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MAIN ARTICLE

Smartphone apps for snoring

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Abstract

Objective: To identify and systematically evaluate user-friendly smartphone snoring apps.

Methods: The Apple iTunes app store was searched for snoring apps that allow recording and playback. Snoring apps were downloaded, evaluated and rated independently by four authors. Two patients underwent polysomnography, and the data were compared with simultaneous snoring app recordings, and one patient used the snoring app at home.

Results: Of 126 snoring apps, 13 met the inclusion and exclusion criteria. The most critical app feature was the ability to graphically display the snoring events. The Quit Snoring app received the highest overall rating. When this app's recordings were compared with in-laboratory polysomnography data, app snoring sensitivities ranged from 64 to 96 per cent, and snoring positive predictive values ranged from 93 to 96 per cent. A chronic snorer used the app nightly for one month and tracked medical interventions. Snoring decreased from 200 to 10 snores per hour, and bed partner snoring complaint scores decreased from 9 to 2 (on a 0–10 scale).

Conclusion: Select smartphone apps are user-friendly for recording and playing back snoring sounds. Preliminary comparison of more than 1500 individual snores demonstrates the potential clinical utility of such apps; however, further validation testing is recommended.

Key words: Smartphone; Mobile Apps; Snoring; Respiratory Sounds; Treatment

Introduction

Snoring is a sign of partial airway obstruction. Snoring commonly occurs during oral breathing; however, in some it can occur during both oral and nasal breathing, or exclusively during nasal breathing.[1] The simple act of changing from upright to supine positions is known to narrow the airway by 33 per cent overall and by 76 per cent at the nasal minimal cross-sectional area.[2] When combined with tissue relaxation during sleep, this narrowing could predispose patients to snoring. Although different nasal factors (e.g. nasal septal deviations, inferior turbinate sizes[3] and polyps) can contribute, the most common source of snoring is palatal flutter during oral breathing.[4] Snorers are often unaware of their snoring until informed of it by their bed partners.

Smartphone snoring apps (mobile device applications) have been designed to record snoring, measure the hourly or nightly frequency and noise intensity of snoring, and even allow for documentation to track the effect of interventions (such as positional therapy, myofunctional therapy,[5] nasopharyngeal airway stenting devices,[6] oral appliances or surgery). It is the authors' experience that some patients bring their recordings to clinic visits to play back the audio file as proof of snoring.

To date, there are very few publications describing smartphones as potentially useful clinical tools in the assessment of snoring. Currently, computer software programmers develop these smartphone snoring apps, often with minimal involvement of sleep medicine practitioners in the development process. This article is perhaps a necessary first step to establish a new standard in the evaluation and development of these smartphone apps. This study aimed to identify and systematically evaluate publically available, user-friendly smartphone snoring apps that record and play back snoring.

Materials and methods

A literature search was performed of studies included (from inception to 4 November 2014) in the following databases: Medline, Scopus, Web of Science and the

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Cochrane library. This involved a search using combinations of the Medical Subject Heading terms 'Cellular Phone' and 'Snoring', and the keywords 'ap*', 'app', 'apps', 'applications', 'smartphone', 'snor*', 'snore', 'snores' and 'snoring'.

There were only four relevant results. The first article described the development of an unconstrained snoring detection technique that could be integrated into a smartphone application.[7] The second article used a smartphone to monitor sound in order to quantify snoring and diagnose obstructive sleep apnoea.[8] The third article described a bone conduction microphone to record snoring sounds as a part of telemonitoring for sleep apnoea.[9] Finally, the fourth article was an editorial[10] commenting on the study by Nakano *et al.*[8]

A search on Google for 'snore app' returned 12 400 results and a search for 'snoring app' returned 23 200 results. Over half of the top 10 listed webpage 'hits' mentioned smartphone apps that were available to download at the Apple iTunes app store.

In phase 1 of the study, iTunes was searched for snoring apps that allow for recording and playback. Next, the authors applied the following inclusion criteria: the snoring app needed to have the ability to record audio, graphically display data and store data for multiple nights. Apps were excluded if: they did not meet the three inclusion criteria, they were free ('lite') versions of a duplicate paid version, or the audio recordings were difficult to play back or could not be played back.

In phase 2, the snoring apps were downloaded, evaluated and rated independently by four authors.

