditions, using actigraphy, self-report, and two versions of a nonwearable sleep tracker (Beddit 3.0 and 3.5).	Beddit 3.0 showed poor reliability (ICC < 0.30), while Beddit 3.5 had excellent agreement with PSG (ICC 0.92–0.998) and outperformed actigraphy. Further validation in clinical populations is needed.
Tran HH, Hong JK, Jang H, Jung J, Kim J, Hong J, et al.	2023	Prediction of Sleep Stages Via Deep Learning Using Smartphone Audio Recordings in Home Environments: Model Development and Validation.	Validation study	Developed and validated a deep learning model for sound-based sleep staging using 812 hospital PSG-audio pairs, 829 home audio recordings, and 8255 home noise samples; tested on 45 home PSG-audio pairs.	Model achieved 76.2% accuracy (wake 63.4%, REM 64.9%, non-REM 83.6%), performing robustly across demographics. Combining transfer learning and consistency training improved accuracy by 7%.
Wylie L.	2025	Business of Apps.	Market analysis	N/A	The health app industry generated $3.43 billion in 2023, with 311 million users and 379 million downloads. Noom led revenue generation, while MyFitnessPal had the largest market share. Wearable technology shifted focus from fitness trackers to multifunctional smartwatches.
Kainec KA, Caccavaro J, Barnes M, Hoff C, Berlin A, Spencer RMC.	2024	Evaluating Accuracy in Five Commercial Sleep-Tracking Devices Compared to Research-Grade Actigraphy and Polysomnography.	Validation study	Compared five consumer sleep trackers, research-grade actigraphy, and PSG in 53 healthy adults during one night in a sleep lab.	Most devices estimated total sleep time comparably to actigraphy, but all showed proportional bias in wake time estimation. Light and deep sleep biases varied by device.

Willoughby AR, Golkashani HA, Ghorbani S, Wong KF, Chee N, Ong JL, et al.	2024	Performance of wearable sleep trackers during nocturnal sleep and periods of simulated real-world smartphone use.	Comparative study	63 participants engaged in common peri-sleep behaviors and wore consumer sleep trackers (Oura Ring Gen 3, Fitbit Sense, AXTRO Fit 3, Xiaomi Mi Band 7) and research-grade actigraphy during nocturnal sleep. They also completed a questionnaire during simulated wake periods. Performance of these devices was compared to polysomnography.	Oura and Fitbit showed better accuracy in detecting sleep/wake transitions compared to lower-priced trackers and actigraphy. Performance was more reliable on nights with suboptimal routines, but devices were less accurate in participants with lower sleep efficiency or disturbed sleep. These findings suggest higher-quality consumer sleep trackers perform well in moderate sleep disturbances but may be less accurate in cases of insomnia.
Zhai H, Yan Y, He S, Zhao P, Zhang B.	2023	Evaluation of the Accuracy of Contactless Consumer Sleep-Tracking Devices Application in Human Experiment: A Systematic Review and Meta-Analysis.	Systematic review and meta-analysis	The review included 26 articles and assessed the effectiveness of contactless consumer sleep-tracking devices in monitoring sleep parameters by searching PubMed, EMBASE, Cochrane CENTRALE, and Web of Science.	CST devices showed better accuracy in experiments with healthy participants, particularly when using mattress-based devices with piezoelectric sensors. Their performance in distinguishing sleep from wake epochs was comparable to actigraphy, and they provided data on sleep stages, unlike actigraphy, making them a promising alternative to polysomnography and actigraphy.
Lee J, Finkelstein J.	2015	Consumer sleep tracking devices: a critical review.	Systematic device review	Evaluated six consumer sleep trackers based on output metrics, theoretical frameworks, systematic evaluation, and FDA clearance.	Most devices lacked validation data; wake detection accuracy was low and inconsistent. No evidence supported their effectiveness in managing sleep disturbances.
Sargent C, Lastella M, Romyn G, Versey N, Miller D, Roach G.	2018	How well does a commercially available wearable device measure sleep in young athletes?	Validation study	Compared FitBit HR Charge with polysomnography in 12 semi-professional soccer players across night-time sleep and daytime naps.	FitBit accurately detected most night-time sleep periods but poorly detected naps. It overestimated total sleep time, with greater error during night-time sleep.
Kawasaki Y, Kasai T, Sakurama Y, Sekiguchi A, Kitamura E, Midorikawa I, et al.	2022	Evaluation of Sleep Parameters and Sleep Staging (Slow Wave Sleep) in Athletes by Fitbit Alta HR, a Consumer Sleep Tracking Device.	Validation study	Compared Fitbit Alta HR with EEG in 40 college athletes.	Strong correlation between Fitbit and EEG for total sleep time and moderate correlation for deep sleep, supporting its use for sleep monitoring in athletes.
Dai J, Xu X, Chen G, Lv J, Xiao Y.	2025	Sleep-wake patterns of fencing athletes: a long-term wearable device study.	Observational study	Monitored sleep in 23 fencing athletes using Huawei Band 6, analyzing sleep-wake patterns and correlations with training schedules, level, and gender.	High-level and female athletes napped more; sleep patterns varied based on training schedules, suggesting sleep rhythm disruption.
Goldman JT, Donohoe B, Hatamiya N, Boland NF, Vail J, Holmes KE, et al.	2024	Baseline Sleep Characteristics in NCAA Division I Collegiate Athletes.	Prospective study	82 Division I student-athletes completed sleep questionnaires (ESS, SISQS) and wore WHOOP 4.0 for ≥14 nights to assess sleep parameters.	No sex differences in total sleep time or sleep architecture; average TST was 409.2 ± 36.3 min, with significant differences in wake time between males and females.
Bigalke JA, Lee KM, Bigalke JR, Scullin MK, Gallucci AR, Carter JR.	2025	Longitudinal assessment of objective sleep and power output in Division I collegiate baseball athletes.	Observational longitudinal study	The study tracked peak power output for 12 weeks in 24 male collegiate baseball players (age: 21 ± 1 years) and assessed objective sleep (Oura ring) over the final 6 weeks. Sleep measures included total sleep time, sleep efficiency, and consistency of maintaining ≥7 hours of sleep or ≥90% sleep efficiency.	Improvements in peak power output were associated with greater total sleep time, higher sleep efficiency, fewer nighttime awakenings, and maintaining ≥7 hours of sleep or ≥90% sleep efficiency on more nights. These findings suggest adequate sleep duration and quality are linked to better performance in college athletes during training.
Baron KG, Duffecy J, Berendsen MA, Cheung Mason I, Lattie EG, Manalo NC.	2018	Feeling validated yet? A scoping review of the use of consumer-targeted wearable and mobile technology to measure and improve sleep.	Scoping review	The review included 43 studies out of 3897 records, focusing on consumer-targeted wearable and mobile technologies for sleep monitoring in adult populations. Studies were screened for inclusion based on criteria such as technology use to estimate or improve sleep, with at least 10 participants.	Most studies (23) focused on validating sleep-monitoring technology against PSG. Fewer studies evaluated interventions (5) or identified sleep disorders (2). Highlights gaps in the literature and suggests a need for multidisciplinary research on the use of these technologies for behavioral interventions and in diverse populations, including those with sleep disorders.

