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SHORT COMMUNICATION

Apps in sleep medicine

Andreas Stippig · Ulrich Hübers · Markus Emerich

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Abstract
Purpose Users of mobile devices such as iPhones or iPads are offered a wide range of applications (apps) regarding sleep and sleep medicine. This article will give an overview about the apps that are available. Moreover, it will present how they work and determine if they can be used in therapy.
Methods The apps' competence to count snoring noises had to be evaluated. This was done with a three-piece test set-up to analyze the apps' ability to distinguish between snoring sounds and disturbing noises such as cars driving past the window, conversations in the bedroom, or even just the rustling of sheets and blankets.
Results The tested apps monitor and record snoring noises well as long as they are used in a soundproof environment. In a real-life environment with various disturbing noises, the apps show difficulties in telling snoring sounds and other noises apart.
Conclusions The tested apps are not accurate enough to replace the common diagnostic standard in therapy. However, they can be a helpful addition. Especially, singles could use them who do not know if their snoring has improved with an OA and do not have anybody to ask.

Keywords Snoring · Obstructive sleep apnea syndrome (OSAS) · Application (App) · Oral appliance · Validation

A. Stippig (✉) · U. Hübers
Praxis für Kieferorthopädie, Hauptstraße 5,
77652 Offenburg, Germany
e-mail: andreas@stippig.de

M. Emerich
Universitätsklinik für Hals-, Nasen- und Ohrenheilkunde,
Killianstraße 5, 79106 Freiburg im Breisgau, Germany

Introduction

Patients with mild to moderate obstructive sleep apnea syndrome (OSAS) can be treated with mandibular advancement devices as the main noncontinuous positive airway pressure (non-CPAP) therapy [1].

So far, patients and their practitioners have had mostly to rely on the feedback of spouses, friends, and family to be informed about the success of oral appliance therapy (OAT) or if further titration is needed. When patients are prescribed a custom-made oral appliance (OA) that shifts the lower jaw forward to open up the airway [2], usually they depend on somebody else's hearing to monitor if the snoring or dropouts have ceased or not. Alternatively, they are given a validated questionnaire such as the "Calgary Sleep Apnea Quality of Life Index" [3] or a two to six-channel screening device such as the ApneaLink Plus (ResMed Germany Inc., Martinsried, Deutschland) [1, 4, 5].

Nowadays, thanks to the wide distribution of smartphones [6], nearly every household has access to technology. This creates new opportunities to monitor and observe changes in snoring and sleeping behavior at home.

Users of mobile devices such as iPhones or iPads are offered a wide range of applications (apps) for health monitoring [7]. Searching the App Store (Apple Inc., Cupertino, CA, USA) for iPhone and iPad apps with the keywords "snore," "sleep laboratory," and "sleep apnea" results in over 300 hits. Do these apps work? How could they be used in therapy?

This article will give an overview about the apps that are available. Furthermore, it will explore what the apps claim to be capable of and how reliably they can record and analyze sleeping sounds. Ultimately, this article will evaluate how current apps could be integrated efficiently into sleep medicine.

Materials and methods

Apps

In order to choose between the over 300 apps regarding sleep medicine, certain inclusion criteria had to be established. It was decided that the app had to be able to produce analyzable data by recording snoring sounds and/or tracing sleeping movements. Subsequently, the description of each app was studied and it was checked if the a priori defined inclusion criteria were met. Thus, seven apps were selected for this research.

SnoreMonitorSleepLab (Adactive AB, ©Leif Soderberg, Lund Sweden)
Quit Snoring (Pointer Software Systems, Ltd. ©PTech HM, Ltd.)
Snore Spectrum (ZURLIN Technologies)
SnoreLab (Reviva Softworks Ltd.)
Sleep Assess (ResMed Germany Inc., Martinsried, Deutschland)
Snore Check (SnoreCheck, ©George Potamitis)
SomnoPose Sleep Position Monitor (Proximal Box Software, ©James Hassett)

The apps were then installed on various mobile Apple devices and all their features were tested.