In phase 3, two patients underwent polysomnography with simultaneous snoring app recordings. After multiple distances were tested, it was concluded that 30 cm was the most accurate distance that the smartphone should be positioned from the patients. The threshold sensitivity feature of the app was set to 55 dB for the first subject. After a detailed analysis, the decision was made to set the sensitivity to 53 dB for the second subject. The app was started at the beginning (lights off) and stopped at the end (lights on/wake-up) of the attended, in-laboratory overnight polysomnography session. The smartphone app data were compared to the polysomnogram using the app graph, with second-by-second playback of the entire recording. More than 1500 individual snoring events were individually compared to the corresponding polysomnogram snores.

In phase 4, one patient prospectively used the snoring app at home over a one-month period.

Results

In phase 1 of the study, the iTunes search identified 91 apps with the term 'snore', 91 apps with the term 'snores' and 84 apps with the term 'snoring'. A total of 126 unique apps were identified; 48 of these apps (13 free and 35 paid apps) were potentially relevant and were downloaded (cost US$0.99–9.99 per app). After review, 13 snoring apps met the inclusion and exclusion criteria. The flow diagram is displayed in Figure 1.

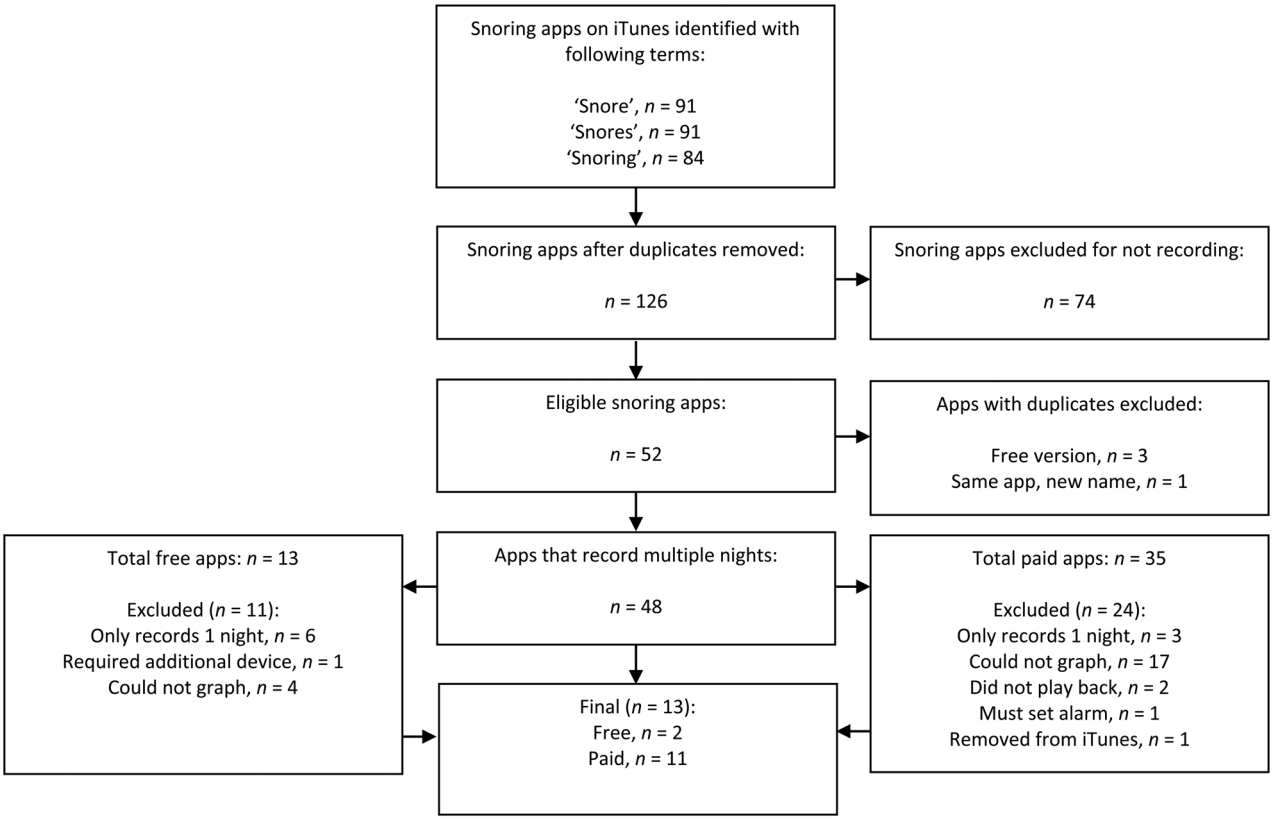

FIG. 1
Flow diagram for the snoring apps identified and evaluated. A total of 13 apps were included in the final analysis.