Birrer V, Elgendi M, Lambercy O, Menon C.	2024	Evaluating reliability in wearable devices for sleep staging.	Scoping review	Analyzed 35 articles (past decade) covering 62 wearable setups with different sensors and algorithms.	Combining accelerometer and PPG improves sleep staging; five recommendations proposed to enhance wearable sleep tracking reliability.
Soldatos CR, Dikeos DG, Paparrigopoulos TJ.	2000	Athens Insomnia Scale: validation of an instrument based on ICD-10 criteria.	Validation study	AIS administered to 299 subjects (105 insomniacs, 144 psychiatric patients, 50 controls); internal consistency, reliability, and validity assessed.	AIS-8 and AIS-5 show high reliability (Cronbach's α ~0.90, test-retest ~0.90) and strong validity (correlation with Sleep Problems Scale: 0.90 and 0.85, respectively).
Spoormaker VI, Verbeek I, van den Bout J, Klip EC.	2005	Initial Validation of the SLEEP-50 Questionnaire.	Psychometric validation	SLEEP-50 administered to 377 students, 246 sleep patients, 32 nightmare sufferers, and 44 healthy volunteers; internal consistency, test-retest reliability, and factor analysis conducted.	High internal consistency (Cronbach's α = 0.85), promising sensitivity/specificity, and substantial agreement with clinical diagnoses (κ = 0.77). SLEEP-50 effective in screening for common sleep disorders.
Horne JA, Ostberg O.	1976	A self-assessment questionnaire to determine morningness-eveningness in human circadian rhythms.	Evaluation study	48 subjects categorized into Morning, Evening, and Intermediate types based on a Morningness-Eveningness questionnaire; oral temperature measured to assess circadian variation.	Morning types showed earlier peak temperatures, higher daytime temperatures, and earlier sleep times compared to Evening types. No significant differences in sleep length were found. The questionnaire correlated well with peak time and is a valid tool, though further evaluation is needed with a larger population.
Johns MW.	1991	A new method for measuring daytime sleepiness: the Epworth sleepiness scale.	Validation study	80 adults (30 normal, 150 with sleep disorders) completed the ESS, rating their likelihood of dozing off in 8 everyday situations.	Development and validation of the Epworth Sleepiness Scale (ESS). ESS effectively distinguished normal subjects from those with sleep disorders, such as obstructive sleep apnea, narcolepsy, and idiopathic hypersomnia. ESS scores correlated with sleep latency, respiratory disturbance index, and minimum SaO2 in sleep apnea patients. Snorers' ESS scores were similar to controls.
Buysse DJ, Reynolds CF, 3rd, Monk TH, Berman SR, Kupfer DJ.	1989	The Pittsburgh Sleep Quality Index: a new instrument for psychiatric practice and research.	Validation study	The PSQI was assessed in 52 healthy subjects and 116 patients (depressed and sleep-disordered), over 18 months. It includes 19 items covering various sleep quality aspects, generating seven component scores and one global score.	The PSQI demonstrated good internal consistency, reliability, and validity. A global score >5 showed 89.6% sensitivity and 86.5% specificity in distinguishing good and poor sleepers. The PSQI is a reliable tool for both clinical and research purposes in psychiatric populations.
Mollayeva T, Thurairajah P, Burton K, Mollayeva S, Shapiro CM, Colantonio A.	2016	The Pittsburgh sleep quality index as a screening tool for sleep dysfunction in clinical and non-clinical samples: A systematic review and meta-analysis.	Review	The review appraised 37 studies on PSQI, assessing construct validity, known-group validity, internal consistency, and test-retest reliability using COSMIN criteria.	PSQI showed good internal consistency, strong reliability, and validity, with moderate structural validity. Significant differences in PSQI scores were found between clinical and non-clinical samples, except for the sleep disturbance subscale. The tool proves effective for screening sleep dysfunction in diverse populations.
Samuels C, James L, Lawson D, Meeuwisse W.	2016	The Athlete Sleep Screening Questionnaire: a new tool for assessing and managing sleep in elite athletes.	Validation study	A convenience sample of 60 elite athletes was divided into two groups: one completed a survey of existing tools, the other completed a revised survey alongside a sleep specialist interview. Item analysis was performed based on clinical assessment.	Development and validation of the Athlete Sleep Screening Questionnaire (ASSQ). Existing sleep-screening tools showed low consistency with clinical assessments, leading to the development of a 15-item ASSQ. The ASSQ demonstrated good internal consistency and reliability, identifying 13.2% of athletes requiring follow-up consultations, which confirmed the tool's accuracy in identifying sleep disturbances. Further validation with objective sleep data is planned.

