World Journal of Otorhinolaryngology-Head and Neck Surgery (2016) 2, 45–49

Available online at www.sciencedirect.com

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REVIEW ARTICLE

Overview of smartphone applications for sleep analysis

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Received 25 August 2015; received in revised form 8 February 2016; accepted 15 February 2016
Available online 5 March 2016

KEYWORDS
Mobile applications;
Smartphone;
Apps;
Sleep monitor;
Actigraphy

Abstract *Objective:* To review and assess the current selection of sleep analysis smartphone applications (apps) available for download.
Methods: The iOS and Google Play mobile app store were searched for sleep analysis apps targeted for consumer use. Alarm clock, sleep-aid, snoring and sleep-talking recorder, fitness tracker apps, and apps geared towards health professionals were excluded. App information and features were obtained from in-store descriptions, and the app developer website.
Results: A total of 51 unique sleep apps in both iOS and Google Play stores were included. The apps were rated 3.8/5 in both stores, and had an average price of $1.12 in the iOS store and $0.58 in the Google Play store. >65% of sleep apps report on sleep structure, including duration, time awake, and time in light/deep sleep, while reporting of REM was limited. The availability of extra features was variable, ranging from 4% to 73% of apps.
Conclusions: There are a variety of sleep analysis apps with a range of functionality. The apps with the most reviews from the each store are featured. Many apps provide data on sleep structure; however the algorithms are not validated by scientific literature or studies. Since patients may inquire about their sleep habits from these apps, it is necessary for physicians to be aware of the most common apps and the features offered and their limitations in order to properly counsel patients.

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E-mail address: onga@musc.edu (A.A. Ong).
Peer review under responsibility of Chinese Medical Association.

Production and Hosting by Elsevier on behalf of KeAi

http://dx.doi.org/10.1016/j.wjorl.2016.02.001

Introduction

Smartphones have been widely adopted by the general public, and have become an integral part of today's society, including the field of medicine. In addition to mobile communication, smartphones allow consumers to download third-party applications (apps) through an online mobile store. The Apple mobile app store and Google Play (Android) mobile app store has over 1.2 million apps and 1.6 million apps, respectively, and the number of apps continues to grow each year.[1,2] This offers users a variety of apps with a broad range of functions to choose from.

There has been increasing interest among the public in using apps to improve health and fitness, and as a result, the number of apps focused on these issues has grown exponentially. There are over 100,000 health apps combined in the Apple and Google Play mobile app store.[3] These health apps range from weight loss aids to asthma management.[4,5] One target for health and fitness app developers has been sleep and sleep hygiene. These apps have a broad range of functions, including smartalarm clocks, sleep aids, sound recording during sleep, and sleep analysis. Others are developing smartphones programs to aid healthcare professionals in screening patients for habitual snoring and obstructive sleep apnea.[6] Despite increasing usage of health apps by the population, physicians still have limited experience with these apps in clinical practice.

As more consumers adopt sleep apps, physicians should be aware of the available apps, and be able to counsel patients appropriately on sleep app data. The purpose of this study is to review the current selection of apps available for sleep analysis, and to provide a resource to familiarize physicians with the most common sleep apps in current use.

Methods

The Apple (iOS App Store) mobile app store and Google Play mobile app store were searched for sleep analysis apps by one author (A.O.). The following search terms were used: *sleep tracker, sleep apnea, sleep analysis, and sleep cycle*. Sleep analysis apps targeted for consumer use were included. Alarm clock, sleep aid, snoring and sleep talk recorder, and fitness-tracker apps were excluded. In addition, sleep apps for health professionals as well as apps not related to sleep were excluded. Data were collected using store description and the developer's website, including app name, functions, price, date of last update, user rating, number of user reviews, and developer information. Each app store was analyzed separately as some apps were found in both mobile app stores.

Results

The Apple and Google Play mobile app store were searched in mid-June 2015. The search terms yielded a total of 593 and 723 unique apps in the Apple app store and Google Play app store, respectively. A total of 60 apps met the inclusion criteria, of which 51 were unique. Thirty-three (65%) apps were available in the Apple app store; 27 (53%) in the Google Play store; and 7 (14%) were found in both stores.