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In phase 2, 4 of the authors independently downloaded and rated the 13 snoring apps using a 5-point scale (the same scale used in iTunes). To decrease rating bias, the apps were evaluated in alphabetical order. The smartphone snoring app that received the highest overall rating was 'Quit Snoring' by Pointer Software Systems (Ramat Yishai, Israel). Table I summarises the evaluated smartphone apps' author rating and overall features. Analysis revealed that the most critical app feature was whether or not the user could zoom in to the snoring events on the graph in order to facilitate playback of the snoring sounds.

For phase 3, the Stanford Institutional Review Board approved Protocol 29914 to study smartphone apps with patients' polysomnography. The first patient's polysomnogram was reviewed by two authors (MC and MR). After independent scoring, the authors met and came to a consensus of 380 snores. The app's data demonstrated 344 snoring events at 55 dB. A review of the app's graphical display demonstrated that if the sensitivity were set to 53 dB, then 378 events would have been identified. The detailed, second-by-second evaluation of the smartphone graph with playback of the individual snoring events demonstrated that the snoring sensitivity was 95.5 per cent at 53 dB and 86.6 per cent at 55 dB, while the positive predictive value was 96.0 per cent at 53 dB and 95.6 per cent at 55 dB.

The second patient also underwent polysomnography with simultaneous smartphone snoring app recordings, with the sensitivity set to 53 dB. The detailed, second-by-second evaluation of the smartphone graphical display with playback of the individual snoring events demonstrated that 53 false positive sounds crossed the app's sound threshold (incorrectly counted by the app as a snoring event) due to noise caused by the subject moving after arousals, not snoring events. In this subject, with significantly more true snoring events captured by polysomnography, the snoring sensitivity (63.6 per cent) and positive predictive value (93.3 per cent) suffered compared to subject 1 (Table II). Figure 2 shows an example of a screenshot from the Quit Snoring app and the corresponding polysomnogram screenshot, demonstrating the start of a series of snoring events.

For phase 4, the Human Subject Research Division of the Stanford Institutional Review Board approved the at-home case study. The patient, a known 'heroic' snorer, was a 35-year-old, married male, with a body mass index of 32 kg/m^2. He recorded himself for 23 separate nights over a period of 1 month while sleeping alone. He documented routine behaviours (e.g. alcohol consumption, dietary habits and exercise) and medical interventions (e.g. oxymetazoline use, positional therapy, the use of two standard pillows, and the combined use of a wedge plus a standard pillow). Medical management was influenced by results reviewed each night, which helped to guide the patient's behaviours. This reduced snoring from 200 to 10 snores per hour.

TABLE I
SUMMARY OF EVALUATED SMARTPHONE SNORING APPS

Snoring app name*	Rating†	Snoring app features							
		Possible to simultaneously play back & view graph?	Possible to localise sound on graph?‡	Continuous playback (sec-by-sec)?	Delayed start option?	Recording sensitivity adjustable?	dB results given?	Snoring events (*n*) per night given?	Allows notes?	Option to e-mail or print data?
Quit Snoring	4.88	Y	Y	Y	Y	Y	Y	Y	Y	Y
SnoreMonitorSleepLab	3.88	Y	Y	Y	N	Y	N	Y	Y	Y
Night Spy – Do you snore…?	3.75	N	Y	N	Y	Y	N	Y	Y	N
iSleeping	3.50	Y	Y	Y	N	N	N	N	N	N
Sleep Talk Recorder	3.13	Y	Y	N	Y	Y	N	Y	Y	Y
Sleep Sounds Recorder Plus	3.00	Y	Y	N	Y	Y	N	Y	N	Y
SnoreLab	2.75	Y	Y	N	Y	N	N	N	N	N
Sleep snore/Apnea/talk Recorder	2.50	Y	N	Y	N	Y	N	N	N	N
Dream Talk Pro	2.50	Y	Y	N	Y	Y	N	Y	Y	Y
iRec – Dreams Recorder	2.25	N	N	N	Y	Y	N	Y	Y	N
Sleep Assess	2.13	Y	N	Y	N	N	N	N	N	N
SnoreSleep Inspector	2.13	N	N	N	Y	Y	Y	Y	N	Y
Silencium	1.50	Y	Y	Y	N	N	N	N	N	N

