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Consumer Sleep Technologies: A Review of the Landscape

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Objective: To review sleep related consumer technologies, including mobile electronic device "apps," wearable devices, and other technologies. Validation and methodological transparency, the effect on clinical sleep medicine, and various social, legal, and ethical issues are discussed.

Methods: We reviewed publications from the digital libraries of the Association for Computing Machinery, Institute of Electrical and Electronics Engineers, and PubMed; publications from consumer technology websites; and mobile device app marketplaces. Search terms included "sleep technology," "sleep app," and "sleep monitoring."

Results: Consumer sleep technologies are categorized by delivery platform including mobile device apps (integrated with a mobile operating system and utilizing mobile device functions such as the camera or microphone), wearable devices (on the body or attached to clothing), embedded devices (integrated into furniture or other fixtures in the native sleep environment), accessory appliances, and conventional desktop/website resources. Their primary goals include facilitation of sleep induction or wakening, self-guided sleep assessment, entertainment, social connection, information sharing, and sleep education.

Conclusions: Consumer sleep technologies are changing the landscape of sleep health and clinical sleep medicine. These technologies have the potential to both improve and impair collective and individual sleep health depending on method of implementation.

Keywords: biomedical technology, educational technology, sleep, sleep disorders

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Consumer sleep technologies (CSTs) are increasingly popular computer-based systems available to the general public for the purpose of improving or self-monitoring sleep. Their primary goals include sleep induction, wake induction, self-guided sleep assessment, entertainment, social connection, information sharing, and sleep education. There is scant literature discussing these technologies.[1,2] Despite a paucity of clinical validation with traditional sleep technologies (e.g., polysomnography (PSG), multiple sleep latency testing (MSLT), and clinical-grade actigraphy), CSTs are here to stay because of their innovative nature, convenience, and affordability.

Although adoption rates are not available, sleep-tracking products such as Fitbit and Jawbone are top sellers in consumer health products.[3,4] The highest-funded health device on Kickstarter was a sleep monitor, which garnered more than $2.4 million in financial backing.[5] A recent search for "sleep" in the Apple iTunes app store returned over 500 different sleep related applications, or "apps," available for download[6]; similar searches on Android and Microsoft's app stores return hundreds of results.[7,8] Certain apps boast more than five million downloads; one of the top five paid apps in 2014 on iTunes was a sleep tracker and alarm clock.[9]

We use the metaphor "over-the-counter" to describe these CSTs, because they are mostly available without a prescription or clinical guidance. Clinical sleep specialists should be aware of these increasingly popular technologies, as patients may request interpretation of derived data. This paper aims to provide a general overview of CSTs and their potential social, ethical, legal, and clinical effect. Although rapid development of these technologies obviates an exhaustive review, we outline some of the more popular, illustrative, or innovative technologies to give sleep specialists an idea of the recent landscape.

METHODS

We searched PubMed and the digital libraries of the Association for Computing Machinery and Institute of Electrical and Electronics Engineers (where technology developers publish peer-reviewed articles), with search terms including "sleep technology," "sleep app," and "sleep monitoring." We eliminated articles that were not relevant to sleep (e.g., applications for controlling a computer's hibernation mode). We ran similar searches on Google, specifically focusing on consumer technology-related websites such as *MIT Technology Review*,[10] *Gizmodo*,[11] *Engadget*,[12] and *Forbes*[13]; and application marketplaces including the *Apple App Store,*[7] *Google Play*,[8] and Microsoft's *Windows Store*.[9] To be included, technologies met the following criteria: (1) a purpose documenting or improving sleep behaviors, (2) current availability on the public market, and (3) use without guidance from a healthcare provider.

Technologies were categorized based on platform of delivery. All searches occurred at or before June 2015.

RESULTS

We identified five primary delivery platforms for CSTs. For each, we provide a description, potential advantages and disadvantages, and example technologies. Some CSTs employ multiple delivery platforms; for the purposes of this review we categorized them by their primary differentiating feature.

Mobile Device Platform

The most popular CSTs are mobile apps running on smartphones and tablets. They do not require external sensors or other accessories beyond the stand-alone mobile device. Common features include sleep tracking, alarm functionality, and sleep and dream logging. These apps leverage mobile device multimedia capabilities to facilitate sleep onset via calming visual graphics, relaxing music, nature sounds, white noise, and even downloadable recordings of professional hypnotists. Advantages include convenience and ease of use, device capability and flexibility, and app accessibility. Disadvantages include reduced processing power and media input/output capabilities compared to high-end stand-alone electronic devices, and sleep disruption from noise and light pollution. Many sleep tracking apps require user activation and device placement on the mattress to monitor sleep. Sensor accuracy may suffer due to multiple individuals on the same sleeping surface, differences in mattress textures and material, and other sources of artifact.

