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# Obstructive Sleep Apnea Home-Monitoring Using a Commercial Wearable Device

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#### Abstract

Obstructive sleep apnea (OSA) is a common sleep disorder and polysomnography (PSG) is the gold standard for its diagnosis and treatment monitoring. There are nowadays several activity trackers measuring sleep quality through the detection of sleep stages. To allow an easier monitoring of the treatment efficacy at home, this work explores the possibility of using one of those commercial smart-bands. To this aim, we studied the signals provided by PSG and a Fitbit smart-band on 26 consecutive patients, admitted to the hospital after the diagnosis of OSA, and submitted to ventilation or positional treatment. They underwent monitoring for three nights (basal, titration, and control). We developed both a visualization software allowing doctors to visually compare the two hypnograms, and a set of statistics for assessing the concordance of the two methods. Results indicate that Fitbit can detect normal sleep patterns, while it is less able to detect the abnormal ones.

# Keywords:

Obstructive Sleep Apnea, Wearable Electronic Devices, Telemedicine, Home-patient monitoring.

# Introduction

Sleep as a biological phase of human life represents approximately one-third of the lifetime. Sufficient night sleep, both in duration and quality, is crucial for physical and mental health and daily life performance [6]. In modern societies, with increasing stress levels, sleep disorders are increasing. Abnormality in sleep not only decreases physical performance, but also has negative effects on cognitive abilities and onset of some pathologies. As an example, obstructive sleep apnea (OSA) can increase risk of cardiovascular diseases, neurocognitive decline and excessive daytime sleepiness [11].

OSA is a common sleep disorder which is presented by momentary and often cyclical cessations in breathing rhythm. This disorder is accompanied often by extra thoracic upper airway obstructive events, a brain stem respiratory motor reduction or cessation output or a combination of central and obstructive

Attended Polysomnography (PSG) has been known as the gold standard evaluation for both OSA diagnosis and assessment of treatment effectiveness, by comprehensively recording physiological changes that occur during sleep [7; 9].

Sleep stages resulted by PSG are divided into five classes: W, N1, N2, N3, and R sleep. Stage W defines the state of wakefulness before sleeping and the so-called "micro-arousals" during the sleep. Stage N1 is the lightest sleep stage and usually covers less than 10% of the total sleep period. Stage N2 is the light sleep state and takes the largest portion of sleep, usually accounting for about 50% of the total sleep period. Stage N1 and N2 are also collectively called "light" sleep. Stage N3 is the deepest state of sleep and covers less than 20% of the total sleep time. N3 is also called "deep" sleep or slow wave sleep (SWS). Stages N1, N2, and N3 are collectively called NREM sleep. Stage R is the sleep state defined by rapid eye movement (REM) and covers for about 20% of the total sleep time. It is the period during which dreaming occurs [7].

In suspicion of sleep apnea, sleep study is recommended, which is often PSG and tells how many times a patient have apnea or hypopnea. The AHI (Apnea-Hypopnea Index) is the number of times a patient has apnea or hypopnea during one night, divided by the hours of sleep. An AHI less than 5 is considered normal, from 5 to 15 denotes mild apnea, 15 to 30 is moderate, while a value greater than 30 is considered severe. With moderate or severe AHI, some treatments are indicated, including both CPAP (continuous positive airway pressure) machine, which blows air into nose, and lifestyle changes that will help keep airways open, like losing weight, exercising, quitting smoking, and sleeping on side or stomach instead of back [8].

People with apnea may have reduced stages N3 and REM when their interrupted breathing causes sleep to be fragmented, possibly alternating between stages N1 and N2 over and over all night [12]. Sleep study may also be useful for titrating CPAP to individual needs [10].

While it is well-agreed that PSG is needed for diagnostic and treatment purposes, using it also for subsequent monitoring of non-hospitalized patients may be difficult, because:

- 1. it requires a large number of sensors to be positioned by a trained healthcare operator, being based on electroencephalogram, electro-oculogram, electromyogram, electrocardiogram, and pulse oximetry, as well as airflow and respiratory effort, to evaluate any underlying cause of sleep disturbances [9];
- 2. the patient must come to the hospital twice, one for the positioning and one for giving back the device.

