

# Consumer Sleep Tracking Devices: A Critical Review

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**Abstract.** Consumer sleep tracking devices are widely advertised as effective means to monitor and manage sleep quality and to provide positive effects on overall health. However objective evidence supporting these claims is not always readily available. The goal of this study was to perform a comprehensive review of available information on six representative sleep tracking devices: BodyMedia FIT, Fitbit Flex, Jawbone UP, Basis Band, Innovative Sleep Solutions SleepTracker, and Zeo Sleep Manager Pro. The review was conducted along the following dimensions: output metrics, theoretical frameworks, systematic evaluation, and FDA clearance. The review identified a critical lack of basic information about the devices: five out of six devices provided no supporting information on their sensor accuracy and four out of six devices provided no information on their output metrics accuracy. Only three devices were found to have related peer-reviewed articles. However in these articles wake detection accuracy was revealed to be quite low and to vary widely (BodyMedia, 49.9±3.6%; Fitbit, 19.8%; Zeo, 78.9% to 83.5%). No supporting evidence on how well tracking devices can help mitigate sleep loss and manage sleep disturbances in practical life was provided.

**Keywords.** Consumer health devices, sleep trackers, review

## Introduction

The wide expansion of consumer health applications and mobile apps has been recently described as a key emerging trend [1]. Sleep tracking devices are being actively introduced for consumer use. Our goal was to systematically review the availability of objective information on performance of consumer sleep trackers.

## 1. Methods

Comprehensive literature review and online searches were conducted in PubMed, Google Scholar, FDA databases, as well as in the vendor information available via product documentation, websites, and linked resources. Using keywords with product names, model names, associated technological terminologies, and previous and current company names, six representative wearable sleep trackers were identified: BodyMedia FIT, Fitbit Flex, Jawbone UP, Basis Band, Innovative Sleep Solutions SleepTracker, and Zeo Sleep Manager Pro. The first four devices can also be used as activity trackers and the remaining two devices function as sleep trackers only. The results from

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comprehensive literature review and online search were presented along the following dimensions: *Metrics, Theoretical frameworks, Evaluation work, and FDA clearance.*

## 2. Results

Excluding Zeo Sleep Manager Pro, five out of six sleep trackers utilize an accelerometer for sleep tracking. Three sleep trackers (Fitbit Flex, Jawbone UP, and Innovative Sleep Solutions SleepTracker) have only an accelerometer, and appear to measure sleep-related metrics depending on only that accelerometer. BodyMedia uses the information from all sensors, especially an accelerometer and a heat flux sensor, in order to detect the times of “in and out of bed,” and estimate the sleep stage using an artificial neural network (ANN) [2]. Basis Band is known to use the accelerometer data and the heart rate measured by its optical blood flow sensor but contribution of the sensors is not clear. For detecting movements with an accelerometer during sleep, all five of these devices are required to be worn on the left upper arm (BodyMedia FIT) or on the wrist (the rest of the devices). Zeo Sleep Manager Pro has no accelerometer but uses dry silver-coated fabric electroencephalogram (EEG) sensors in a headband. For measuring a single bi-polar channel of EEG, the sensors are advised to be located at approximately prefrontal Fp1-Fp2 positions. Among the devices, only BodyMedia FIT discloses its accuracy (Accelerometer:  $\pm 0.08g$ ; Heat Flux:  $\pm 10.0W/m^2$ ; GSR:  $\pm 9.0nS$ ; Skin Temperature:  $\pm 0.8^\circ C$ ). All devices commonly provide the total time awake, total time asleep, and sleep quality index, even if they are called by slightly different names. Unlike total time awake and total time asleep, each device seemed to have its own definition of sleep quality index, and regrettably, their exact definitions could hardly be found. BodyMedia FIT and Basis Band are capable of detecting the onset of sleep without any prior input or information, which the other devices should have in order to start seeking the onset of sleep since then. The prior input or information is to press a specific button for Fitbit Flex, Jawbone UP, and Innovative Sleep Solutions SleepTracker, and to wear a headband for Zeo Sleep Manager Pro. For detecting the onset of sleep, Fitbit Flex, Jawbone UP, and Innovative Sleep Solutions SleepTracker check if the measured vector magnitude of its accelerometer drops below a predetermined threshold. In addition, BodyMedia FIT appears to utilize lowered heat flux [2] and Basis Band detects decreased heart rate for sleep onset tracking. Zeo Sleep Manager Pro utilizes a combination of time and frequency features from the brain waves. Fitbit Flex and Jawbone UP are able to not only detect sleep epochs, but also determine whether the sleep depth of a detected epoch is light or deep according to the amount of body movement. However, only Zeo Sleep Manager Pro can characterize each detected sleep epoch into: Wake, REM, Light sleep, and Deep sleep.

