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The new frontier in sleep diagnostics: Unveiling the power of wearables

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Abstract

Wearable sleep devices have emerged as valuable tools in the field of sleep medicine, providing an accessible and cost-effective alternative to traditional methods like polysomnography (PSG) and Home Sleep Apnea Testing (HSAT) for monitoring sleep. These devices, ranging from consumer-grade fitness trackers to advanced medical-grade sensors, offer a convenient means of tracking sleep patterns, quality, and associated health metrics in real-time. The growing demand for personalized healthcare has driven the adoption of wearable sleep technology, which bridges the gap between subjective sleep complaints and objective data, both in clinical and consumer setting. Traditionally, the assessment of sleep disorders has been reliant on costly and time-consuming in-lab studies. However, wearable devices offer a more affordable and convenient approach, enabling continuous at-home monitoring of sleep. These devices typically track parameters such as sleep stages (light, deep, and REM sleep), heart rate, respiratory patterns, movement, and environmental factors like room temperature and noise levels. The data provided can help identify a range of sleep disorders, including insomnia, sleep apnea, restless leg syndrome, and circadian rhythm disturbances. Furthermore, some wearable devices incorporate features aimed at improving sleep quality, including personalized sleep coaching, relaxation techniques, and biofeedback mechanisms. These technologies not only aid in the diagnosis of sleep disorders but also provide ongoing treatment and management for chronic conditions such as insomnia or obstructive sleep apnea. In this review, we explore the development, functionality, and clinical utility of wearable sleep devices, examining their role in the diagnosis and management of sleep disorders. We discuss the advantages and limitations of these devices, as well as the growing body of evidence supporting their use. The review also highlights their potential to improve patient outcomes by facilitating personalized, real-time monitoring of sleep health. As sleep medicine continues to evolve, wearable devices are poised to play an increasingly prominent role in transforming how sleep health is monitored, understood, and managed. Despite their growing adoption, challenges remain regarding the accuracy of these devices, particularly in detecting sleep stages (e.g., REM vs. deep sleep) and accurately identifying wakefulness. With continued technological innovation and further validation studies, wearable sleep devices have the potential to revolutionize sleep monitoring, enabling personalized, real-time sleep health management for both consumers and healthcare professionals.

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Introduction

In recent years, wearable sleep devices have emerged as powerful tools in the field of sleep medicine, offering an innovative and accessible way to monitor and analyze sleep patterns. These devices, which range from fitness trackers and smartwatches to specialized sleep sensors, provide patients and healthcare providers with valuable data about sleep architecture, quality, and associated health metrics. As the demand for personalized healthcare increases, wearable sleep technology has become an integral part of both clinical practice and consumer wellness, bridging the gap between subjective sleep complaints and objective sleep data. Traditionally, the assessment of sleep disorders has required expensive and time-consuming in-lab studies, such as polysomnography (PSG), or home sleep apnea testing (HSAT). However, wearable devices offer a more convenient and cost-effective alternative for continuous, at-home monitoring of sleep. These devices typically track variables such as sleep stages (light, deep, and REM sleep), heart rate, respiratory patterns, movement, and even environmental factors like room temperature and noise levels. The data collected can help identify common sleep disorders, including insomnia, sleep apnea, restless leg syndrome, and circadian rhythm disturbances. Beyond monitoring, some wearable sleep devices also offer features designed to improve sleep quality, such as personalized sleep coaching, relaxation techniques, and biofeedback mechanisms. These technologies have the potential not only to aid in the diagnosis of sleep disorders but also to serve as tools for ongoing treatment and management, particularly in patients with chronic conditions such as insomnia or obstructive sleep apnea. In this review, we explore the development, functionality, and clinical utility of wearable sleep devices, examining their role in sleep disorder diagnosis, patient management, and the evolving landscape of sleep medicine. We will discuss the advantages, limitations, and the growing body of evidence supporting their use, as well as consider their potential in improving patient outcomes through more personalized, real-time monitoring of sleep health. As the field of sleep medicine continues to evolve, wearable devices are poised to play an increasingly prominent role in transforming how sleep health is monitored, understood, and managed.

