

## Analysis of snoring sound by psychoacoustic parameters

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**Abstract** The analysis of snoring sounds has been in focus for the past two decades. Conventional approaches by fast Fourier transformation face various limitations and demonstrate the necessity for alternative methods of investigation. Psychoacoustic analyses which are common for environmental noise analyses propose a potential approach. The present study investigates the psychoacoustic qualities (loudness, sharpness, roughness) of three different real snoring sounds (primary snoring, PS; Upper airway resistance syndrome, UARS; obstructive sleep apnea syndrome, OSAS) and their alterations under increasing, artificially created sound pressure levels (SPL) from 60–85 dB. PS and UARS were detected to obtain a greater loudness as well as a higher increase under increasing SPL than OSAS. The sharpness was higher in PS and UARS, remaining stable under rising SPL compared to OSAS. The intensities of roughness were at higher levels for PS compared to UARS and OSAS, with an increase of all snoring sounds under rising SPL. By merging the psychoacoustic qualities, an individual acoustic fingerprint can be created to differentiate the three types

of snoring. A potential application is proposed for the analysis of snoring sounds during polysomnography as well as for an adequate evaluation of the annoyance by snoring sounds.

**Keywords** Snoring · Analysis · Psychoacoustic · OSAS · UARS

### Introduction

The acoustical analysis of snoring sounds has been in focus of research during the last two decades [1, 6, 8–12, 17, 24, 26–28]. According to several authors, it seems possible to distinguish between different types of snoring like palatal or tongue base snoring. The vast majority of studies perform a frequency analysis of the investigated snoring sounds by fast Fourier transformation (FFT). By means of FFT, the mean and peak frequencies as well as power spectral bands can be obtained. Despite numerous efforts, a sufficient determination of snoring sounds has not been developed yet. Snoring sounds, which obviously sound different to the listener, might reveal a similar power spectrum during frequency analysis. This specific flaw remains still a major problem for the acoustic evaluation of snoring.

Apart from the regular FFT analysis, the determination of psychoacoustic parameters is in use, especially for the investigation of environmental sounds [14–16, 20–23, 29, 33]. By means of psychoacoustic analysis, the perceptual aspects of noise like annoyance can be determined.

The aim of the present study was to evaluate the application of psychoacoustic parameters for the analysis of snoring sounds.

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## Materials and methods

### Recording of snoring sounds

Three snoring sounds which were subject to investigation were recorded during routine polysomnography in male patients with suspected sleep disordered breathing. The aim of the study was not to investigate the psychoacoustic properties of a large population sample, but to establish a novel technique of investigation by means of psychoacoustic analysis. Therefore, only three snoring samples, which were clearly acoustically different, were elected. Snoring samples were chosen on base of the acoustical appearance and polysomnographic results. Sample 1 (primary snoring, PS) was from a 45-year-old patient with primary snoring without apnoeic events (AHI: 1.2; Sao2 mean: 98.4%; oesophageal pressure (cm H<sub>2</sub>O): at specific snoring episode, -5.1; mean, -2.3). Sample 2 (upper airway resistance syndrome snoring, UARS) was taken from a 47-year-old patient with the clinical diagnosis of an upper airway resistance syndrome (AHI: 3.7; Sao2 mean: 98.2%; oesophageal pressure (cm H<sub>2</sub>O): at specific snoring episode, -20.4; mean, -10.3). The authors are aware that the UARS is no longer included in the new ICSD. Nevertheless, the snoring sample was chosen as there is a difference between PS and snoring during an obstructive sleep apnea syndrome in terms of acoustical appearance and pathogenesis. Sample 3 (obstructive sleep apnea snoring, OSAS) was chosen from a 46-year-old patient with an obstructive sleep apnea syndrome (AHI: 43.5; Sao2 mean: 86.4%; oesophageal pressure (cm H<sub>2</sub>O): at specific snoring episode, -33.7; mean, -20.8). All three snoring samples were original snoring sounds of real patient recordings. Sound recordings were performed by an air coupled dual-diaphragm condenser microphone (C3 Behringer, Willich, Germany) which was placed 30 cm in front of the patients' mouths. A digital mixer was used for recording the snoring sounds (Phonic Helix Board FW 18 MKII Compact Mixer, Phonic Cooperation, Tampa, FL, USA). Data acquisition was performed by Adobe Audition II (Adobe Systems, München, Germany).

### Creation of snoring samples

All the three snoring samples were amplified according to their peak sound pressure levels [ $L_{\text{peak}}$  (dB) SPL (sound pressure level)]. The peaks were amplified to the levels 60, 65, 70, 75, 80 and 85 dB without filtering the specific frequencies. Amplification

was performed by the software programme Adobe Audition II.