The average app price in the Apple store was $1.12, ranging from $0.00 to $9.99, and $0.58 in the Google play store, ranging from $0.00 to $4.49. Twenty (61%) Apple apps and 21 (78%) Google Play apps were free of charge. There were 42 unique developers for the 51 apps. There was minimal information on developers' websites regarding prior experience handling and analyzing medical data.

User ratings/reviews

Ratings were obtained from the mobile app store and had a rating scale of 1—5. Nine (27%) Apple apps and 2 (7%) Google Play apps did not have a rating listed. For the apps with available ratings, the average Apple app rating was 3.8 (range: 2.0—4.7) and the average Google Play app rating was 3.8 (range: 2.7—4.7).

Features

All included apps were evaluated for functionality. Table 1 summarizes percentage of apps that include each feature. All 33 (100%) Apple apps and 27 (100%) Google Play apps report sleep duration, while reporting of sleep structure was more variable. The Apple apps showed the following: 23 (70%) had time spent awake; 21 (64%) had time in light sleep; 23 (70%) had time in deep sleep; and 6 (18%) had time in REM. The Google Play apps had 20 (74%) showing time spent awake; 21 (78%) time in light sleep; 21 (78%) time in deep sleep; and 7 (11%) time in REM. A total of 15 (45%) Apple apps and 19 (70%) Google Play apps calculate sleep efficiency, while 3 (9%) Apple apps and 7 (11%) Google Play apps report sleep debt.

Many apps included features in addition to sleep analysis. Eight (24%) Apple apps and 3 (11%) Google Play apps provide graphs on movement during sleep. Almost half of

Table 1 Number of apps by feature offered.

	Mobile app store	
	iOS	Android
Sleep Structure		
Duration	33 (100%)	27 (100%)
Awake	23 (70%)	20 (74%)
Light Sleep	21 (64%)	21 (78%)
Deep Sleep	23 (70%)	21 (78%)
REM	6 (18%)	7 (11%)
Sleep Efficiency	15 (45%)	19 (70%)
Sleep Debt	3 (9%)	7 (11%)
Extra Features		
Movement Tracker	8 (24%)	3 (11%)
Sound Recorder	15 (45%)	7 (11%)
Smart Alarm	24 (73%)	15 (56%)
Sleep Aid	9 (27%)	8 (30%)
Notes	12 (36%)	17 (63%)
Heart Rate Monitor	6 (18%)	1 (4%)
Apple Health	11 (33%)	N/A

REM (rapid eye movement).

the Apple apps (45%) record sound during sleep, while only a handful of Google Play apps (11%) could do the same. The majority of Apple apps (73%) featured a smart alarm, designed to wake the user during light sleep, whereas half the Google Play apps (56%) had this feature. Nine (27%) Apple apps and 8 (30%) Google Play apps included optional white noise to aid in initiating sleep. The majority of Google Play apps (63%) could record wake up mood or notes to track activities and its effect on sleep, compared to a few Apple apps (36%). Not many apps (18% Apple and 4% Google play) could record heart rate. Unique to Apple and the iPhone, 11 (33%) apps could sync data with the built-in iPhone Health app.

Table 2 displays the ten most reviewed apps in the Apple and Google Play mobile app store. By far, the most reviewed app is the Sleep as Android app, only available from the Google Play store. For a two week trial, users have access to all features, including snore recorder and sleep aid. This app utilizes CAPTCHA technology for its smart alarm to ensure the user is awake and out of bed. To turn off the alarm, the user must scan a QR code located in the bathroom or shake the phone heavily. It also can sync to a commercially available smartwatch to track sleep using the watch's built-in motion sensor, or accelerometer, and an anti-snoring feature that vibrates the watch when it detects snoring. The upgraded version, also a featured app, Sleep as Android Unlock, gives users unlimited access to the app's features beyond the two week trial.

The Apple app with the most reviews is Sleep Cycle, also found in the Google Play store. While the app does not record sound, it does offer a sleep aid, and note taking capability to monitor a user's habits and its effect on sleep. Using the smartphone's camera, the app can measure heart rate on awakening by analyzing the color changes on the tip of the user's finger by photoplethysmography, which measures the pulse wave using the smartphone's flash as a light source and camera as a photo sensor.[7,8] In addition, data on sleep analysis and heart rate can be integrated to the built-in Health app on newer iPhones.