Types of wearable sleep devices: Wearable sleep devices come in various forms, each offering different features and levels of sophistication. These devices range from simple fitness trackers to advanced medical-grade monitors, catering to both general consumers and clinical patients. Below is an overview of the main types of wearable sleep devices:

Wearables used in sleep medicine can be broadly categorized into:

Consumer-grade sleep devices

Consumer-grade sleep devices are wearable gadgets and tools designed primarily for personal use, allowing individuals to track and improve their sleep without the need for a clinical setting.

Examples: Fitbit, Smartwatches with enhanced sleep tracking (Ex: apple watch, Oura Ring).

Features: Accelerometry-based sleep tracking, heart rate monitoring, SpO_2 estimation.

Use cases: General sleep monitoring, sleep hygiene improvement.

Advantages: Ease of use, affordability, and the convenience of at-home monitoring.

Medical-grade devices

Medical-grade wearable sleep devices are designed to provide accurate, clinically validated measurements of sleep and related health metrics. These devices are commonly used for diagnosing sleep disorders (such as sleep apnea, insomnia, or restless leg syndrome) and for monitoring patients with chronic conditions.

Examples: Actigraphy devices (MotionWatch 8, Philips Actiwatch), NightOwl, WatchPAT One.

Features: Multi-sensor integration (EEG, PSG, PPG, respiratory sensors).

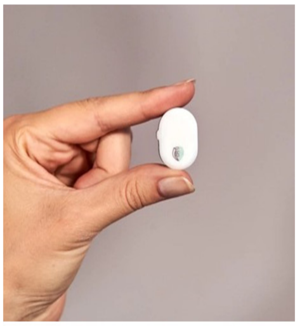
Use cases: Diagnostic support for OSA, circadian rhythm disorders, and insomnia.

What is the technology behind these devices?

The technology powering these devices is primarily of 2 types: Photoplethysmography and Non Photoplethysmography based:

PPG Based

Photoplethysmography (PPG) is a non-invasive optical technique used to measure changes in blood volume by emitting light into the skin and detecting the light reflected, which fluctuates with each heartbeat, allowing sensors to track heart rate, blood oxygen saturation (SpO_2), and sometimes even stress levels or respiratory rate. Peripheral arterial tonometry (PAT), measures changes in peripheral arterial tone to assess vascular health and sympathetic nervous system activity during sleep. PAT adds valuable data on blood flow and arterial stiffness, complementing traditional polysomnography (PSG) that monitors brain activity, heart rate, and muscle tone. By analyzing these signals, the device estimates sleep apnea severity using indices like the Apnea-Hypopnea Index (AHI) or Respiratory Disturbance Index (RDI), aiding in the diagnosis and monitoring of sleep disorders [1]. Watch PAT and Night Owl are both FDA-approved devices use Peripheral Arterial Tonometry (PAT) technology and have been validated through studies comparing them to Polysomnography (PSG). Watch PAT is a more advanced, larger device with a pneumo-optic finger probe that applies a controlled sub diastolic pressure to minimize venous pooling and provide accurate PAT signals. Night Owl, on the other hand, is a smaller, more portable device with a fingertip sensor that collects actigraphy, PPG, and PAT data to monitor heart rate, oxygen saturation, and vascular health, offering a more convenient option for at-home sleep monitoring [2,3]. Medicare covers home sleep apnea tests like the Watch-PAT and Night Owl when deemed medically necessary for diagnosing Obstructive Sleep Apnea (OSA).



NightOwl

Source: iSD Health Solutions.