### Frequency analysis

Frequency analysis was performed by Adobe Audition II. The peak intensities of the specific snoring sample were detected (Fig. 1a, b, c) at all different levels of  $L_{\text{peak}}$  (60–85 dB).

### Psychoacoustic analysis

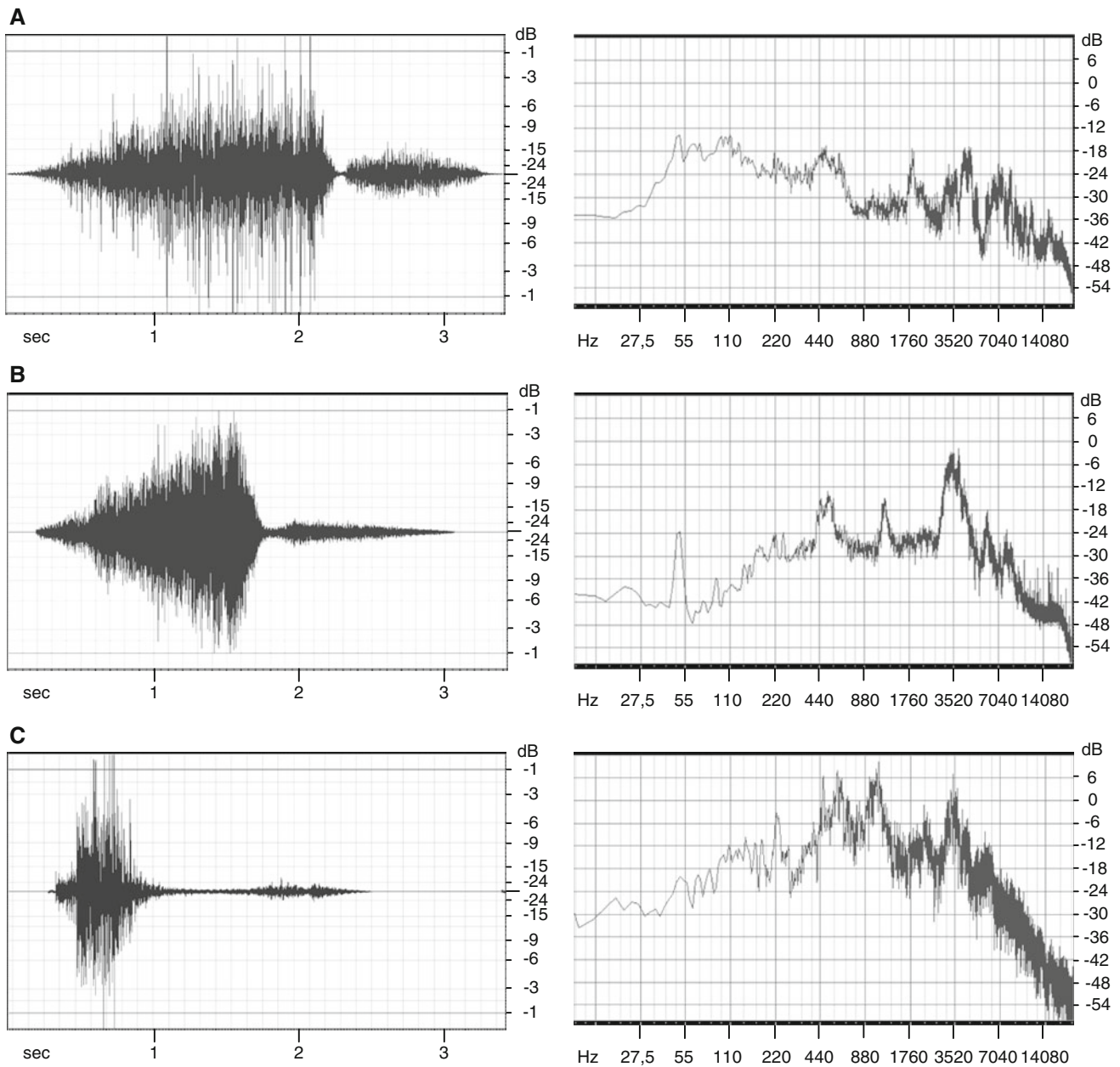
Psychoacoustic analysis was performed by VIPER V 3.14 (Visual Perception of Audio Signals, CORTEX INSTRUMENTS GmbH). The parameters "loudness", "roughness" and "sharpness" were calculated of the specific snoring sample under increasing SPLs.