- *Example 1:* Sleep Cycle[14]: This Apple and Android app was one of Apple's top five best-selling paid apps of 2014[7] and the best-selling paid health app on Google Play.[15] Sleep Cycle helps users track "sleep trends" over time. When placed on the sleep surface, the mobile device's built-in accelerometer measures movement as a surrogate indicator of the presence or absence of sleep. The program features a "smart" alarm clock, engineered to wake the user within a preset time range each morning triggered when the app senses a period of "light sleep," with the hopes of producing a more pleasant awakening experience.
- *Example 2:* SleepBot[16]: The first-place winner of the National Institute of Health's 2011 "Go Viral to Improve Health" competition, this Apple and Android app measures movements to estimate "sleep cycles," records ambient sounds including sleep talking and snoring, produces bedtime alerts to remind users to go to bed, allows users to change the mobile device to silent and/or airplane modes at bedtime, and has a "smart alarm" similar to Sleep Cycle. Integrated trending graphs track sleep patterns over each night as well as over many days, and record sleep statistics including hours of sleep each night and "sleep debt."
- *Example 3:* Sleep As Android[17]: Listed in *TIME* magazine as one of the 50 best Android apps of 2013,[18] this app has multiple features including: nature sounds to facilitate sleep onset; accelerometer-derived "sleep cycle" tracking; snoring detection and "antisnoring" (e.g., phone vibrates or emits tongue-click sounds to rouse the patient to stop snoring); smart alarm with fail-safes to prevent the user from accidentally falling back asleep in the morning (e.g., the app will require the user to complete a mentally or physically engaging task such as answering arithmetic questions before the wake-up alarm will terminate); sleep graphs illustrating sleep duration, "sleep debt," and "light" and "deep" sleep percentages; incorporation into wearable motion trackers/alarms such as Pebble and Android Wear; and integration with Phillip's HUE smart bulbs to enable sunrise-like graded light exposure for awakening.
- *Example 4:* Sunriser[19]: This Apple app sets a wake-up alarm to the exact time the sun rises in the user's geographic location.
- *Example 5:* Entrain[20]: This Android and Apple app encourages timed light exposure to reduce jet lag. The user specifies the time zone change, arrival time, and arrival date for an upcoming trip and the app creates a personalized pretrip schedule of timed light (including intensity) and dark exposure to preemptively shift the user's circadian rhythm.
- *Example 6:* Go! to Sleep[21]: Created by the Cleveland Clinic Sleep Disorders Center, this app uses a lifestyle and sleep habit questionnaire to create a sleep score, and tracks this score over time. It also provides daily sleep advice to improve one's score.

Wearable Platforms

Wearable devices involve an attachment or sensor placed directly on the body (e.g., bracelet, pendant), or attached to or embedded in clothing. These devices directly track a person's body movements or biometric information, with presumably increased accuracy via direct contact with the wearer. Disadvantages include discomfort, limited battery life, potential device misplacement before or during sleep, and sensor damage and inaccuracy from frequent use.

- *Example 1:* FitBit[22]: This brand encompasses gadgets ranging from a simple clip-on pedometer to high-end wristbands, smartwatches, and designer jewelry with built-in accelerometers and wireless biometric sensors. Certain models automatically detect and track "sleep" (with performance comparable to clinical-grade actigraphy[23]), estimate "sleep efficiency," and use vibration to create a silent wake alarm, thereby limiting disruption to bed partners. Data can be directly displayed on certain models; long-term trends and graphs are accessed online with a desktop or mobile device.
- *Example 2:* Jawbone UP[24]: A rubber wristband or clip-on device that tracks body movements and other biometrics with vibration wake alarm capability. It also claims to sense "light" and "deep" sleep and has a "smart" alarm.
- *Example 3:* Smartwatches: These encompass several devices including Android Wear platform watches,[25] the Apple Watch,[26] and Microsoft Band,[27] which have motion and heart rate tracking capabilities. These devices are limited by their short battery life (given their power-hungry multimedia capabilities), which

limits their functionality as wearable sleep trackers. Microsoft Band has built-in sleep tracking software, whereas Android Wear watches and the Apple Watch require the download/purchase of an integrated sleep tracking app.