Driller MW, Mah CD, Halson SL.	2018	Development of the athlete sleep behavior questionnaire: A tool for identifying maladaptive sleep practices in elite athletes.	Validation study	564 participants (242 athletes, 322 non-athletes) completed the 18-item ASBQ, along with the SHI, ESS, and PSQI. A subgroup underwent test-retest reliability and wrist-actigraphy sleep monitoring.	The ASBQ demonstrated moderate to large correlations with existing sleep questionnaires. Athletes had significantly higher ASBQ global scores than non-athletes. The tool showed good reliability (ICC = 0.87) and a moderate relationship with total sleep time (r = -0.42). The ASBQ is a valid and reliable tool to assess sleep behaviors in elite athletes and may guide improvements in their sleep habits.
Trabelsi K, Saif Z, Driller MW, Vitiello MV, Jahrami H.	2024	Evaluating the reliability of the athlete sleep behavior questionnaire (ASBQ): a meta-analysis of Cronbach's alpha and intraclass correlation coefficient.	Meta-analysis	Systematic search across 10 databases; included studies reporting internal consistency and/or test-retest reliability of the ASBQ. Random-effects model used for reliability estimation.	Internal consistency of ASBQ was moderate (Cronbach's alpha = 0.73), and test-retest reliability was very good (ICC = 0.88). The ASBQ is reliable for evaluating and monitoring athletes' sleep behavior over time, with no evidence of publication bias. Further refinement is needed to optimize internal consistency and validate across diverse athletic populations.
Bender AM, Lawson D, Werthner P, Samuels CH.	2018	The Clinical Validation of the Athlete Sleep Screening Questionnaire: an Instrument to Identify Athletes that Need Further Sleep Assessment.	Validation study	199 Canadian National Team athletes completed the ASSQ; 46 athletes participated in a sub-study with clinical sleep interviews by a sleep medicine physician (SMP) for comparison.	The ASSQ demonstrated good internal consistency (Cronbach's alpha = 0.74), high test-retest reliability (r = 0.86), and strong agreement with the SMP (Cohen's kappa = 0.84). It had diagnostic sensitivity of 81%, specificity of 93%, positive predictive value of 87%, and negative predictive value of 90%. The ASSQ effectively identified athletes requiring clinical sleep intervention, and sleep improved following recommendations.
Tan C, Wang J, Lu J, Yin J, An Y, Ye J, et al.	2024	The Limitations of Using the Pittsburgh Sleep Quality Index to Assess Athletes' Sleep Quality: Evidence from Reliability and Validity in Chinese Professional Athletes.	Validation study	581 Chinese professional athletes participated. Exploratory and confirmatory factor analyses were performed on the Chinese PSQI. Test-retest reliability was assessed over various time intervals (2 weeks, 1 week, and 2-3 days within 1 month). Convergent validity was examined using ISI, ASSQ, and actigraphy.	The PSQI exhibited a two-factor structure (sleep quality and sleep efficiency) with good model fit. Test-retest reliability was satisfactory (r = 0.721–0.753) for intervals of one week or more. The total score and sleep quality showed good correlation with ISI and ASSQ (r = 0.701–0.839). Monthly responses correlated well with the most recent weeks (r = 0.732–0.866).
Natale V, Léger D, Bayon V, Erbacci A, Tonetti L, Fabbri M, et al.	2015	The consensus sleep diary: quantitative criteria for primary insomnia diagnosis.	Retrospective analysis Methods:	Analyzed 295 sleep diaries from insomnia patients and 536 from normal sleepers. Quantitative criteria were derived using the Youden index, and receiver operating characteristic curves were used to test accuracy.	The sleep diary's quantitative criteria are valid for differentiating insomnia patients from normal sleepers and could serve as a useful screening tool for primary insomnia.
Leduc C, Tee J, Phibbs P, Read D, Ramirez C, Sawczuk T, et al.	2020	Objective sleep patterns and validity of self-reported sleep monitoring across different playing levels in rugby union.	Observational cohort study	Sleep data were recorded for 38 rugby union players across four age groups (U16, U18, senior academy, elite senior) over 253 nights. Sleep measures were assessed through wristwatch actigraphy (objective) and self-reported data (subjective). Linear mixed models and magnitude-based decisions were used for analysis.	Players across all age groups obtained an average of seven hours of sleep per night, with minimal differences between the groups. When comparing subjective sleep measures (such as self-reported bedtime and wake-up time) to objective measures (via wristwatch actigraphy), a strong correlation was found for bedtime (r = 0.56) and wake-up time (r = 0.70). However, there was a large standard error (1.50) for total sleep time. Subjective reports did not always align closely with the objective measurements.
Buysse DJ, Ancoli-Israel S, Edinger JD, Lichstein KL, Morin CM.	2006	Recommendations for a standard research assessment of insomnia.	Consensus Statement	A panel of 25 researchers reviewed insomnia literature, discussed recommendations in a meeting, and refined them in writing.	Standardized research assessments for insomnia should include definitions/diagnosis, qualitative measures, sleep diaries, polysomnography, actigraphy, and measures of daytime consequences (fatigue, mood, performance, quality of life).

Research2Guid-ance	2024	Global Digital Health Business Outlook Survey – 2024.	Report	A comprehensive analyses drawn from the perspectives of 831 digital health stakeholders and decision-makers worldwide	The number of commercially available devices is expected to continue rising, as industry experts and stakeholders anticipate that smartwatches, fitness trackers, and smart rings will drive the highest business potential within the digital health industry
Grand View R.	2024	mHealth Apps Market Size, Share & Trends Analysis Report By Type (Medical Apps, Fitness Apps), By Platform (Android, iOS), By Region, And Segment Forecasts, 2024 - 2030.	Report	A combination of bottom-up and top-down approaches, data triangulation, preliminary data mining, statistical modeling, and primary validation through industry interviews.	The global mHealth apps market size was estimated at USD 32.42 billion in 2023 and is anticipated to grow at a CAGR of 14.9% from 2024 to 2030. The industry growth is expected to be facilitated by the increasing penetration of smartphones. According to the Mobile Economy 2023 report, smartphone penetration was at 76% in 2022 and is predicted to reach 92% by 2030.
Abd-Alrazaq A, Aslam H, AlSaad R, Alsahli M, Ahmed A, Damseh R, et al.	2024	Detection of Sleep Apnea Using Wearable AI: Systematic Review and Meta-Analysis.	Systematic Review	Reviewed 38 studies on wearable AI for sleep apnea detection, analyzing accuracy, sensitivity, specificity, and influencing factors.	Wearable AI has high accuracy in detecting apnea events (0.893) and classifying apnea types (0.815), but lower accuracy in assessing severity (0.651). Performance varies by algorithm, data type, and device placement.
Bazoukis G, Bollepalli SC, Chung CT, Li X, Tse G, Bartley BL, et al.	2024	The Impact of Daytime Napping Following Normal Night-Time Sleep on Physical Performance: A Systematic Review, Meta-analysis and Meta-regression.	Systematic review and meta-analysis	PRISMA-guided review of studies on the effects of daytime napping after normal sleep (7-9 hours) on physical performance in active individuals and athletes. Seven databases were searched for studies published before September 2022.	Napping improved performance in distance and fatigue index during the 5-m shuttle run test (5MSRT), but had no effect on muscle force. Effects on other performance measures like sprinting, jump performance, and endurance were mixed.
Patterson MR, Nunes AAS, Gerstel D, Pilkar R, Guthrie T, Neishabouri A, et al.	2023	40 years of actigraphy in sleep medicine and current state of the art algorithms.	Systematic evaluation	Compared 8 sleep-scoring algorithms using wrist-worn accelerometry against PSG as ground truth.	Simple regression-based and heuristic algorithms outperformed complex machine learning models in sleep-wake classification and sleep outcome estimation. Deep learning models struggled with generalization.
Bechny M, Monachino G, Fiorillo L, van der Meer J, Schmidt MH, Bassetti CLA, et al.	2024	Bridging AI and Clinical Practice: Integrating Automated Sleep Scoring Algorithm with Uncertainty-Guided Physician Review.	Validation study	Trained and refined U-Sleep on 19,578 PSGs, validated uncertainty estimation on 8,832 PSGs from diverse populations.	U-Sleep achieved ~76% agreement with PSG scorers. Confidence network effectively identified uncertain predictions, allowing selective review of <29% of epochs to reach $\kappa \geq 90\%$.
Perez-Pozuelo et al.	2022	Detecting sleep outside the clinic using wearable heart rate devices.	Validation study	A heart rate-based algorithm for sleep monitoring was developed and tested across four cohorts using both research- and consumer-grade devices. The algorithm was evaluated with over 2000 nights of data, including both 24-hour free-living and lab-based night-only recordings. It was compared against PSG, sleep diaries, and an acceleration-based method.	The heart rate-based algorithm performed well, with low mean squared error (MSE) when compared to sleep diaries (0.04–0.06) and PSG (0.06–0.11). Time deviation from PSG ranged from 29.07 to 55.04 minutes. The results highlight the effectiveness of this device-agnostic algorithm for reliable sleep inference in free-living conditions without human annotations.
Mohamed M, Mohamed N, Kim JG.	2023	Advancements in Wearable EEG Technology for Improved Home-Based Sleep Monitoring and Assessment: A Review.	Narrative Review	N/A	Advances in wearable EEG offer promising solutions for sleep monitoring, supporting broader applications in health and well-being.
Jiang Z, Lee YS, Wang Y, John H, Fang L, Tang Y.	2024	Advancements in Flexible Sensors for Monitoring Body Movements during Sleep: A Review.	Narrative Review	N/A	Flexible sensors, integrated into textiles or wearable devices, offer continuous sleep monitoring without being obtrusive, making them more suitable for home environments compared to traditional methods like polysomnography (PSG).