In this situation, attempts have been studied to find alternative methods for sleep monitoring in non-laboratory settings [7]. Such methods are based on portable monitoring devices such as some commercial smart bands or activity trackers [1]. For example, Fitbit has been shown in the literature to perform well in sleep monitoring in healthy adults. In particular, Fitbit Charge 2 showed promise [2] in distinguishing sleep/wake state (0.96 sensitivity, i.e., accuracy to detect sleep, and 0.61 specificity, i.e., accuracy to detect wake) and sleep stage composition relative to PSG, especially for REM sleep. In OSA subjects, instead, Fitbit devices still have insufficient accuracy. In [5], for instance, they found statistically significant differences between Fitbit and PSG measures for all sleep outcomes, except for REM sleep.

Being aware of those limitations, in this paper we illustrate a further attempt to utilize a Fitbit smart band to monitor the treatment efficacy, at least in terms of sleep stabilization (i.e., not for OSA diagnostic purposes).

# **Patients and Methods**

#### **Patients**

All patients included in the study (26) were clinically diagnosed with OSA and underwent PSG for confirming the diagnosis and then providing ventilation or positional treatment. Included patients are more than 18 years old and have signed infomative consent for the study. Patients with other sleep disorders and who had severe systematic comorbidities, for example, Chronic Obstructive Pulmonary Diseases (COPD), Congestive Heart Failure (CHF) or decompensated diabetes, which can adversely affect sleep stability, were excluded. Patient recruitment and data collection began in September 2020. Data collection will continue even after the conclusion of this paper. The study received the approval of the ethics committee of ICS Maugeri on 23 April 2020.

# Polysomnography

The PSG available at the Sleep Medicine Unit at ICS Maugeri is provided with a software that allows to simultaneously examine all the signals collected. By observing them, the doctor manually assigns one of the following five sleep stages to each 30-seconds interval (epoch): WAKE, N1, N2, N3 or REM.

### The wearable device

Monitoring of biological signals is the basis of all sleep monitoring methods that, according to the measured biomarker, may be defined as EEG-based, Movement-based, Respiration-based and Heart rate- based sleep monitoring [7]. The Fitbit smart band, in particular the Charge 3 model, used in this study, provides a record of the sleep stages estimated by using a combination of movement and heart-rate patterns. It assumes that the user is asleep based on (i) not having body movements for a while and (ii) having movements duration that is indicative of sleep behavior. The device also tracks heart rate variability (HRV), defined as the beat-to-beat changes in heart rate, which fluctuate as transitions occur between light sleep, deep sleep, and REM sleep stages. The sleep stages data helps to track the sleep patterns and notice variation [4]. Sleep stages provided by Fitbit are Wake, Light, REM and Deep stages.

#### Data collection

During hospitalization, for each patient, three full-night sleep measurements were taken at three different points: basal registration (T0), before undergoing treatment; titration (T1), i.e. after the adaptation period to therapy; at the end of the treatment period (T2).

Patients wore the Fitbit Charge 3 band over the full night when they underwent polysomnography. The day after the procedure, data was synchronized by the trained personnel. Sleep stages estimated by Fitbit algorithm were downloaded from Fitbit data cloud in JSON format. The JSON files contain start date, time of sleep and sleep stages for each one minute.

#### Data processing and analysis

According to the objective of comparing PSG with Fitbit sleep stage classification, the PSG output was manually transferred into a file reporting sleep stage for every minute over the procedure duration. Since Fitbit output does not distinguish between N1 and N2 stages, PSG stages N1 and N2 were labelled as "Light", while N3 was labelled as "Deep".

# **Data visualization**

To allow the sleep medicine expert comparing PSG and Fitbit hypnograms, we developed a software to visualize them both in the same diagram and separately, useful for an inspection "ata-a-glance" (Figure 1 shows the two separated graphs).

#### Results

As mentioned, 26 patients have been enrolled. However, 6 patients were excluded from the analysis due to absence of respiratory disorders at basal (and thus not continuing with the monitoring), not wearing the Fitbit appropriately, or too many signal artifacts.

# Qualitative results

A sleep medicine expert (FF) reviewed the diagrams to check if features and patterns detected by PSG, and useful to assess the treatment efficacy, are detectable also in the Fitbit results. According to [12], in OSA patients there are some known changes, like decreasing REM and N3 stages and switching between N1 and N2.