WatchPAT ONE

Source: ZOLL Itamar

Samsung Galaxy Watch

Apple Ultra Watch

Devices based on PPG technology
Fitbit Sense
Oura ring
Apple watch
Samsung galaxy watch
Night owl
Watch PAT

Non-PPG based

The non-PPG-based wearable sleep devices rely on alternative sensors and mechanisms to monitor physiological parameters, such as heart rate, motion, temperature and brain activity. They use different techniques, often involving mechanical, electrical, or thermal measurements such as accelerometers, gyroscopes, EEG (electroencephalography), and temperature sensors-to monitor sleep quality, stages, and disturbances.

Accelerometers and gyroscopes (Motion sensors): These sensors detect changes in velocity and direction and angular velocity respectively which provide more precise information on posture, orientation, and detailed motion tracking. By monitoring movement, wearables can differentiate between active (awake), light sleep, and deep sleep stages and overall sleep quality.

Skin temperature sensors: These sensors are typically thermistors or thermocouples or infrared thermometers that measure the heat emitted from the skin and converts this data into a temperature reading. They track body temperature fluctuations to estimate sleep quality or even detect abnormal variations that could signal a disrupted sleep cycle (Ex: insomnia or circadian rhythm disorders).

Pulse oximetry: While pulse oximetry is often associated with PPG-based devices, there are non-PPG versions that use other methods, such as impedance pneumography, a technique that measures changes in electrical impedance as the chest expands and contracts with breathing, allowing for the detection of respiratory patterns and rate and monitor oxygen saturation.

Galvanic skin response (GSR) and skin conductance: Galvanic Skin Response (GSR), or skin conductance, is a measure of the electrical conductance of the skin, which varies with moisture levels (sweat). Changes in skin conductance can reflect emotional arousal or stress, which are often linked to sleep quality. Higher GSR levels can indicate periods of stress or anxiety, which can disrupt sleep or contribute to sleep disorders like insomnia.

Electroencephalography (EEG): EEG sensors detect the electrical impulses in the brain. These electrical signals, generated by the synchronous activity of neurons are divided into different frequency bands, which correspond to various mental states, including wakefulness, light sleep, deep sleep, and REM sleep. It provides detailed and accurate data on sleep stages and quality.

Example: Accelerometer based (Mi Band 6), EEG based (Dream EEG).

Device	Placement	Technology
AcuPebble	Front of neck	Acoustic sensing
BresoDX1	On neck/trachea	Acoustic sensing and Accelerometer
Sunrise	Chin	Mandibular movements
Wesper Lab	Chest and abdomen	Respiratory inductive plethysmography (RIP)

Acu Pebble Sa 100 [4].

Breso DX 1 [5]

CST: Consumer Sleep Tracker; ECG: Electrocardiography; EEG: Electroencephalography; EMG: Electromyography; EOG: Electro-oculography; PPG: Photoplethysmography; PSG: Polysomnography.
Source: Sleep Health (2023). DOI: 10.1016/j.sleh.2023.11.005 [6].

Examples of wearable sleep tracker devices: **(a)** Zeo headband; **(b)** Sleep image ring; **(c)** Fitbit; **(d)** Lark wristband; **(e)** Wake mate wristband actigraphy; **(f)** Jawbone motion sensor; **(g)** Body media sense wear armband accelerometer; **(h)** Hex Oskin and **(i)** OURA ring [7].

The FDA has approved several wearable devices to detect obstructive sleep apnea (OSA) in adults.

Devices	FDA approval for sleep apnea
AcuPebble SA100	November 30, 2021
Belun Sleep system	Februaru 28, 2023
Samsung Galaxy Watch	February 6, 2024
Apple watch	Sept. 13, 2024