App check

Sleep Assess A special trait of this app is its screening questionnaire and its sleep laboratory finder. However, the finder does not seem to be designed for all markets, i.e., the German market for example, since sleep laboratories in the close proximity were not found. Moreover, the app can only record snoring noises and not count them.

Snore Check A noteworthy feature of this app is the telemedical analysis of a questionnaire, of a self portrait of the user's tonsils, and of the recorded sleeping sounds. Snore Check is a telemedical app from Greece. For the analysis of the information, the data has to be transmitted digitally. When testing the app in the course of this research, the forwarding of the data did not work therefore resulting in no telemedical analysis.

SomnoPose Sleep Position Monitor This app mainly monitors the sleeping position of its user. The app's goal is to prevent the user from lying on his/her back by conditioning him/her with the aid of vibrations. Unfortunately, the app cannot record snoring noises. Thus, it is difficult for the user to maintain if the app indeed helps to reduce the snoring or not.

SnoreMonitorSleepLab, *Quit Snoring*, *Snore Spectrum*, and *SnoreLab* have not only proven the ability to record snoring noises but also to count them and deliver data. Whereas the data of *SnoreMonitorSleepLab*, *Quit Snoring*, and *Snore Spectrum* was comprehensible, *SnoreLab*'s major feature, a so called "snore score," turned out to be in-transparent. The app does not disclose how it calculates the score. For scientific purposes, it is therefore dispensable.

The audio recording function and the snore counting function of *SnoreMonitorSleepLab*, *Quit Snoring*, and *Snore Spectrum* seemed to be the most advantageous feature for clinical use. However, it appeared as if not only snoring noises were counted but also any other noise above a certain threshold.

To check the reliability of these three apps, hence a test set-up was required.

Set-up

To evaluate the apps' abilities to distinguish between snoring and disturbing noises such as cars driving past the window, conversations in the bedroom, or even just the rustling of sheets and blankets, a three-piece test set-up was designed.

In the first set-up, a sound sample consisting of three equal snoring noises and one different snoring sound was played 150 times on an audio device in a soundproof environment. The apps running on four mobile devices (one iPhone 4, one iPhone 5, one iPad mini, and one iPad 2nd Generation) had to count the 600 snoring noises. This was repeated six times per app.

The second set-up resembled the first with one major difference. The test was undertaken in a real-life environment with various disturbing noises.

The third set-up was a comparison between the apps and the ApneaLink Plus (ResMed Germany Inc., Martinsried, Deutschland) screening device which was attached to a test subject spending one night with and one night without the OA Narval (ResMed Germany Inc., Martinsried, Deutschland).

App functions

SnoreMonitorSleepLab Generally, the app recorded the snoring well. However, it was unable to distinguish between snoring noises and other noises resulting in the highest standard deviation in the second set-up (Table 2; Fig. 2). Moreover, the calibration function that helps the app to tell noises such as the rustling of the sheets apart from snoring is difficult to adjust.

Quit Snoring The app proved to work quite well. The "dynamic threshold" function makes it easy to use. It worked adequately in the first two set-ups (Figs. 1 and 2; Tables 1 and 2). But it seems to become too

Table 1 App results in soundproof environment

App	Device	Mean	*N*	Standard deviation
Sleep lab	iPhone1	601,33	6	1,966
	iPhone2	601,67	6	2,251
	iPad mini	600,00	6	0,000
	iPad	589,50	6	9,854
	Total amount	598,13	24	7,024
Quit Snoring	iPhone1	609,17	6	7,548
	iPhone2	599,67	6	1,211
	iPad mini	600,83	6	1,472
	iPad	600,33	6	0,516
	total amount	602,50	24	5,373
Snore Spectrum	iPhone1	614,83	6	16,376
	iPhone2	602,33	6	3,011
	iPad mini	594,67	6	6,861
	iPad	600,83	6	1,329
	Total amount	603,17	24	11,262

sensitive when the test subject does not snore resulting in higher outcomes than expected in the third set-up (Fig. 3). The graphic summary is quite good and allows the user to interpret the night's snoring results at one glance (Figs. 4 and 5).