One app was the first place winner at The Health Data Initiative Forum by the Institute of Medicine.[9] The app, SleepBot, does not provide sleep structure data, but alternatively measures the amount of movement by the user during sleep. It can record sound during sleep, which can be played back in the morning, and lets users rate their sleep quality. The app also provides strategies for users to get to sleep, and information on different sleep disorders.

Four apps were created by fitness companies, and most offered a number of other health apps on the developer's website. In addition to tracking sleep, MotionX 24/7 also doubles as a pedometer, and calculates calories burned from walking. Sleep Better by Runtastic places more of an emphasis on the effect of daily habits, such as exercise, caffeine consumption, and even stress, on sleep. Smart Alarm Clock by Plus Sports and Sleep Time by Azumio features similar sleep structure analyses as other apps, and allows users to virtually back up recorded sleep data.

EasyWakeup PRO is the oldest app featuring a smart alarm, created in 2008. Like SleepBot, it reports amount of movement instead of sleep structure, and can record notes and mood in a dream diary. It is the most expensive app offered at $9.99, and another app by the same developer, Easy Wakeup Classic, is available for half the price, but does not include dream diary capability. Good Night's Sleep Alarm and Sleep Analyzer are two apps only available in the Google Play store, and offer similar sleep analyses as other apps. Good Night's Sleep Alarm does require in-app purchases to access certain features, and Sleep Analyzer has the lowest rating of the apps featured, mainly due to unreliability of the alarm. Smart Sleep Manager is an app developed out of Japan with many different sleep reports for users to view. It offers a few relaxing sleep aid sounds to

Table 2 Ten most popular apps for iOS and android by number of user reviews.

App name	Platform	Cost $	Rating	No. reviews	Developer
Absalt EasyWakeup Classic	iOS	$4.99	4	408	FreeTerra
Absalt EasyWakeup Pro	iOS	$9.99	4.5	990	FreeTerra
Good Night's Sleep Alarm	Android	$0.00	4.1	7736	Ateam Inc.
MotionX 24/7	iOS	$0.99	4.5	2263	MotionX
Sleep Analyzer	Android	$0.00	3.1	2072	A1 Brains Infotech
Sleep As Android	Android	$0.00	4.3	179,626	Urbanoid Team
Sleep as Android Unlock	Android	$4.49	4.5	16,637	Urbanoid Team
Sleep Better	iOS	$0.00	4	788	Runtastic
	Android	$0.00	4	60,021	
SleepBot	iOS	$0.00	4	1020	SleepBot
	Android	$0.00	4	44,626	
Sleep Cycle	iOS	$1.99	4.5	75,932	Northcube AB
	Android	$1.69	4.5	11,547	
Sleep Time	iOS	$0.00	4.5	4775	Azumio
	Android	$0.00	4	18,881	
Sleep Time+	iOS	$1.99	4.5	7240	Azumio
Smart Alarm Clock	iOS	$1.99	4	3716	Plus Sports
	Android	$0.00	3.9	27,165	
Smart Sleep Manager	iOS	$0.00	N/A	N/A	株式会社C2
	Android	$0.00	4.1	7418	

help users fall asleep faster and peacefully, but requires in-app purchase to access these.

Discussion

With the ubiquitous nature of smartphones, the use of health-related apps, including sleep analysis apps, will only increase.[10] Although sleep apps were not designed for medical use, patients may approach physicians with questions regarding the information obtained from these apps. Our goal was to review the major features provided by the current sleep analysis apps available for smartphones.