Discussion

Validation and accuracy of wearable sleep devices

Worn sleeping devices have increasingly gained credibility as alternatives to conventional polysomnography (PSG) within sleep monitoring. The devices give instant feedback, are easy to use, and are cost-friendly alternatives to monitoring sleep in personal or clinical settings. However, ensuring that distinct sleep periods or episodes can accurately be identified remains a key challenge. One recent study, A Validation of Six Worn Devices for Estimating Sleep, Heart Rate, and Heart Rate Variability in Healthy Adults, challenged the validity of six consumer-based wearable devices—specifically, Apple Watch S6, Garmin Forerunner 245 Music, Polar Vantage V, Oura Ring Generation 2, WHOOP 3.0, and Somfit-against reference measures that entail PSG for sleep assessment and electrocardiography (ECG) for heart rate and variability determination [8]. The study compared data generated by 53 healthy individuals within controlled sleep lab conditions. When detecting sleep, a binary classification (sleep or wake) had high sensitivity (>90%) to detect sleep using each of the devices, while overall concordance rates were within 86% to 89%. The specificity of detecting wake, on the contrary, had greater variations, where WHOOP and Somjit outshone that of Apple Watch and Garmin. The multi-stage classification (light, deep, and REM sleep), on its part, had lower levels of correctness, where agreement levels were within 50% to 65%, hence indicating that there is need for developing better identification of distinct sleep episodes.

Comparing consumer wearables for sleep tracking

Robbins et al. (2024) conducted a study, Accuracy of Three Commercial Wearable Devices for Sleep Tracking in Healthy Adults, evaluating the Oura Ring Gen3, Fitbit Sense 2, and Apple Watch Series 8 against PSG [9]. In a controlled inpatient setting, 35 participants underwent a single-night PSG while wearing the devices. All three wearable devices had considerable sensitivity (≥95%) to detect sleep but had differing classification of sleep into four stages: the Oura Ring had the highest degree of agreement (76.0–79.5%), followed by Fitbit (61.7–78.0%), while the Apple Watch had issues detecting specific sleep stages (50.5–86.1%). For overall sleep duration, Oura device closely tracked PSG but had slight bias, whereas Fitbit overreported light sleep by 18 minutes but underreported deep sleep by 15 minutes. The Apple Watch also overstated light sleep by 45 minutes but understated deep sleep by 43 minutes, along with also having a bias in waking duration and WASO. Bland-Altman analysis had moderate concordance for overall sleep duration (ICC: 0.74–0.85), but poor agreement for deep sleep and REM sleep (ICC: 0.13–0.37). Substantial limitations included loss of data on several of our participants (Apple Watch: 6, Fitbit: 2) along with restrictions of our design to only one night.

Challenges of wearable devices in real-world settings

While wearable devices show high sensitivity (>90%) for sleep detection, their specificity for wake detection remains low (<60%) [10,11]. This poses a significant challenge, particularly in individuals with disrupted sleep. Adrian R et al. (2024) explored these limitations in their study, Performance of Wearable Sleep Trackers During Nocturnal Sleep and Periods of Simulated Real-World Smartphone Use [12]. They tested Oura Ring Gen3, Fitbit Sense, AXTRO Fit 3, Xiaomi Mi Band 7, and ActiGraph GT9X against PSG during nocturnal sleep and simulated real-world smartphone use. Results indicated that while Oura and Fitbit performed well on nights with minor disturbances, their accuracy declined during fragmented sleep or suboptimal bedtime routines. These findings reinforce concerns about the ability of consumer wearables to track sleep stages reliably in diverse real-world conditions.

Conclusion

Wearable sleep devices have evolved into valuable tools for personal sleep monitoring and clinical applications, providing cost-effective alternatives to traditional PSG. While their accuracy in detecting sleep stages continues to improve, key challenges remain in distinguishing REM and deep sleep and accurately detecting wakefulness, particularly in fragmented sleep conditions. Machine learning and AI-driven algorithms offer promising solutions for enhanced sleep classification, yet further validation in real-world scenarios is essential. Future research should focus on improving device accuracy, incorporating advanced machine learning models, and expanding long-term validation studies. By addressing these challenges, wearable technology can move toward more reliable, personalized sleep management for both consumers and healthcare professionals.

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