Snore Spectrum The app worked just as well as the former two—with the same limitations regarding the distinction between snoring noises and other sounds. However, occasionally, it has not been available in the App Store. It is important to note that apps are no medical devices. There is no guarantee as to their availability.

Results

The boxplot in Fig. 1 and Table 1 show that all three apps monitor and record snoring noises well as long as they are used in a soundproof environment. In a real-life environment with various disturbing noises, Fig. 2 and Table 2 show that the applications have problems to distinguish between snoring sounds and other noises in the bedroom or close by. Moreover, the performance of the apps also differed from each other depending on the mobile device they were used on. In the third test set-up, Fig. 3 illustrates that the results of the apps did not correspond with the ApneaLink Plus (ResMed Germany Inc., Martinsried, Deutschland) screening device. Some of the apps (and mobile devices they were running on) showed

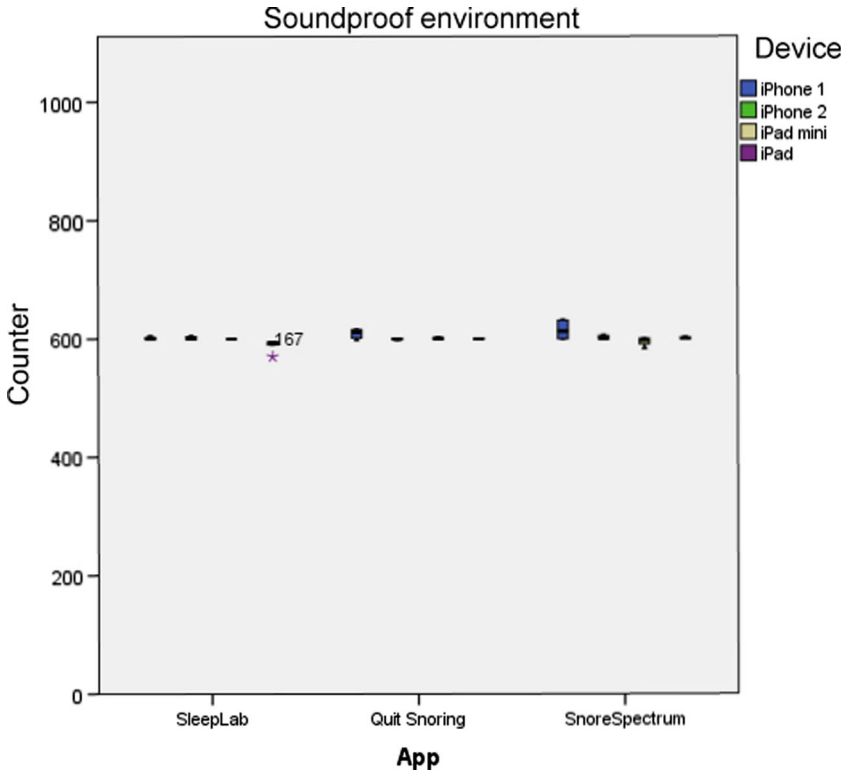

Fig. 1 App results in soundproof environment (SPSS)

Table 2 App results in real-life environment with various disturbing noises

App	Device	Mean	N	Standard deviation
SleepLab	iPhone1	738,50	6	163,979
	iPhone2	655,00	6	26,510
	iPad mini	713,83	6	122,809
	iPad	628,33	6	31,652
	Total amount	683,92	24	107,376
Quit Snoring	iPhone1	684,50	6	81,64
	iPhone2	624,33	6	4,676
	iPad mini	630,17	6	6,616
	iPad	630,50	6	9,203
	Total amount	642,38	24	45,882
SnoreSpectrum	iPhone1	628,78	9	14,255
	iPhone2	654,43	7	17,728
	iPad mini	622,71	7	9,878
	iPad	622,57	7	11,788
	Total amount	631,90	30	18,355

rather strong variations. Even though the count was never congruent with the results of the ApneaLink Plus screening device, the apps did show the same tendency which Quit Snoring visualized well enough (Figs. 4 and 5).