Pierson-Bartel R, Ujma PP.	2024	Objective sleep quality predicts subjective sleep ratings.	Observational longitudinal study	Data from the Budapest Sleep, Experiences and Traits Study (BSETS) were used, involving 246 participants who recorded their sleep for seven consecutive days using a Dreem2 mobile EEG headband. Participants completed evening and morning diaries and sleep quality was subjectively reported.	The study indicates that objective sleep quality is reflected in subjective sleep ratings, suggesting that previous findings on the weak relationship between self-reports and objective sleep might have been confounded by between-subject effects.
Schutte-Rodin S, Deak MC, Khosla S, Goldstein CA, Yurcheshen M, Chiang A, et al.	2021	Evaluating consumer and clinical sleep technologies: an American Academy of Sleep Medicine update.	Consensus Statement	Reviewed sleep technologies, including device/app capabilities, FDA status, validation studies, and clinical applicability.	Standardized reporting and collaboration between stakeholders are needed to enhance confidence in consumer and clinical sleep technologies.
Peake JM, Kerr G, Sullivan JP.	2018	A Critical Review of Consumer Wearables, Mobile Applications, and Equipment for Providing Biofeedback, Monitoring Stress, and Sleep in Physically Active Populations.	Narrative Review	The review compiled a list of emerging technologies for monitoring physiology, performance, and health by searching scientific literature (e.g., PubMed) and commercial websites using relevant terms.	The review discusses various emerging technologies for health and performance monitoring, including those for hydration, sleep, heart rate, and concussion. A matrix was proposed to evaluate technologies based on the strength of evidence and their effectiveness, guiding consumers on how to assess these technologies.
Jakowski S, Stork M.	2022	Effects of sleep self-monitoring via app on subjective sleep markers in student athletes.	Experimental intervention study	2-week sleep self-monitoring with sleep apps (Sleep Score or Sleep Cycle) and online diaries for university students (n=98). Comparisons with control groups using only online diaries or questionnaires.	App-based sleep self-tracking had no clear benefits or harms. Addressing bedtime procrastination may improve sleep quality in student athletes.
Cunha LA, Costa JA, Marques EA, Brito J, Lastella M, Figueiredo P.	2023	The Impact of Sleep Interventions on Athletic Performance: A Systematic Review.	Systematic review	PRISMA guidelines and PICOS approach, analyzing studies published from 2011 to 2021 on sleep interventions and their effects on performance and recovery in athletes. 25 included.	Sleep extension and naps were the most effective interventions for improving sleep and performance. Mindfulness and light manipulation showed promise but require more research. Sleep hygiene, electronic device removal, and cold water immersion showed no significant effects.
Simpson NS, Gibbs EL, Matheson GO.	2017	Optimizing sleep to maximize performance: implications and recommendations for elite athletes.	Narrative Review	Empirical articles published before October 2015 on sleep and athletic performance, with a focus on sleep quality, duration, and performance across various domains (endurance, speed, neurocognition, injury risk).	Positive relationship between sleep and performance, but athletes often experience poor sleep due to scheduling, training demands, and lack of awareness. Sleep deprivation negatively affects performance, cognitive function, and health (e.g., injury risk).
Sirohi P, Khan MH, Sharma S, Nuhmani S, Al Muslem WH, Abualait T.	2022	A systematic review of effects of daytime napping strategies on sports performance in physically active individuals with and without partial-sleep deprivation.	Systematic Review	A systematic search of randomized controlled trials (RCTs) assessing the impact of daytime napping on sports performance in physically active adults (18+ years). Databases searched included Cochrane CENTRAL, PubMed, and Web of Science.	Most studies showed positive effects of daytime napping on sports performance, especially with longer naps (~90 minutes). Only one study found no significant impact, likely due to methodological differences and shorter nap durations.
Boukhris O, Trabelsi K, Suppiah H, Ammar A, Clark CCT, Jahrami H, et al.	2023	Application of artificial intelligence in the diagnosis of sleep apnea.	Systematic review	A systematic search of Medline, EMBASE, and Cochrane databases was conducted through January 2022, identifying 132 studies that explored the use of machine learning (ML) in diagnosing, classifying, and treating sleep-related breathing disorders.	ML models have shown strong performance in diagnosing sleep apnea using features from electrocardiograms, pulse oximetry, and sound signals. They are also effective in classifying sleep apnea into obstructive and central categories, predicting apnea severity, and guiding treatments such as surgical outcomes and optimizing continuous positive airway pressure therapy.