- *Example 4:* Basis Peak[28]: This smartwatch with heart rate, perspiration, and skin temperature sensors and an accelerometer purports to sense "light," "deep," and "rapid eye movement" (REM) sleep. Basis claims to have validated its sleep staging technology with polysomnography data from the San Francisco VA Medical Center.[29]
- *Example 5:* Mimo Baby Monitor[30]: For infants aged 0–12 months old, this bodysuit has respiratory sensors, an accelerometer to monitor body movements and position, and a temperature sensor. A large "turtle"-shaped Bluetooth transmitter on the abdomen sends information to an online data cloud as well as the caretaker's mobile device.
- *Example 6:* Sleep Shepherd Sleep Hat[31]: This beanie-like accessory is worn on the head and employs auditory stimulation called "Virtual Hammock Technology" to facilitate sleep onset. The device claims to measure "brainwaves" to track "sleep/awake states."
- *Example 7:* SleepImage[32]: Although this US Food and Drug Administration cleared device is available for individual purchase, it requires a medical prescription and therefore is not technically "over the counter" but instead labeled a "prosumer" device. SleepImage uses cardiopulmonary coupling (CPC), the dynamic relationship between autonomic and respiratory oscillations in sleep, to analyze sleep stability. Two electrodes and a three-axis accelerometer on the chest track electrocardiogram (EKG), snoring, body position, and movements. The coupling of heart rate variability (as determined by R-R intervals) with breathing cycles (as determined by QRS complex amplitude changes) is analyzed using Fourier-based techniques. High frequency coupling appears associated with stable, "non-cyclic alternating pattern (CAP) sleep," low-frequency coupling with "unstable CAP sleep," and very low-frequency coupling with "REM sleep" and wakefulness.[33] These coupling states do not correlate well with traditional sleep staging by conventional PSG, but do correlate to some degree with visual scoring of CAP on conventional PSG in adults.[34] Certain patterns of low frequency coupling may have utility in identifying central or obstructive sleep disordered breathing in adults.[35]

Embedded Platforms

These CSTs are non-wearable unique physical devices embedded into the user's native sleep environment. Advantages include relative unobtrusiveness and increased functionality beyond that of a standard mobile device. However, these devices raise privacy concerns due to implantation and easy concealment (e.g., a sensor embedded into a sleep mattress or a camera embedded into the bedroom wall), and may require additional cost and space.

- *Example 1:* Tanita Sleep Scan[36]: A mat placed under the mattress with a "vibration microphone" to record breathing patterns, heart rate, and movements.
- *Example 2*: Sleep Number x12[37]: The bed allows the user to adjust mattress firmness via remote control, elevate the head or foot of the bed and, in the event of bed partner snoring, independently elevate the bed partner's side of the bed.
- *Example 3*: Luna[38]: This mattress cover, slated to be released in early 2016, claims to monitor "sleep stages" or other biometrics, incorporates a "smart alarm," and can independently adjust the mattress temperature for each partner's half of the bed.

Desktop or Website Platforms

These technologies are computer programs or websites designed to run on a full desktop operating system (e.g., Windows, Mac, Linux, etc.). Advantages include increased host device processing power, larger data storage capacities, more robust visual and auditory experiences, and improved input/output interfaces providing a richer exchange of information. Disadvantages include potentially higher cost, decreased portability, and large platform variability.

- *Example 1:* MedHelp Sleep Tracker[39]: This website allows users to record "sleep patterns" and other health habits through a single common interface, construct detailed charts of each user's information, and provide an online community for various health issues.
- *Example 2:* MyApnea.org[40]: This website provides an online community for sleep apnea patients, sleep physicians, and sleep apnea researchers, with a discussion forum, aand informational articles about ongoing research efforts into sleep apnea.
- *Example 3:* SHUTi[41] (pronounced "shut-eye") and Sleepio[42]: Two online options for cognitive behavioral therapy for insomnia (CBT-I), using a standardized multimedia approach, which may be especially useful for patients with difficult schedules or those living in remote locations, where traveling to in-person CBT-I sessions may not be feasible.
- *Example 4:* SleepyHead[43]: Available for Linux, Mac 10.6.x or higher, and Windows XP or higher, this software allows users to view their own continuous positive airway pressure (CPAP) machine nightly usage, residual apnea-hypopnea index, air leak, and other data. Supported CPAP machines include Phillips Respironics System One, Resmed S9 and S10 series, and three other brands, as well as a few oximeter attachments. SleepMapper[44] and MyAir[45] are similar options available for Phillips Respironics and Resmed devices, respectively, accessed through an online portal.