Every smartphone app analyzed on both platforms reported sleep duration, although reporting data on sleep structure, including time in light sleep, deep sleep, and REM, was inconsistent. To gather data on sleep structure, the reviewed apps rely on the smartphone's built-in accelerometer to register movement during the night, and this measurement of human rest/activity cycles, also known as actigraphy, correlates decreasing amounts of movement to the transition from light to deep sleep. Each app has their own proprietary algorithm to relate the amount of movement detected by the accelerometer to specific stages of sleep. Actigraphy has received increased attention to assess patient's sleep patterns as an alternative to polysomnogram.[11] One study looked at healthy volunteers who underwent in-laboratory polysomnography while simultaneously using a featured sleep app, Sleep Time by Azumio. The authors found that there was no correlation between the polysomnogram findings and sleep app with regard to sleep efficiency, light sleep percentage, deep sleep percentage, or sleep latency.[12] They reported the app was highly sensitive in detecting sleep, although had poor specificity, which confirmed previous studies.[13,14] Bhat et al. advised that their findings could not be generalized to other sleep apps; however, no app provided information about the algorithms used to determine sleep structure, or cited scientific publications to back the accuracy of the app. More research should confirm the measurement validity of these apps and encourage further development of sleep app algorithms, which may help future researchers obtain data on sleep using an inexpensive format.[15] To properly counsel patients on similar apps, the physician must be aware of the limitations of actigraphy and its use in smartphone apps that monitor sleep. Thus far, these apps cannot replace polysomnography in monitoring sleep.

One major attraction for users when downloading sleep apps is the smart alarm, which reportedly wakes the user at the optimal time. Users can set an alarm within the app to create a 30 min window during which the app would wake the user as they transition to light sleep. The app correlates the increased movement to light sleep, a time when users should be easily awakened. There is still research needed on this subject, and as mentioned before, actigraphy is not as accurate in detecting wakefulness. Currently, the perceived benefit of the smart alarm by users remains unclear.[16,17]

Fifteen Apple apps and seven Google Play apps could record sound during sleep. These apps utilize the smartphone's built-in microphone to either record sound during the entire night's duration, or selectively record sounds that exceed a pre-determined threshold. The ability to record sounds during sleep may benefit physicians screening patients who are unaware of potential habitual snoring. Habitual snoring has been found to be an increased risk factor for cardiovascular morbidity, and may hint at the possibility of obstructive sleep apnea.[18] Although the apps are not intended for screening, its use in snoring identification in specific populations may be useful. Single patients who do not have a consistent bed partner may not be aware of their snoring.[19] The authors also suggested the potential of snore recorder apps to track the efficacy of snoring interventions, such as oral appliances, in patients without a consistent bed partner. Only future studies can confirm the reliability of sound recorder apps for monitoring snoring therapy success.

An advantage of sleep apps is accurately listing the time a patient went to bed (time turning on the app), and time of sleep initiation, due to its high sensitivity in detecting sleep. In addition, twelve Apple apps and sixteen Google Play apps can record notes on their sleep quality (similar to a visual analog scale), any causes for difficulty falling asleep, habits that may affect sleep, such as coffee ingestion or exercise at night, and mood upon awakening. When evaluating patients for the first time, sleep physicians recommend use of a sleep diary to gather information about a patient's sleep patterns.[20] This is particularly critical for patients who may suffer from hypersomnia due to poor sleep hygiene, insomnia, or circadian or phase shift disorders.

Information from the app on time in bed, sleep initiation, and time of waking may serve as an adjunct to this paper sleep diary. One study comparing the use of a smartphone app to use of a website and paper diary for weight loss found that those in the smartphone group had a statistically significantly higher rate of adherence to self-monitoring than those that used the website and paper diary.[21] Since smartphones are consistently available throughout the day, patient recording is easier, and may allow for more complete sleep diaries. Future studies could assess the adherence rate of a sleep diary app to paper sleep diary in the management of sleep disorders.

This study has some limitations. This study only included apps used for sleep analysis and sleep tracking, and there were many other sleep apps, including apps that exclusively record snoring, which may be beneficial to physicians. In addition, we excluded sleep apps that were targeted for use by healthcare professionals that could be helpful in the management of patients with sleep disorders. Apps for wearable devices, such as the FitBit and Jawbone, were not included as well, and their accuracy in sleep analysis is unclear.[22] We were also limited by the information available in the mobile app store and the developer's website. The apps were not downloaded, thus more potential information regarding the app may be missing. Technology is constantly changing, and while new apps and devices are developed, our study provides an up-to-date review of the apps currently available for sleep analysis among the major smartphone operating systems.

Conflicts of interest

None.

Financial disclosures

Dr. Gillespie receives research support from Inspire Medical and Olympus, and is a consultant for Olympus and Medtronic.

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Edited by Jing Li