Auris Nasus Larynx xxx (2017) xxx–xxx

Contents lists available at ScienceDirect

Auris Nasus Larynx

journal homepage: www.elsevier.com/locate/anl

Comparison of snoring sounds between natural and drug-induced sleep recorded using a smartphone☆

Soo Kweon Koo [a,*], Soon Bok Kwon [b], Ji Seung Moon [a], Sang Hoon Lee [a], Ho Byung Lee [a], Sang Jun Lee [c]

[a] Department of Otorhinolaryngology, Busan Saint Mary's Hospital, Busan, South Korea
[b] Department of Language and Information, College of Humanities, Pusan National University, South Korea
[c] Department of Otorhinolaryngology, Sleep laboratory, Busan Saint Mary's Hospital, Busan, South Korea

ARTICLE INFO

Article history:
Received 12 May 2017
Accepted 5 September 2017
Available online xxx

Keywords:
Sleep apnea syndrome
Diagnosis
Snoring
Acoustics

ABSTRACT

Objectives: Snoring is an important clinical feature of obstructive sleep apnea (OSA), and recent studies suggest that the acoustic quality of snoring sounds is markedly different in drug-induced sleep compared with natural sleep. However, considering differences in sound recording methods and analysis parameters, further studies are required. This study explored whether acoustic analysis of drug-induced sleep is useful as a screening test that reflects the characteristics of natural sleep in snoring patients.

Subjects and materials: The snoring sounds of 30 male subjects (mean age = 41.8 years) were recorded using a smartphone during natural and induced sleep, with the site of vibration noted during drug-induced sleep endoscopy (DISE); then, we compared the sound intensity (dB), formant frequencies, and spectrograms of snoring sounds.

Results: Regarding the intensity of snoring sounds, there were minor differences within the retrolingual level obstruction group, but there was no significant difference between natural and induced sleep at either obstruction site. There was no significant difference in the F_1 and F_2 formant frequencies of snoring sounds between natural sleep and induced sleep at either obstruction site. Compared with natural sleep, induced sleep was slightly more irregular, with a stronger intensity on the spectrogram, but the spectrograms showed the same pattern at both obstruction sites.

Conclusion: Although further studies are required, the spectrograms and formant frequencies of the snoring sounds of induced sleep did not differ significantly from those of natural sleep, and may be used as a screening test that reflects the characteristics of natural sleep according to the obstruction site.

1. Introduction

Snoring is caused by the vibration of soft tissues secondary to turbulent airflow through a narrow oropharynx in the upper airway, and is an important clinical feature of obstructive sleep apnea (OSA) [1]. In addition, snoring may be a useful marker when screening for obstructive sleep disordered breathing (SDB). In the 1980s, several studies on snoring were performed, including acoustic analyses by Takenosuke Ikematsu and David

☆ This research protocol was reviewed and approved after deliberation by the Busan Saint Mary's Hospital Institutional Review Board (IRB).

* Corresponding author at: Department Otorhinolaryngology-Head and Neck Surgery, Busan Saint Mary's Hospital, 538-41, Yongho-dong, Nam-gu, Busan, South Korea. Fax: +82 51 956 1956.
E-mail address: koosookweon@naver.com (S.K. Koo).

http://dx.doi.org/10.1016/j.anl.2017.09.005
0385-8146/

Fairbanks [2]. For the past 20 years, Ben Israel [3] and many other researchers have attempted to perform phonetic analyses of various snoring events.

Drug-induced sleep endoscopy (DISE), designed by Croft and Pringle [4] in 1991, can be used to observe the occlusion site during sleep, which allows for the analysis of snoring sounds according to occlusion site. However, DISE requires the patient to be sedated until snoring occurs. Recent studies suggest that the acoustic quality of snoring is markedly different between drug-induced and natural sleep, but there are differences according to the sound recording method and analysis parameters. Thus, further studies are required using a consistent recording technique [1]. The majority of snoring sounds are recorded using relatively expensive laboratory equipment, which gives results somewhat different to the snoring sounds that occur in the real-life sleep environment. To address this, smartphone-based sleep measurement techniques have been developed, which take advantage of advances in telemedicine [5–7]. The purpose of this study was to analyze and compare snoring sounds, recorded with a smartphone, between natural and induced sleep according to the obstruction site and to explore whether acoustic analysis of drug-induced sleep is a useful screening test of snoring patients.