Accessory Appliance Platforms

This category includes any physically separate or accessory device that may or may not interface with mobile devices or with the Internet, such as novelty alarm clocks or electronic sleep accessories. Compared with self-contained mobile device apps or embedded devices, advantages include feature design flexibility and improved functionality. Disadvantages include increased financial cost of purchasing a standalone device and diminished economy of space.

- *Example 1:* Clocky[46]: This specialized alarm clock with large rubber wheels is designed to literally get people out of bed in the morning. Upon pressing the snooze button, the clock spins off the bedside table and moves to a random location within the room. The user has to then get out of bed to find the clock and turn it off.
- *Example 2:* Philips Wake-Up Light[47] and HUE Smart Bulbs[48]: Both employ "smart" light bulbs designed to give the user a more pleasant awakening experience by turning on dimly 30 min before a preset wake-up time, and gradually brightening to gently wake the user. At wake-up time a natural sound or radio will turn on and gradually get louder. Users can change the color of the HUE smart bulb using an integrated mobile device app and program lights to turn on or off at specific times.
- *Example 3:* emWave[49]: This biofeedback device facilitates sleep onset using self-relaxation and stress reduction. It measures a person's pulse with a thumb sensor or an accessory ear clip sensor, and provides visual and audio feedback on current stress. It guides the user through a patterned breathing technique that aims to reduces stress.
- *Example 4:* Resmed S+[50]: This soda can-sized device includes light, temperature, and noise sensors; an integrated mobile device app tracks breathing and "deep," "light," and "REM" sleep stages, provides a smart alarm, gives a nightly "sleep score," and provides sleep advice. Another feature is "Relax to Sleep," where rhythmic computer-generated nature sounds are programmed to match the user's own respiratory rate prior to sleep, then are gradually decelerated to try to slow the user's breathing and thus induce sleep. "Mind Clear" allows the user to record "to-do" lists and other memos to be addressed the next day.
- *Example 5:* Sense with Sleep Pill[51]: A palm-sized glowing white ball, this device has multiple sensors to measure and record ambient noise, light, temperature, and humidity. An air particulate sensor claims to estimate allergen load in the bedroom. Soothing sounds and light displays aim to facilitate sleep onset and trigger awakening. A clip attaches to the user's pillow; it tracks the user's "sleep cycles" and drives a smart alarm.
- *Example 6:* Withings Aura[52]: This is a trio of standalone bedside device, motion sensor mat placed into a native mattress, and mobile app. It aims to track sleep, has a smart alarm, and uses gradually softening and loudening sounds to facilitate sleep onset or awakening, respectively. The bedside device tracks temperature, light, and sound; it also has a large light monitor that displays narrow spectrum red light at bedtime and changes to narrow spectrum blue light upon awakening, presumably affecting endogenous melatonin production and thereby aligning the circadian rhythm. Although the effect of this device on endogenous melatonin has not been validated, there is evidence supporting the use of blue versus red spectrum light to alter melatonin production and circadian rhythms.[53–53]

DISCUSSION

Over the past few years, CSTs are increasingly spotlighted by the media and have gained traction among consumers. Their user friendliness, synergy with everyday mobile devices, affordability, and novelty make them highly appealing to patients, with immense potential to affect sleep. Although interesting and innovative with great promise, these technologies also have potential pitfalls.

The CST effect on sleep compared to in-laboratory PSG, MSLT, clinical grade actigraphy, and home sleep apnea tests, or even compared to natural sleep in an electronics-free bedroom, is yet to be determined. On the upside, the integration of CSTs into bed mattresses, sleep clothing, or other parts of a patient's native sleep environment may minimize detrimental observer effect when monitoring sleep. Also, by providing advice regarding one's sleep schedule, sleep hygiene, and other lifestyle choices, CSTs help raise public awareness of the importance of sleep. However, CSTs may unintentionally disrupt sleep through discomfort, introduction of inadvertent noise or light, or erroneous effects of "smart alarms." Lack of validation studies and FDA approval for many CSTs is a concern and very few were created or endorsed by American Academy of Sleep Medicine-accredited sleep facilities or sleep specialists (notable exceptions include the Go! to Sleep app created by the Cleveland Clinic Sleep Disorders Center and a similar sleep hygiene education app named ShutEye[54] developed at the University of Washington).