Lastella M, Halson SL, Vitale JA, Memon AR, Vincent GE.	2021	To Nap or Not to Nap? A Systematic Review Evaluating Napping Behavior in Athletes and the Impact on Various Measures of Athletic Performance.	Systematic Review	Databases searched for observational and experimental studies on napping behavior in athletes. Quality appraisal was conducted using the Downs and Black Checklist.	Napping benefits various athlete outcomes, including physical and cognitive performance, perceptual measures, psychological state, and night-time sleep. Napping may supplement night-time sleep without compromising sleep quality. However, most studies lacked consistent information on nap frequency, duration, and timing.
Rowland DL, Moyle G, Cooper SE.	2021	Remediation Strategies for Performance Anxiety across Sex, Sport and Stage: Identifying Common Approaches and a Unified Cognitive Model.	Narrative Review	Identification and categorization of anxiety-related remediation strategies across sex, sport, and stage domains. Strategies are examined through the lens of the Reflective/Deliberative-Impulsive/Automatic Model (RIM).	A unified information-processing framework (RIM) is beneficial for conceptualizing performance-related anxiety, guiding cross-disciplinary research, and enhancing remediation strategies.
Hasanah U, Refanthira N.	2020	Human problems: competitive anxiety in sport performer and various treatments to reduce it.	Systematic Review	Analysis of 23 studies on interventions for reducing competitive anxiety in athletes, focusing on methods like self-talk, guided imagery, yoga, relaxation, and mindfulness.	Techniques such as self-talk, guided imagery, yoga, relaxation, and mindfulness were effective in reducing competitive anxiety. Combined treatments (e.g., relaxation + imagery, or self-talk + imagery + relaxation) showed enhanced effectiveness.
Guest NS, VanDusseldorp TA, Nelson MT, Grgic J, Schoenfeld BJ, Jenkins NDM, et al.	2021	International society of sports nutrition position stand: caffeine and exercise performance.	Narrative Review	N/A	Caffeine is effective for improving exercise performance, but side effects such as sleep disturbance and anxiety may occur, especially at higher doses.
Barnard J, Roberts S, Lastella M, Aisbett B, Condo D.	2022	The Impact of Dietary Factors on the Sleep of Athletically Trained Populations: A Systematic Review.	Systematic Review	Search of 4 electronic databases for studies published up to May 2022. Studies included had dietary factors, sleep outcomes, and athletically trained participants. 35 studies were reviewed.	Caffeine intake after 5 p.m. (>2 mg·kg−1 body mass) negatively impacted sleep (decreased duration, efficiency, and increased latency). High glycemic index carbohydrates and tryptophan-rich protein may reduce sleep latency. More research is needed on probiotics, cherry juice, and beetroot juice. Athletes with sleep difficulties should be screened for caffeine use and consider dietary strategies to improve sleep.
Gardiner C, Weakley J, Burke LM, Roach GD, Sargent C, Maniar N, et al.	2023	The effect of caffeine on subsequent sleep: A systematic review and meta-analysis.	Systematic Review	A systematic search identified 24 studies assessing caffeine's effects on sleep characteristics.	Caffeine reduced total sleep time by 45 minutes, sleep efficiency by 7%, and increased sleep onset latency by 9 minutes and wake after sleep onset by 12 minutes. Caffeine also increased light sleep duration and decreased deep sleep duration. To avoid sleep disturbances, caffeine should be consumed at least 8.8 hours before bedtime for coffee and 13.2 hours before for pre-workout supplements.
Rosa JPP, Silva A, Rodrigues DF, Simim MA, Narciso FV, Tufik S, et al.	2018	Effect of bright light therapy on delayed sleep/wake cycle and reaction time of athletes participating in the Rio 2016 Olympic Games.	Intervention study	22 athletes from the Brazilian Olympic Swimming Team underwent 8 days of bright light therapy (30–45 minutes daily starting on day 3), with sleep/wake cycles monitored via actigraphy and reaction times assessed using the Psychomotor Vigilance Test before (day 1) and after (day 8) the intervention.	Bright light therapy delayed the athletes' sleep/wake cycles on days 3, 7, and 8 (p=0.01). Reaction times improved significantly, with better average, minimum, and maximum reaction times in both morning (p=0.01, p=0.03) and evening (p=0.02–0.04) tests by day 8 compared to day 1. The therapy effectively modulated sleep/wake cycles and enhanced reaction times, making it beneficial for athletes performing in late-night competitions.

Mello MTd, Simim MAdM, Narciso FV, Rosa JPP, Rodrigues DF, Freitas LdSN, et al.	2020	DURATION AND QUALITY OF SLEEP IN SPRINT AND RECOVERY PERFORMANCES AMONG ELITE SWIMMERS.	Prospective comparative intervention study	14 athletes (10 males, 4 females) were followed during two preparation periods (baseline and intervention). Reaction Time (RT) and Competition Time (CT) were recorded for different swimming modalities. Intervention strategies included light therapy and sleep hygiene.	The intervention reduced total wake time (Δ = −13%, ES = 1.0) and sleep latency (Δ = −33%, ES = 0.7), while increasing total sleep time (Δ = 13%, ES = 1.1, p = 0.04). Athletes in competition finals showed improved RT (Δ = −2.2% to −1.0%, ES = 0.2 to 0.5).
Hoshikawa M, Uchida S, Dohi M.	2020	Intervention for Reducing Sleep Disturbances After a 12-Time Zone Transition.	Randomized controlled trial	Two groups of participants flying from Tokyo to Rio received either an intervention (bright light exposure, sleep schedule shifts, and ramelteon) or no treatment (control group). Sleep onset latency (SOL), sleep efficiency, and subjective tiredness were measured using wristwatch actigraphy.	The experimental group showed significantly shorter SOL (7.7 vs 16.3 minutes) and higher sleep efficiency (88.5% vs 82.9%) compared to the control group. These results suggest that the intervention effectively reduced sleep disturbances after a 12-time zone transition. The intervention may benefit athletes facing similar time zone transitions.
Knufinke M, Fittkau-Koch L, Møst EIS, Kompier MAJ, Nieuwenhuys A.	2018	Restricting short-wavelength light in the evening to improve sleep in recreational athletes – A pilot study.	Within-subject crossover trial	15 recreational athletes (18–32 years) wore amber-lens glasses (light restriction) or transparent glasses (control) for four nights each, with sleep assessed via actigraphy and sleep diaries.	Blocking blue light in the evening reduced subjective sleep onset latency by 7 min, improved sleep quality, and increased morning alertness, but actigraphy showed no significant differences.
Knufinke M, Nieuwenhuys A, Geurts SAE, Møst EIS, Moen MH, Maase K, et al.	2020	Dim light, sleep tight, and wake up bright – Sleep optimization in athletes by means of light regulation.	Within-subject crossover trial	26 athletes followed a light regulation intervention (morning light-emitting goggles and evening amber-lens glasses) with fixed sleep schedules. Sleep was assessed via actigraphy and sleep diaries.	Light regulation improved self-reported sleep onset latency (by 8 min in lenient schedules and 17 min in strict schedules) and subjective sleep quality, but actigraphy data showed no significant differences. Compliance with fixed sleep schedules was low.
Kellmann M, Kallus KW.	2001	Recovery-stress questionnaire for athletes: User manual.	Descriptive manual	The manual details five versions of the RESTQ tailored for different populations: general (RESTQ-Basic), athletes (RESTQ-Sport), coaches (RESTQ-Coach),children/adolescents (RESTQ-CA), and work settings (RESTQ-Work).	The RESTQs provide a comprehensive view of an individual's recovery and stress states, offering valuable insights into areas needing improvement for stress and recovery across various contexts (sports, work, health, etc.). The tool can be applied in a variety of research and applied settings, expanding its use beyond sports to broader fields like health and work.
Jahrami H, Trabelsi K, Saif Z, Manzar MD, BaHammam AS, Vitiello MV.	2023	Reliability generalization meta-analysis of the Athens Insomnia Scale and its translations: Examining internal consistency and test-retest validity.	Systematic review and meta-analysis	A systematic literature search was conducted to identify studies reporting Cronbach's alpha (internal consistency) and test-retest reliability coefficients for the AIS. Pooled estimates and moderator analyses were used to calculate reliability measures.	The AIS demonstrated excellent internal consistency (Cronbach's alpha = 0.84) and test-retest reliability (0.86). However, significant heterogeneity was observed, highlighting the need for future studies to include and report their own reliability estimates when using the AIS.