Conclusion

This research suggests that all three apps can be integrated into therapy—but with caution. The data collected by the apps is of different value to the work of practitioners: The audio recordings are generally good. Analyzing and drawing conclusions from the recordings is the difficult part. The reproducibility of the data is fairly poor as the results of the various apps do not only differ from each other but also strongly depend on the mobile device the apps are used on. Thus, the apps are not reliable and can certainly not replace the common diagnostic standard. However, they can tell patient and practitioner if the patient snores and roughly how much. So far, the apps are indeed useful as a follow-up tool for patients. Especially singles could use them who do not know if their snoring has

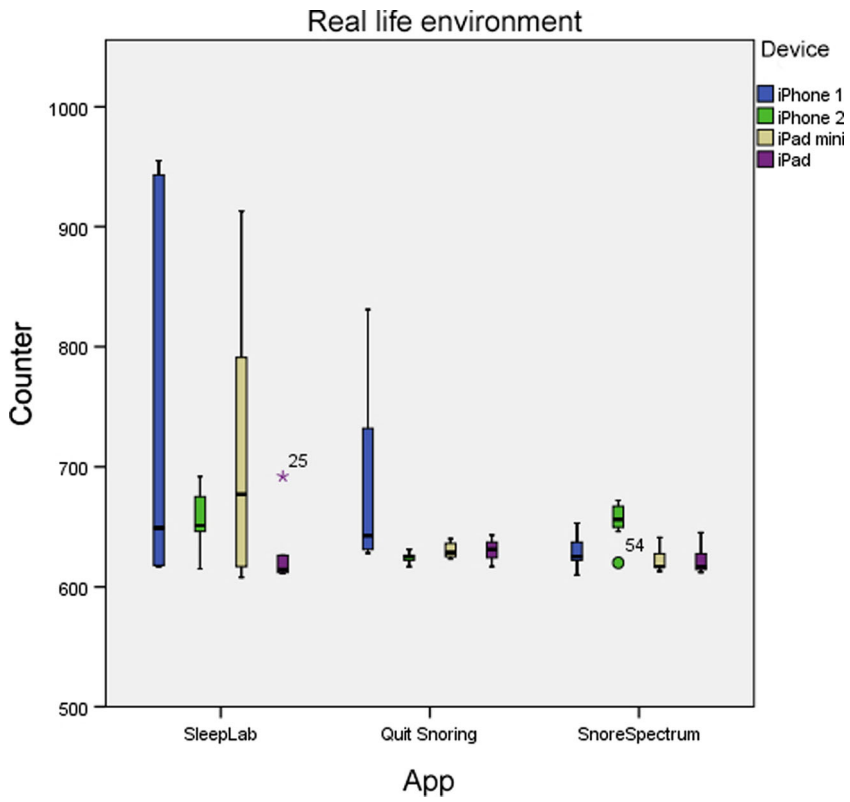

Fig. 2 App results in real-life environment with various disturbing noises (SPSS)