2. Materials and methods

2.1. Materials

Patients complaining of snoring and OSA, and who underwent DISE and overnight polysomnography (PSG) at our hospital from January 2016 to January 2017, were enrolled. The snoring sounds of 30 male subjects (mean age = 41.8 years) were recorded using a smartphone (Samsung Galaxy Grand 2 SM-G710K; Samsung Electronics Ltd., Suwon, Korea) during natural and induced sleep, with the site of vibration noted during DISE. Natural sleep was recorded during overnight PSG, while induced sleep was recorded during DISE. Among the subjects, 15 were classified as having a retropalatal level obstruction (mean age = 40.8 years) and 15 as having a retrolingual level obstruction (mean age = 42.8 years); all patients had OSA (Table 1). We excluded females because the effect of sex on the acoustic properties of snoring sounds remains unclear. The research protocol was reviewed and approved by our institutional review board (BSM2017-05).

2.2. Recording of snoring sounds and acoustic analysis

During PSG and DISE, we recorded snoring sounds using a smartphone (Samsung Galaxy Grand 2 SM-G710K; Samsung Electronics Ltd., Suwon, Korea). The smartphone was placed above the shoulder (within arm's reach) of each subject just before he fell asleep during PSG and DISE. However, there was no special restriction with respect to placing the phone on the bed [4,5]. We made three recordings and, from these, selected the first snoring sounds made immediately after an OSA event during PSG and DISE. Each recording was a minimum of 10 s in length [6]. The amr (adaptive multi-rate) file recorded on the smartphone was converted into mp3 file and analyzed in Praat software (ver. 5.2.16). The sampling rate was converted to 44,100 Hz and analyzed. We measured the sound intensity (dB), the difference between the spectrogram and the formant frequencies of natural and induced sleep.

Table 1
Demographic characteristics of the patients.

	Retropalatal	Retrolingual	Total
Number of patients	15	15	30
Mean age of patients (Mean ± SD)	40.8 ± 10.8	42.8 ± 13.7	41.8 ± 12.3
Mean BMI (Mean ± SD, kg/m^2)	26.8 ± 3.4	27.7 ± 5.1	27.3 ± 4.3
Mean AHI (Mean ± SD, events/h)	35.0 ± 23.7	32.0 ± 21.9	33.5 ± 22.8
Mean lowest SaO_2 (Mean ± SD, %)	77.9 ± 12.4	82.0 ± 8.9	78.0 ± 10.7

Retropalatal, region posterior to the soft palate; Retrolingual, region of the pharynx posterior to the vertical portion of the tongue; BMI, body mass index; AHI; apnea-hypopnea index; SaO_2, oxygen saturation; SD, standard deviation.

2.3. Statistical analysis

We evaluated differences in snoring sounds between natural and induced sleep according to obstruction level. Independent sample t tests were used and all statistical tests were performed using SPSS software (ver. 18.0; IBM Corp.,Armonk, NY, USA). A p value of <0.05 was considered to indicate statistical significance

3. Results

3.1. Intensity (dB) of snoring sounds

In the retropalatal level obstruction group, the mean intensity of the snoring sounds was 67.0 ± 7.7 dB during natural sleep and 66.9 ± 7.1 dB during induced sleep (p = 0.980). In the retrolingual level obstruction group, the mean intensity of the snoring sounds was 67.4 ± 6.0 dB during natural sleep and 68.6 ± 6.4 dB during induced sleep (p = 0.600). Regarding the intensity of snoring sounds, there were minor differences within the retrolingual level obstruction group, but there was no significant difference between natural and induced sleep at either obstruction site (Tables 2 and 3).

3.2. Formant frequency

Within the retropalatal level obstruction group, F_1 was 730.3 ± 224.7 Hz during natural sleep and 596.4 ± 214.5 Hz during induced sleep (p = 0.106); and F_2 was 1788.0 ± 490.8 Hz during natural sleep and 1559.7 ± 364.8 Hz in induced sleep (p = 0.159). In the retrolingual level obstruction group, F_1 was 607.1 ± 209.6 Hz during natural sleep and 701.5 ± 190.5 Hz during induced sleep (p = 0.208); and F_2 was 1880.5 ± 308.0 Hz during natural sleep and 1842.1 ± 490.6 Hz during induced sleep (p = 0.799). There was no significant difference in the F_1 and F_2 formant frequencies of snoring sounds between natural sleep and induced sleep at either obstruction site (Tables 2 and 3).

3.3. Spectrogram

Compared with natural sleep, induced sleep within the retropalatal level obstruction group was slightly more irregular

Please cite this article in press as: Koo SK, et al. Comparison of snoring sounds between natural and drug-induced sleep recorded using a smartphone. Auris Nasus Larynx (2017), http://dx.doi.org/10.1016/j.anl.2017.09.005