Baize D, Meriaux-Scoffier S, Chrétien A, Hayotte M, Piponnier E, d'Arripe-Longueville F.	2023	Sleep Assessment in Competitive Athletes: Development and Validation of French Versions of the Athens Insomnia Scale and the Athlete Sleep Behavior Questionnaire.	Cross-sectional validation study	Four studies were conducted with 296 French athletes. These studies assessed dimensionality, reliability, temporal stability, and concurrent validity using confirmatory factor analysis and comparisons with psychological factor scales.	The AIS-FR included 2 subfactors: nocturnal and diurnal symptoms, while the ASBQ-FR had 3 subfactors: behaviors affecting sleep, related to anxiety, and sleep disturbances. Both scales demonstrated satisfactory psychometric properties. The tools were validated for use with competitive athletes, with further testing needed when pandemic restrictions are lifted.
Zhang B, Bender A, Tan X, Wang X, Le S, Cheng S.	2022	Assessment of sleep disturbances with the athlete sleep screening questionnaire in Chinese athletes.	Cross-sectional study	Sleep quality and associated factors were assessed using the Athlete Sleep Screening Questionnaire (ASSQ) in 394 Chinese athletes aged 18-32 years. Participants' sleep quality was categorized using Sleep Difficulty Scores (SDS), and ordinal logistic regression analysis was used to explore factors associated with poor sleep.	14.2% of athletes had moderate to severe sleep problems (SDS ≥8). Evening chronotype, older age, and travel-related sleep disturbances were significantly associated with worse sleep quality. For each additional year of age, the odds of poor sleep increased, while additional years of training decreased the odds of poor sleep. The findings suggest that chronotype, age, training experience, and travel issues are key factors affecting sleep quality in athletes.
Rabin JM, Mehra R, Chen E, Ahmadi R, Jin Y, Day C.	2020	Assessment of sleep health in collegiate athletes using the Athlete Sleep Screening Questionnaire.	Cross-sectional study	College athletes from four NCAA institutions were surveyed using the Athletic Sleep Screening Questionnaire to determine sleep difficulty, clinical sleep problem category, and need for physician assessment.	25% of the 1055 participants reported clinically meaningful sleep problems. Athletes in their second or higher year of college were more likely to report worse sleep than those entering their first year ($p < 0.001$). The study highlights that many college athletes experience poor sleep health, suggesting the need for targeted interventions.
Cook JD, Gratton MKP, Bender AM, Werthner P, Lawson D, Pedlar CR, et al.	2023	Sleep Health, Individual Characteristics, Lifestyle Factors, and Marathon Completion Time in Marathon Runners: A Retrospective Investigation of the 2016 London Marathon.	Cross-sectional study	Marathon participants (N = 943) from the 2016 London Marathon completed the Athlete Sleep Screening Questionnaire and a survey capturing individual characteristics and lifestyle factors. Linear regression was used to explore relationships.	Pre-bedtime electronic device use and sleep tracker use negatively impact sleep health, with orthosomnia potentially playing a role in sleep tracking-related issues for marathoners.
Tsukahara Y, Kodama S, Kikuchi S, Day C.	2023	Athlete Sleep Behavior Questionnaire in Japanese (ASBQ-J): An Adaptation and Validation Study.	Validation study	111 female collegiate athletes completed the Japanese version of the Athlete Sleep Behavior Questionnaire (ASBQ-J) for both test and retest. Reliability was assessed with Cronbach's alpha, intraclass correlation, and Pearson's correlation for subcomponents.	19.8% of athletes reported poor sleep. The ASBQ-J showed good internal consistency (Cronbach's alpha = 0.62-0.65) and test-retest reliability (intraclass correlation = 0.78). Significant correlations were found between ASBQ-J total scores and its subcomponents.
American Academy of Sleep Medicine.	2020	Healthy Sleep Habits.	Article	N/A	A small list of healthy sleep habits available to the public on American Academy of Sleep Medicine’s website.
Hartstein LE, Mathew GM, Reichenberger DA, Rodriguez I, Allen N, Chang A-M, et al.	2024	The impact of screen use on sleep health across the lifespan: A National Sleep Foundation consensus statement.	Consensus Statement	Modified Delphi RAND/UCLA Appropriateness Method, with a 16-person expert panel reviewing literature and voting on statements about the impact of screen-based media on sleep health.	The panel concluded that screen use generally impairs sleep health in children and adolescents, especially when content is viewed before bed. Behavioral strategies and interventions may help mitigate these negative effects.

Table II – Overview of all frequently measured sleep parameters, including their description and recommended values.