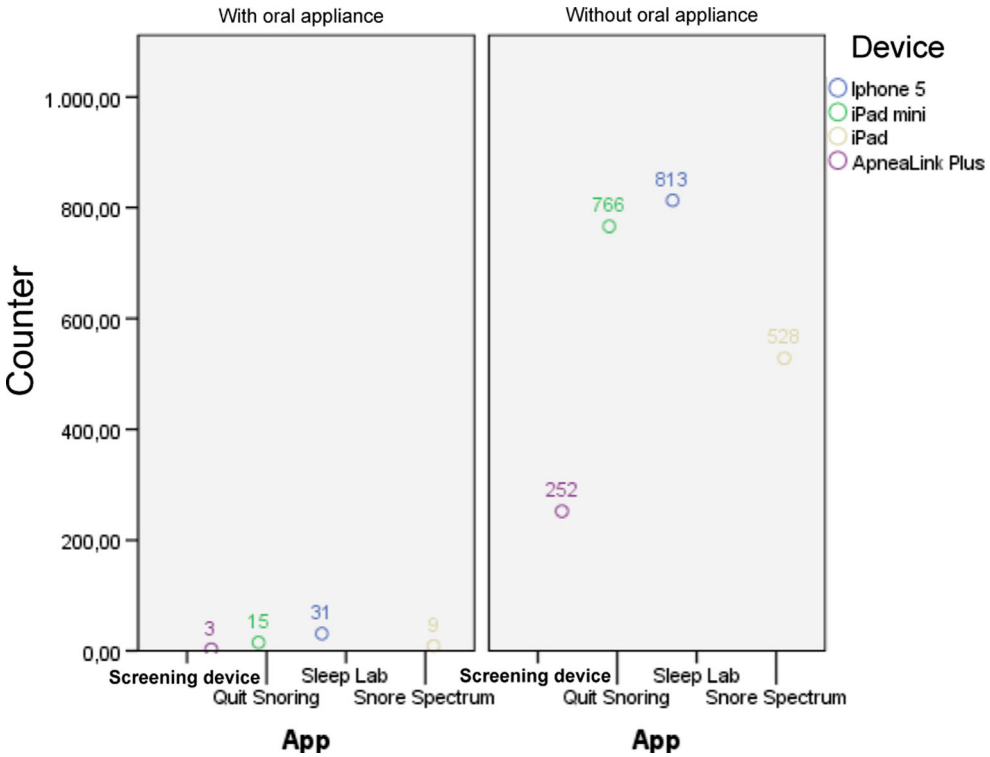

Fig. 3 Comparison between the apps and the ApneaLink Plus (ResMed Germany Inc., Martinsried, Deutschland) screening device (SPSS)

improved with an OA and do not have anybody to ask. Moreover, as practitioner and patient try to improve the patient's sleep behavior over the course of many nights by changing the patient's routine and adapting