*Apps are listed in order of mean author rating. †Apps were rated independently by four authors, on a 0–5 scale. ‡One can click on the graph to view sound waveforms and hear the corresponding sounds. Sec = second; Y = yes; N = no

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TABLE II
IN-LABORATORY POLYSOMNOGRAPHY VERSUS SNORING APP FINDINGS

Subject number, sensitivity threshold setting	Total recording time (hours)	Total snores (*n*)		Snores per hour (*n*)		True positive snores on app (*n*)	False positive snores on app (*n*)	False negative snores on app (*n*)	App snoring sensitivity (%)	App snoring positive predictive value (%)
		App	PSG	App	PSG					
Subject 1, 53 dB	6.3	378	380	60.00	60.32	363	15	17	95.53	96.03
Subject 1, 55 dB	6.3	344	380	54.60	60.32	329	15	51	86.58	95.64
Subject 2, 53 dB	7.3	790	1158	108.22	158.63	737	53	421	63.64	93.29

PSG = polysomnography

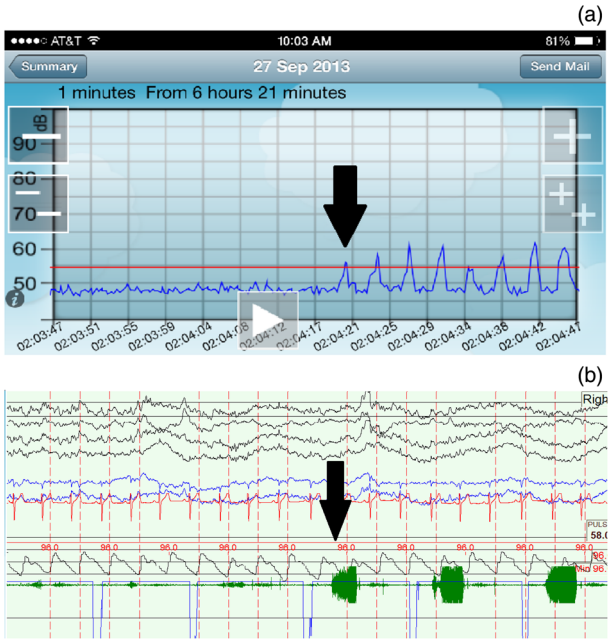

FIG. 2

Screenshots of (a) the Quit Snoring app and (b) the corresponding polysomnography snoring data. The large black arrows indicate the start of snoring. There is a characteristic waveform appearance of snoring sounds on the right half of the smartphone snoring app screenshot. The app's '+' and '−' features allow for zooming in and out, while the white arrow at the bottom of the app screenshot allows for audio playback. The Quit Snoring app screenshot is reproduced with permission from Pointer Software Systems.

It also improved the bed partner (spouse) snoring complaint visual analogue scale score, which decreased from 9 to 2 (0 = no snoring, 10 = snoring could be heard through a closed door) without weight loss or surgery.

Discussion

Smartphone apps that record, play back and graphically display snoring sounds can be potentially valuable tools for snoring patients and those who treat snoring. Such apps allow patients to assess the effects of behaviours and medical or surgical interventions. Snoring apps could also have clinical potential for physicians and dentists who treat snoring, as they provide objective data before and after interventions. For the two in-laboratory polysomnography patients, there was substantial agreement in the first patient and good agreement in the second patient when the snoring app's results were compared with the total number of snores detected on the polysomnogram (more than 1500 combined individual snores).

Although all 13 snoring apps reviewed provide playback of the recording with graphic representation, only 6 of them allow the user to view the graph, listen to the sound and then zoom in to the area of interest. For most apps, it is possible to e-mail or print data from the recordings, which could be potentially useful for healthcare practitioners. Very few apps provide decibel levels for the snoring sounds.