Thus, it is important to investigate if the Fitbit can detect the possible stabilization of these patterns due to treatment. The expert reported that Fitbit does not perform very well during the titration registration, probably due to a "rebound" effect, typical of the initial phase of the treatment, especially for particularly severe patients. However, when sleep become more regular, the two hypnograms become more similar. In the last registration, except for the initial and the final part, most of the graphs are very similar. This can be appreciated in Figure 1, that allows a visual comparison of the hypnograms drawn from the two devices. For example, Fitbit failed to detect a significant amount of deep sleep at T0, while overestimating the number of REM stages. At T2, after an initial "unscored" period, probably due to the fact that the patient did not wear the device correctly, the three REM phases, which are very important to assess the regularity of the sleep cycles, are correctly captured, as well as (roughly) the amount of deep sleep. Overall, even if it is not able to capture microarousals and even if light/deep sleep is not always correctly detected, the Fitbit signal suggests a quite "regular" sleeping, which is an information that the doctor may interpret as the persistence of the treatment effect.

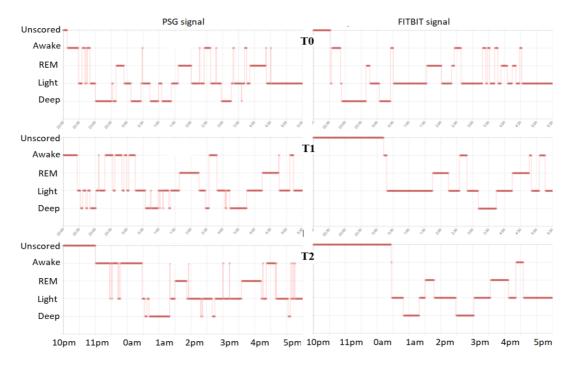


Figure 1 – PSG (left) and Fitbit (right) hypnograms visualization for a single patient. The three layers represent basal(T0), titration (T1) and control (T1) measurements.

# Quantitative results

For each night, we considered the following sleep outcomes: total sleep time (TST), sleep onset latency (SOL), wake after sleep onset (WASO), percentages of time spent in the four different stages, and sleep efficiency (SE).

Differences between PSG and Fitbit were estimated through correlation analysis of the measurements made by the two devices. Results obtained are reported in Table 1.

Table 1 – Correlation between sleep indicators provided by Fitbit and PSG.

	T0		T1		T2	
	r	p-value	r	p-value	r	p-value
TST	0.8	< 0.0001	0.9	< 0.0001	0.9	< 0.0001
SOL	0.3	0.25	0.2	0.412	0.6	0.003
WASO	0.4	0.08	0.6	0.012	0.7	0.001
%wake	0.6	0.007	0.8	< 0.0001	0.7	< 0.001
% light	0.8	< 0.0001	0.9	< 0.00001	0.9	< 0.0001
% deep	0.5	0.03	0.7	< 0.001	0.6	0.008
%RE M	0.5	0.02	0.7	< 0.001	0.9	<0.0001
SE	0.8	< 0.0001	0.8	< 0.0001	0.9	< 0.0001

Except for SOL and WASO, the correlation coefficients (r) show a good relationship between the measurements made by the two devices at each moment of the treatment. The strength of the correlation and the significance of the results are confirmed by the p-values (p < 0.05). As for SOL and WASO, we observed an improvement after the treatment.

We then calculated sensitivity (i.e. the proportion of asleep epochs correctly identified as such by the Fitbit), specificity (i.e. the proportion of awake epochs correctly identified by the activity tracker), the overall accuracy and the accuracy in detecting sleep stages (Table 2).

Table 2 – Fitbit sensitivity, specificity, and accuracy

	T0	T1	T2
sensitivity	0.92	0.90	0.93
specificity	0.56	0.59	0.58
overall accuracy	0.61	0.59	0.61
accuracy 'light'	0.73	0.66	0.69
accuracy 'deep'	0.41	0.38	0.44
accuracy 'REM'	0.59	0.60	0.68

As we can see, Fitbit show an overall improvement in measuring sleep-wake state and sleep stage composition following the treatment, especially for REM sleep stage.

# Discussion

The main objective of the study was to evaluate the possibility of using a commercial, user-friendly, and low-cost device to monitor the persistence of treatment response of patients discharged from the hospital after OSA treatment.

As we reported in the introduction, Fitbit results may not be accurate enough to make OSA diagnosis. As a matter of fact, due to its time granularity of one minute, it is not sensitive to the short time micro-arousals, typical of OSA patients. However, since the Fitbit hypnogram, after the treatment, seems able to detect significant "macro" changes towards normal features, we are confident that it can be used to monitor home-patients sleep stability.

# **Conclusions**

Although preliminary, results show that Fitbit Charge 3 is reliable in any phase (from T0 to T2) for what concern most of the summary sleep indicators, while the stage classification improves after treatment.

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