Sleep Parameter	Acronym	Measurement	Description	Recommended Values (Adults)	Inappropriate Values (Adults)
Total Sleep Time	TST	minutes/hours	Total time spent asleep across all sleep stages: TIB – (SOL + WASO + TWAK).	7–9 hours	<6 hours or >10–11 hours
Sleep Onset Latency	SOL	minutes	Time to transition from wakefulness to the first epoch of sleep.	≤15 minutes	≥45 minutes
Sleep Efficiency	SE	%	Typically calculated as (TST / TIB) × 100; lacks consensus on calculation method.	≥85%	≤74%
Wakefulness After Sleep Onset	WASO	minutes	The total amount of time spent awake during the intended sleep period, following the initial onset of sleep.	≤20 minutes	≥41 minutes
REM Onset Latency	ROL	minutes	Time from sleep onset to the first epoch of REM sleep.	90–120 minutes	Significant deviations from recommended
Number of Awakenings	NWAK	number	Count of awakenings lasting ≥5 minutes per night.	≤1 per night	4 or more per night
Sleep Stage Percentages (N1, N2, N3, REM)	-	%	Proportion of TST spent in each sleep stage.	Approximately: 5% N1, 50% N2, 20% N3, 25% REM	Elevated REM (≥41%) and reduced N3 sleep (≤5%)
Time in Bed	TIB	minutes/hours	Total time from bedtime ("lights out") to morning rise ("lights on").	-	-
Terminal Awakening	TWAK	minutes	Time between final awakening and getting out of bed.	-	-
Bedtime	BD	hr:min	Self-reported clock time at which individual went to bed to attempt to sleep.	-	-
Waketime	WT	hr:min	Self-reported clock time at which individual got out of bed and stopped attempting sleep.	-	-
Sleep Quality	SQ	-	Definition varies widely. Objectively may be calculated by SE and Fragmentation index (% of sleep epochs where activity is >0).	-	-

Table III – Summary of commonly used questionnaires, their characteristics and recommended use in athletes. PSQI[83-85, 89]. ESS [82]. HOCQ [81, 117]. RESTQ-Sport [121]. AIS [30, 79, 122, 123]. SLEEP-50 [30, 80]. ASSQ [85, 88, 124-126]. ASBQ [86, 87, 123, 127].

Questionnaire's Name	Description	Optimal Context and Means of Use	Use in Athletic Population
Pittsburgh Sleep Quality Index (PSQI)	A 19-item self-report questionnaire that evaluates seven clinically derived domains of sleep difficulties (e.g., quality, latency, duration, habitual efficiency, sleep disturbances, use of sleeping medications, and daytime dysfunction), in which a threshold score shows high sensitivity and specificity for identifying sleep impairment. Considered an accepted reference or gold standard for self-perceived sleep quality.	Compute scores separately for sleep quality and efficiency (SE), emphasizing the first; utilize a one-week response timeframe; supplement with Actigraphy or consensus sleep diaries when the focus is SE; exercise caution in interpreting results, considering they may reflect recent states rather than a consistent pattern over the entire timeframe.	The sleep quality dimension seems to have robust validity, contrary to the SE one. Has been flagged as inadequate for subjective sleep screening of athletes, despite being one of the most used in this population.
Epworth Sleepiness Scale (ESS)	Self-report 8-item questionnaire producing scores from 0 to 24. Scores greater than 10 suggest significant daytime sleepiness. Has good psychometric properties and correlates with objective measures of sleepiness.	Can differentiate between individuals with/without sleep disorders or sleep deprivation.	Used in several sleep studies involving athletes.
Hörne and Ostberg Chronotype Questionnaire (HOCQ)	Composed by 19 self-evaluating questions on which the individual must register his preferential times in routine situations of the daily life. Scores above 58 classify individuals as morning persons, below 42 as afternoon persons and from 42 to 58, as intermediate or indifferent persons.	May be used to define an athlete's chronotype. Whether they are morning types (retire and arise significantly earlier than evening types) or evening types.	Used in several sleep studies involving athletes.
Recovery Stress Questionnaire for Athletes (RESTQ-Sport)	A 76-item questionnaire that was developed to assess the physical and mental impact of training stress and to facilitate the formulation of strategies for the enhancement of recovery. There are 12 General subscales and 7 Sport subscales of the RESTQ-Sport, that reflect various aspects of stress and recovery.	Used to measure general parameters of training stress which can be useful in evaluating its effects on sleep quality and recovery.	Used in several sleep studies involving athletes.
Likert Scale for Sleep Quality Assessment	A Likert-type scale ranging from 1 (very good) to 5, 7, or 10 (very poor), used to assess sleep quality (e.g., "How would you evaluate the quality of your sleep in the past few days?").	May be used daily or periodically to evaluate larger periods of time.	One of the most common ways to measure subjective sleep quality in the athletic population.
The Athens Insomnia Scale (AIS)	A self-administered instrument consisting of 8 items, developed to detect insomnia based on International Classification of Diseases-10 (ICD-10) criteria. Two versions of the scale exist, the entire eight-item scale (AIS-8) with a score ranging from 0 to 24 (most severe degree of insomnia), or the brief five-item version (AIS-5), with a total score ranging from 0 to 15. For the AIS-8, the first 5 items correspond to criterion A for the diagnosis of insomnia, while the last 3 items refer to daytime symptoms that often emerge as a consequence of it. Symptoms are required a minimum frequency (at least three times a week) and duration (1 month), corresponding to criterion B of the ICD-10. Each item severity can be rated 0–3.	The AIS-8 is intended for use in a fully developed clinical setting, while the AIS-5 is used to focus solely on difficulty with sleep quantity and quality. The AIS is an appropriate instrument for evaluating insomnia in different groups and contexts.	Validated amongst elite athletes and translated to other languages.
SLEEP-50 Questionnaire	Designed to detect sleep disorders as listed in the Diagnostic and Statistical Manual of Mental Disorders. Made of 50 items in total. Several subscales exist comprised of small groups of those 50 items, each for a different sleep disturbance (e.g., sleep apnea [Items 1–8]). The time frame is the past 4 weeks and each item is scored on a 4-point scale: 1 (not at all), 2 (somewhat), 3 (rather much), and 4 (very much).	May be used to detect sleep disorders.	Displayed high internal consistency and good 1-month test-retest reliability for athletes.

The Athlete Sleep Screening Questionnaire (ASSQ)	A 15-item questionnaire developed to assess both sleep and circadian factors of sleep quantity, sleep quality, insomnia, and chronotype with a timeframe of “over the recent past.” Answers from the first seven questions are compiled to create a sleep difficulty score (SDS) which categorized athletes into four categories of clinical sleep problems—none, mild, moderate and severe.	Recommended to assess the SDS first (items 1, 3, 4, 5, and 6), then the modifiers of sleep-disordered breathing (items 13 and 14), travel (items 11 and 12), and chronotype (items 7–10), and finally evaluate the items of interest (e.g., item 2, 15, 16) to inform more specific sleep optimization strategies.	Displayed good internal consistency and reliability. Clinically validated for athletes and used successfully in several studies.
Athlete Sleep Behavior Questionnaire (ASBQ)	An 18-item survey that includes questions on sleeping behavior and habits thought to be common areas of concern for elite athletes. The survey asks participants how frequently they engage in specific behaviors (never, rarely, sometimes, frequently, always). Weightings for each response (1 = never, 2 = rarely, 3 = sometimes, 4 = frequently, 5 = always) are summed to provide an ASBQ global score. A higher global score is indicative of poor sleep behaviors.	Designed as a practical tool to identify areas where improvements in sleep behavior could be made, rather than a clinical screening tool. May be a valuable tool for tracking changes in sleep habits over time, or for testing the efficacy of sleep hygiene interventions to improve sleep.	Displayed moderate level of internal consistency and high levels of test-retest reliability. Validated and translated to various languages including French, Japanese, Turkish, Portuguese and Arabic.