An important feature of these smartphone apps is the ability to adjust the recording threshold sensitivities, thereby allowing correction for background noises. The use of snoring apps where there is a noisy background can cause the app to score the non-snoring noises that cross the sound threshold as a snoring event, which will falsely increase the number of total events. Conversely, a snoring sound produced while the person is facing away from the smartphone may not register as a snoring event because the sound threshold may not be reached. Another consideration is that if a patient's bed partner snores, and the app is used in the same bedroom, then it will potentially count the bed partner's snoring as well. For optimal data, the patients should ideally sleep alone, in a room with low environmental noise. Table III outlines the suggested set-up to improve recording accuracy.

A noteworthy result from this study was that app snoring positive predictive values and especially app snoring sensitivities fell in the second patient, with about twice the snoring frequency compared to the first patient at the same decibel threshold. However, one cannot exclude measurement and protocol differences between these patients as the true cause of such a difference. Regardless, the app's snoring positive predictive value remained excellent among both subjects (range, 93.3–96.0 per cent). Further studies are needed to validate snoring apps, using larger sample sizes and multiple thresholds.

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TABLE III
STEPS FOR RECORDING WITH A SMARTPHONE SNORING APP

1. Plug in smartphone to an AC outlet to avoid draining battery
2. Place smartphone on stand with microphone towards user's face
3. The 1st time, smartphone should be calibrated; user should create a few snoring sounds & play back sounds to ensure they are detected. Move smartphone closer if necessary to ensure snoring is detected. Sensitivity may also be adjusted
4. Once calibrated, select delayed recording or start recording immediately
5. Record overnight, then stop recording in morning
6. Review number of snoring events & play back graphs & snoring sounds. Snoring events typically have sawtooth appearance. Zoom into graph for better assessment
7. Scroll through recording; make note of how often app picked up background noise & ensure that events documented are actually snoring events. Ensure that any snoring events crossed the threshold set previously & were detected, otherwise phone may need to be moved closer or sensitivity recalibrated
8. Click on function to write notes, & annotate any interventions that may have contributed to snoring overnight
9. Record multiple nights & compare results

Note: sleeping alone, in a room with low environmental noise, will help improve reporting accuracy of snoring events. AC = alternating current

- **Select smartphone snoring apps can be useful for recording and playing back snoring sounds**
- **The most critical app feature is the ability to graphically display overnight events, with a zooming function for second-by-second analysis**
- **Comparison with in-laboratory polysomnography data demonstrated excellent positive predictive values for app snoring detection (93.3–96.0 per cent)**
- **This study demonstrates the potential utility of smartphone apps**

Another key component of these snoring apps is the ability to graphically display and play back the snoring sounds. The zoom function facilitates analysis of snoring events. Without this function, the patient or person treating the snoring would need to listen to the entire night's sound recording or sort through multiple sets of sound files. The Quit Snoring app and SnoreMonitorSleepLab app both have a graphic user platform that allows for zooming, to the point where users can view the waveform of the snoring events as they occur, second by second. Although snoring apps hold great promise for future incorporation as an objective snoring assessment tool, we caution against relying strictly on such apps' data, snore scores or results, as many factors may affect the results, including the positioning of the smartphone microphone, calibration of the sound thresholds, environmental noises and bed partner snoring.

This study has limitations. First, only iTunes apps were downloaded and included. Nevertheless, this is the largest smartphone app platform.[11] This paper aimed to introduce smartphone apps to the medical community using scientific research methodology, not to comprehensively review all smartphone platforms, as this would involve additional significant time and expense. Second, the publically available smartphone snoring apps cannot rule out obstructive sleep apnoea. There is currently no widely available, validated app with that capability. Third, one app, 'Snore Spectrum', was initially available and downloaded. This app then was removed from iTunes and excluded from this review, before being subsequently re-added to iTunes; therefore, it did not make it into this review. Lastly, this paper included only two in-laboratory polysomnography patients and only one case study. However, the review of each individual snoring sound identified on polysomnography, with detailed playback of 6–8 hours (with pausing, counting and documenting) of app recording per individual, and with individual analysis of over 1500 snoring events on both the polysomnogram and the snoring app, was a very laborious process. Repeating this process for additional patients is beyond the scope of this study.

Conclusion

Select smartphone apps are user-friendly for recording and playing back snoring sounds. Preliminary comparison of more than 1500 individual snores demonstrates potential clinical utility; however, further validation testing is recommended.

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