BodyMedia SenseWear Armband or its later model (Armband Pro3) was reported that, compared to the polysomnography (PSG), its sleep/wake agreement reached approximately 80% [3] and no significant difference was found in both the control group and the obstructive sleep apnea (OSA) group, in terms of total time awake and sleep efficiency [4]. Zeo Sleep Manager Pro revealed about 75% sleep stage agreement and about 92% sleep/wakefulness agreement compared to PSG [5]. Regarding Innovative Sleep Solutions SleepTracker, there is no published or opened article to the public. Fitbit Flex, Jawbone UP, and Innovative Sleep Solutions SleepTracker are assumed to be based on previous research but they do not reveal their theoretical frameworks at all. BodyMedia has declared that its own theoretical background—

embodied by an ANN-based proprietary algorithm with raw data gathered from all the sensors and certain derived measures—was based on a preliminary study and that it could not be presented in detail [2]. Basis Band is known to detect the onset of sleep with decreased activity and lowered heart rate, but does not disclose its theoretical background. Zeo is known to use one channel of EEG, recorded at the sampling rate of 128Hz, to estimate sleep stage [5]. Estimating sleep stage with multi-channel EEG has a well-established theoretical background.

Sleep tracking evaluation studies included two articles on BodyMedia [3–4], one article on Fitbit [6] and one article on Zeo [5]. In terms of total sleep time, total wake up time, and sleep efficiency, BodyMedia SenseWear Armband was reported to produce similar to PSG results, both in control patients and in OSA patients [4]. This device was also reported to have high sleep/wake epoch-by-epoch agreement rate ( $79.9\pm 1.6\%$ ) and high sensitivity of sleep estimation ( $88.7\pm 1.5\%$ ). However the device could not estimate wake with high accuracy (specificity,  $49.9\pm 3.6\%$ ) [3]. Montgomery-Downs et al. evaluated and compared the sleep/wake detection performance of Fitbit and standard actigraphy (Actiwatch-64, Philips Healthcare, Andover, MA). As a result, Fitbit and Actiwatch-64 showed 97.8% and 95.7% of agreement rates with PSG for sleep detection but 19.8% and 38.9% for wake detection, respectively [6]. Finally, both devices were found to consistently misidentify wake as sleep and thus overestimated both total sleep time and sleep efficiency. Shambroom et al. reported that Zeo was able to achieve better sleep/wake agreement rates (92.6% and 91.1%) than actigraph (86.3% and 85.7%) when each device's sleep/wake scoring was compared with two experienced technician's PSG scores. It also provided a good sleep stage agreement rate (75.8% and 74.75%) while an actigraph could hardly estimate sleep stage [5]. There were no published articles related to SleepTracker, Jawbone UP, and Basis Band. No sleep trackers were registered with the U.S. FDA for the purpose of sleep tracking, sleep analysis, or similar purposes.

### 3. Discussion

The review identified a critical lack of basic information about the devices: five out of six devices provided no supporting information on their sensor accuracy and four out of six devices provided no information on their output metrics accuracy.

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