Table IV. – Summary of main monitoring tools and their advantages and disadvantages.

Monitoring Tool	Description	Advantages	Limiting Factors	Measured Variables
Polysomnography	A comprehensive sleep assessment technique that utilizes multiple sensors (EEG, ECG, EOG, EMG, airflow, respiratory effort, oxygen saturation) to provide detailed data for sleep stage classification and the diagnosis of sleep disorders.	The most in-depth and reliable method to assess sleep stages and objective parameters. Extensively validated and regarded as gold standard.	Expensive. Intrusive with high participant burden. Requires specialized equipment and expertise. Unfamiliar sleep environment may alter results.	TST, SE, WASO, SOL, Sleep Disorders, REM Onset Latency, REM Sleep, NREM Sleep, Heart Rate, Body Temperature and Breathing.
Research-grade Actigraphy	Utilizes a variable number of wearable, motion (accelerometers, gyroscopes) and/or biometrical sensors (heart rate, temperature), to estimate sleep-wake patterns over configurable epochs.	Less Invasive than PSG. Well validated and developed solely for precise clinical sleep tracking. Allows for threshold customization and raw data exportation. Allows for long-term monitoring.	Limited assessment of sleep stages. Patient movement or stillness can limit accuracy of parameters. Restricted disorder diagnosis capability.	TST, SE, WASO, SOL, time awake, TIB, wake time, heart rate, body movements, luminosity and body temperature.
Sleep Questionnaires	Subjective instruments (e.g., PSQI, ESS, and athlete-specific questionnaires like the ASSQ and ASBQ) that assess perceived sleep quality, disturbances, and sleep-related behaviors over a given period.	Almost free of cost. Simple to administer without specialized equipment. Non-intrusive. Short and long-term assessments. Captures the individual's subjective perception.	Subject to memory and response biases. May overestimate sleep parameters.	TST, SE, SOL, TIB, bedtime, waketime, time awake, subjective sleep quality, sleepiness, sleep complaints, sleep-related behaviors, chronotype.
Sleep Diaries	Self-reported daily logs where individuals record sleep timings (bedtime and wake time), perceived sleep quality, and any external factors that might influence sleep, maintained over multiple nights.	Almost free of cost. Long-term daily monitoring. Minimal recall bias. Easy to implement. Captures the individual's subjective perception.	Depends on responsibility and effort. Subject to memory and response biases. May overestimate sleep parameters.	TST, SE, SOL, number of awakenings, perceived restorative quality of sleep, bedtime, waketime.
Wearable CSTs	Consumer devices (e.g., smartwatches, wristbands, rings) that use various sensors such as photoplethysmography (PPG) and accelerometers to estimate sleep metrics.	Cost-effective and user-friendly. Minimal effort needed. May be able to track other useful metrics other than sleep. Allows for continuous monitoring with minimal impact in daily life.	Harder to validate. Less accurate than PSG or research-grade actigraphy. High environmental susceptibility. Proprietary algorithms not disclosed. May lack appropriate data privacy.	Highly dependent on the sensors and algorithms used. Overall similar to research-grade actigraphy, may also measure sleep stages.
Nearables CSTs	Non-wearable devices usually placed either under/on the mattress or in the proximity of the user, that utilize a diverse array of sensors to estimate sleep.	Very comfortable and easy to use. Cost-effective. Familiar sleep environment.	Harder to validate. Less accurate than PSG or research-grade actigraphy. High environmental susceptibility. Proprietary algorithms not disclosed. May lack appropriate data privacy.	Highly dependent on the sensors and algorithms used. Overall similar to research-grade actigraphy, may also measure sleep stages.
Airable CSTs (Smartphone Apps)	Smartphone applications, usually requiring the phone to be in the proximity of the user and leveraging the its sensors to estimate sleep.	Very comfortable, easy to acquire and use. Cost-effective. Familiar sleep environment. Does not require additional hardware.	Higher battery consumption. Harder to validate. Less accurate than PSG or research-grade actigraphy. High environmental susceptibility. Proprietary algorithms not disclosed. May lack appropriate data privacy.	Highly dependent on the sensors and algorithms used. Overall similar to research-grade actigraphy, may also measure sleep stages.

Table V. – General sleep hygiene recommendations [43, 107, 128]. (a): For adults, a 2024 National Sleep Foundation statement did not reach a consensus on whether the light emitted by devices, before sleep, impairs the aforementioned [129].

1. Maintain a Consistent Sleep Schedule: • Go to bed and wake up at the same time every day, including weekends and vacations, to help regulate your circadian rhythm.
2. Create a Sleep-Conducive Environment: • Ensure your bedroom is quiet, dark, and cool—similar to a cave—to promote optimal sleep conditions. • Limit exposure to bright or ambient light in the evenings.
3. Set an Appropriate Bedtime: • Choose a bedtime that allows for at least 7–8 hours of sleep. • Only go to bed when you feel genuinely sleepy.
4. Limit Pre-Sleep Electronic and Alerting Activities: • Avoid screen-based digital media at least 30–60 minutes before bedtime. (a) • Turn off electronic devices 30 minutes before sleep to reduce light exposure and stimulation. • Avoid other alerting activities in the evening.
5. Establish a Relaxing Bedtime Routine: • Incorporate calming activities such as reading or taking a warm bath during a 30–60-minute wind-down period before bed. • Use consistent bedtime rituals to signal to your body that it is time to sleep.
6. **Use the Bed Exclusively for Sleep and Intimacy:** • Do not use your bed for activities such as watching television, computer work, or phone use. • If you cannot fall asleep within approximately 20 minutes, leave the bed and engage in a quiet, non-stimulating activity until you feel sleepy again.
7. Monitor Pre-Bed Dietary and Fluid Intake: • Avoid eating large meals before bedtime; if you're hungry, choose a light, healthy snack. • Reduce fluid intake before bed to minimize nighttime awakenings.
8. Manage Stimulant and Substance Use: • Avoid consuming caffeine in the afternoon or evening. • Limit alcohol consumption before bedtime. • Refrain from smoking or using nicotine products, especially close to bedtime.
9. Engage in Regular Physical Activity and Maintain a Healthy Diet: • Exercise regularly to support overall sleep quality, but avoid high-intensity workouts close to bedtime, as they may elevate cortisol levels and impair sleep.
10. Optimize Napping Practices: • Aim for a full night's sleep and minimize daytime napping. • If a nap is necessary, limit it to under one hour and schedule it before mid-afternoon.

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