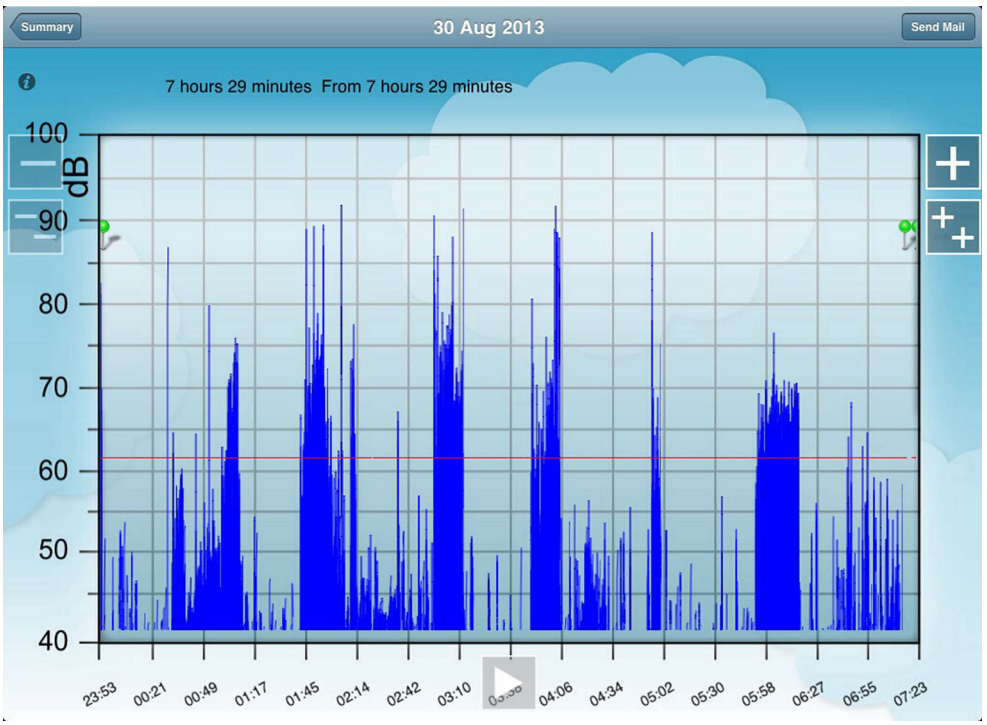

Fig. 4 Quit snoring screenshot of the proband's night without the oral appliance

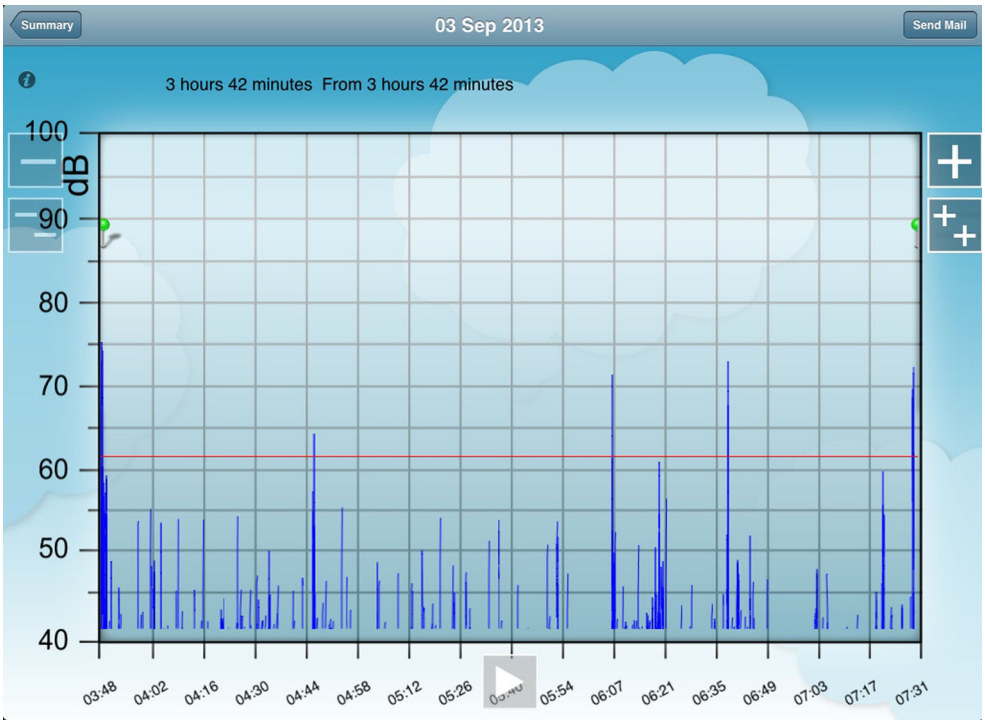

Fig. 5 Quit snoring screenshot of the proband's night with the oral appliance

the OA, the information provided by an app might even be more detailed than the testimonies of sleeping partners. The information could be made more reliable by integrating a questionnaire for monitoring purposes like the "Calgary sleep apnea quality of life index" [3] into the monitoring process. Other questionnaires like the "Berlin Questionnaire" [8] could be used in apps for screening to identify patients at risk.

Although the telemedical analysis in this study with *Snore Check* failed, technically it can easily be done. In sleep medicine, telemedicine is already put to use to transfer polysomnography (PSG) data from small hospitals directly to specialized centers [9, 10].

In the future, home-based sleep monitoring devices connected to smartphones might change the importance of home-based sleep monitoring [11]. Gadgets like Fitbit (Fitbit Inc., San Francisco, CA, USA) which can track activity [12] or ZEO (ZEO Inc., Newton, MA, USA) which collects electroencephalography (EEG) data [13, 14] can be connected to smartphones. Once the reliability of the data generated by gadgets and apps is (scientifically) proven, they could be brought together to build small home-based sleep laboratories and transfer data directly to the practitioner.

It is important to note that the more apps we integrate into our daily routine, the more we have to discuss if governance and a legal framework are needed [15].

So far, the apps on the market are not accurate enough to play a big role in therapy. However, they can be a helpful addition and might play a big role in the future.

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