Only a handful of CSTs, such as the Basis Peak and the now-discontinued Zeo Personal Sleep Manager, purport to have validation studies for their sleep tracking software.[29,55,56] For others, precise methods and algorithms for determining "sleep cycles," "sleep quality," and other measures are not clearly defined. The role of triaxial accelerometers found in actigraphs for sleep assessment is established in the literature,[57,58] but the role of the accelerometers found in standard mobile devices and commercial wearables for sleep is not well delineated. Sensor accuracy may be limited, especially for devices placed on the sleeping surface or otherwise not directly attached to the user. Unconventional sleeping surfaces and the presence of additional people in the sleep environment can also compromise accuracy. The so-called "smart alarm" function, available in many CSTs, claims to help users improve their awakening experience by timing a morning alarm to a moment when the user is in a "light sleep" stage, but this depends on how accurately these devices can detect sleep stages. Further, the ability of the smart alarm to improve the subjective experience of awakening currently has little support in the literature. Studies on sleep inertia and cognitive performance suggest decreased cognitive performance after awakening from non-rapid eye movement compared to REM sleep,[59] and similarly from N3 compared to N2 sleep.[60] Yet another study found no relationship between degree of sleep inertia, cognitive performance, and sleep stage prior to awakening.[61] To our knowledge there are no studies analyzing performance or mood with use of these consumer smart alarms.

Practically speaking, lack of validation may be premeditated by some developers, who run the risk of their technology being debunked or labeled inferior if compared to clinical standards such as in-laboratory PSG. Without validation, companies can still profit from their claims to benefit the user's sleep and health. On the other hand, CSTs may measure qualitatively valid aspects of sleep not currently assessed by standard clinical instruments. For example, some devices claim to measure ambient noise and dust particles in the user's home sleep environment, which in-laboratory PSG does not, yet arguably those factors do influence sleep. In short, validating CSTs with standard tools such as PSG may be akin to comparing apples and oranges—the measured factors may not be the same, and the clinical significance of those differences is unclear.

Whether any of these CSTs can become sensitive or comprehensive enough for clinical diagnostic purposes is an intriguing question. Research is growing on the potentials and limitations of modern technology in evaluating sleep.[1,62,63] A recent study compared data from conventional PSG with snore recordings from a standard smartphone taped to a subject's chest, and found good agreement on snore data, high correlation between respiratory disturbance index ("smart-RDI") on the smartphone and apnea-hypopnea index (AHI) on the PSG, and high specificity of the smart-RDI for diagnosing moderate to severe OSA (AHI $\geq$ 15 identified on PSG).[64] The Sonomat, a contactless sleep monitoring system embedded into a foam mattress and designed to detect conventional events such as apneas and hypopneas, was recently compared to PSG and found to have good AHI, apnea index, and hypopnea index correlation, especially for AHI $<$ 50. Interscorer agreement for events scored on Sonomat, differentiation of central versus obstructive events, and evaluation of snoring were also comparable to that of PSG.[65] Cardiopulmonary coupling, as noted previously, is a promising technology for assessing sleep stability and tracking sleep disordered breathing. Can these technologies eventually be used as adjuncts or even substitutes for conventional diagnostic testing for sleep disordered breathing? It is conceivable that specific characteristics of breathing patterns or movements detected by a smartphone may one day accurately identify sleep disordered breathing, total sleep time, or other PSG features. Perhaps accelerometer and camera technology can evolve to differentiate movements due to restless legs from movements due to REM sleep behavior disorder, or perhaps speech recognition technology can be engineered to recognize sleep talking. Electronic devices could be designed to be "sleep-friendly," with the ability to minimize screen brightness or apply "virtual" selective-light filters to electronic displays, mute unnecessary smartphone sounds when asleep, and maximize comfort and discretion of devices to promote natural sleep. With guidance and input from sleep specialists, new CSTs could have immense clinical value in the future.

There exist many social and ethical issues surrounding CSTs, with privacy concerns being paramount. Users may find it inherently disturbing to have a device actively recording or monitoring their sleep. Some apps collect information from individual users and make pooled data, both regionally and globally, available for public consumption, research, or marketing purposes, without the user's enduring consent or knowledge.[66,67] Legal concerns may arise regarding the social consequences, courtroom admissibility, and unintentional sharing or criminal tampering of sensitive data such as video or audio recordings during sleep or in the bedroom.

Legal liability and governmental regulation of consumer health technologies, including those related to sleep, are developing fields currently in their infancy. Cortez et al.[68] recently reviewed the FDA's ongoing efforts to determine which technologies should be federally regulated, and the FDA recently released a guidance document describing the type of mobile apps that it intends to regulate,[69] which will surely evolve over time. Those against regulation argue the process of governmental supervision may slow and stifle the development of these technologies. It must be stressed, however, that in the field of consumer health technologies, regulation is crucial in determining which technologies are safe to use and clinically valid. Many health-related consumer technologies on the market today claim to be "entertainment devices" and deny any official medical claims in fine print, yet public awareness of this is lacking. The potential implications of safety and legality become very complex and alarming when considering whether these popular technologies could someday be used in a court of law or for criminal or medicolegal purposes.

Sleep specialists are increasingly confronted with questions about CSTs, including their safety, accuracy, and clinical impact. Without robust data linking them to known clinical factors or outcomes and without means of regulation, many sleep specialists are left adrift about how to address these technologies with their patients. Yet providers may feel obligated to comment, given the influence CSTs have on patients' sleep habits—especially in the case of self-diagnosis and self-treatment, when patients with serious sleep disorders are convinced otherwise by information from an unvalidated sleep device, or when healthy sleepers are falsely informed by their sleep app they have a sleep problem. CSTs may offer unsubstantiated or even dangerous advice on sleep and other lifestyle choices. These technologies, at their worst, may preclude users from seeking professional evaluation and management, may damage or alter the physician-patient relationship by providing conflicting advice, or cause unnecessary harm or stress to the patient. More generally speaking, the progressive encroachment of electronic devices into the sleep environment may in and of itself worsen our patients' sleep due to excessive light, noise, or other intrusive aspects of these devices. However, CSTs can and do benefit users in many ways—perhaps most importantly, by making the average consumer more cognizant of the importance of sleep and the effect of sleep disorders on overall health.

Imagine a future where sleep information and technology is fully integrated into the home and into the consumer's lifestyle. Users could set their sleep and wake times, and learn about ideal sleep durations from their smartphones. A sleep reminder would sound at bedtime, with a fully integrated home environment where all lights would dim and switch to red wavelengths only, all electronic devices would enter a sleep-facilitating mode, and curtains would close. Ambient temperature, humidity, noise dampening, and air quality would all be optimized for maximum sleep comfort. Bed firmness and temperature would be set to the user's specific preferences. Relaxing music or soothing white noise would automatically start at a set time before bedtime and gradually quiet and shut off as sleep onset is detected. Sleep disturbances such as excessive movement, snoring, sleep apnea, and parasomnia behavior would be automatically and accurately detected and recorded for future review by users and their sleep specialist. A function to trigger lucid dreaming might allow the user to have more pleasing and fulfilling dream experiences. A gradated light and sound alarm designed to wake the patient in light sleep, with smart measures to ensure full alertness upon awakening, and feedback of sleep quality would be waiting in the morning. Special functions for daytime naps or treatment of jet lag would be optional.

One may view this hypothetical experience as either the future of sleep medicine, or the ultimate corruption of the natural sleep experience. However, it is undeniable that CSTs have the potential to largely affect our patients' sleep behavior and health, and our ability as sleep specialists to critically evaluate and even refine these technologies may offer large benefits to our patients and our field in the future.

Limitations of this review included the inability to fully assess the technical aspects of the aforementioned CSTs in great detail, due to paucity of publically accessible information regarding development and design of these technologies. Attempts were made to contact some of the companies or their representatives to obtain more information, with variable results. In addition, due to the large number and rapid evolution of CSTs, an exhaustively comprehensive snapshot of this field was out of the scope of this review.

In conclusion, "over-the-counter" consumer sleep technologies are increasingly encountered by patients and healthcare providers due to their ease of use, integration with mobile and other electronic devices, affordability, and entertainment value. These technologies have the potential to help raise awareness and promote education of sleep disorders and healthy sleep habits. However, many questions surrounding their clinical significance, effect on the future of sleep medicine, legal and social implications, and the evolution of governmental regulation remain unanswered. CSTs might catalyze the sleep health community to reconsider the number, nature, and characteristics of biometric sensors necessary to effectively and efficiently diagnose sleep disorders. Engagement of the sleep medicine community is crucial to ensure that these technologies enhance personal and public sleep health, rather than intrude upon the sanctity of sleep.

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