### Loudness

The parameter "loudness" describes the hearing perception of a specific sound pressure as the magnitude of an auditory sensation. The unit of loudness  $N$  is sone. The loudness level  $L_N$  of 40 phon (narrowband noise centred at 1 kHz) with a sound pressure level of 40 dB equals 1 sone. A 10-phon gain in the loudness level  $L_N$  doubles the loudness  $N$ . The loudness level and the loudness were analysed in accordance with DIN 45631 and ISO 532 B respectively [4]: the time interval was fixed as 2 ms. The high temporal resolution corresponds to the temporal resolution of the human ear. For each time interval, the sound levels in 20 approximated critical bands were computed using a third octave filter bank. The critical band levels were weighted according to the transfer from the free sound field through the outer- and middle ear. By a power law relationship, the weighted critical band levels were transformed into specific loudness values  $N'$ . Loudness  $N$  was calculated by integrating the specific loudness  $N'$  [5].

### Roughness

Fast modulation (between 20 and 300 Hz) in sounds is perceived as roughness, e.g. rough voice, noise of a flying beetle, electric motor or piston engine. The maximum of the roughness for a 1-kHz tone is reached with modulating frequencies by 70 Hz. The unit of roughness is asper (1 asper = 100 cA), referenced to a 1 kHz tone at 60 dB sound pressure level that is frequency-modulated by a 70-Hz sine wave with a modulation factor of 1 (100%). The instances of roughness were calculated in accordance with a model of Aures [2].



**Fig. 1** Properties of snoring sound samples. **a** Snoring sample 1 (PS) represents a snoring episode with predominately deep frequency spectra with a peak intensity at 100 Hz. **b** Snoring sample 2 (UARS) represents a snoring episode with a high frequency spectrum with a peak

intensity at 3,500 Hz. **c** Snoring sample 3 (OSAS) represents a snoring episode with spectra at 500 and 3,500 Hz. *Left row* recording track, *axis* time (sec), intensity (dB); *right row* FFT, *axis* frequency (Hz), sound pressure (dB)

### Sharpness

The parameter “sharpness” describes the perception of timbre (tone colour), depending on the spectral envelope of the sound. The sharper a noise sounds, the more the percentage of high frequencies in the sound grows. Perceived sharpness is proportional to spectral centre of gravity. Sharpness is measured in acum referenced to narrowband noise centred at 1 kHz with a sound pressure level of 60 dB.

### Statistical analysis

Statistical analyses were performed by SPSS 18 (Chicago, Ill, USA). The Mann–Whitney *U* test was performed where appropriate. A probability level of 5% was considered as significant. Approximately, 30,000 samples per noise were statistically analysed. It needs to be mentioned that even minimal differences between the specific noise samples or the specific SPLs turn significant with such a high amount

**Table 1** Statistical analysis of the psychoacoustic parameters

Parameter	Noise	Sound pressure level (dB)																	
		60 dB			65 dB			70 dB			75 dB			80 dB			85 dB		
		MD	M	SD	MD	M	SD	MD	M	SD	MD	M	SD	MD	M	SD	MD	M	SD
Sharpness	PS	1.66	1.22	0.85	1.67	1.23	0.83	1.68	1.26	0.79	1.66	1.27	0.77	1.82	1.92	0.33	1.82	1.95	0.37
	UARS	2.03	1.50	0.91	2.02	1.50	0.91	1.98	1.47	0.88	1.96	1.51	0.81	2.04	2.05	0.14	1.89	1.45	0.85
	OSAS	0.01	0.68	0.79	0.05	0.76	0.83	0.11	0.80	0.85	0.22	0.82	0.85	0.30	0.83	0.85	0.34	0.83	0.85
Roughness	PS	15.06	28.07	30.53	19.13	33.81	35.07	25.76	43.28	41.87	32.98	52.84	48.44	39.15	59.41	51.79	46.72	66.09	53.24
	UARS	5.50	7.18	6.62	9.05	9.23	7.67	20.06	16.02	10.69	24.47	19.34	12.06	29.92	24.68	14.53	36.33	31.16	18.11
	OSAS	0.10	6.68	14.15	0.34	10.20	18.80	1.00	14.35	24.09	2.95	19.87	32.15	7.36	27.02	45.61	12.28	29.52	51.74
Loudness	PS	1.77	2.20	2.19	2.59	3.00	2.88	4.61	4.88	4.45	7.93	8.18	7.23	11.95	12.11	10.30	21.15	21.13	17.42
	UARS	1.59	2.57	2.85	2.08	3.19	3.45	4.09	5.62	5.70	5.49	7.31	7.21	8.97	11.50	11.01	16.20	20.11	18.88
	OSAS	0.00	0.80	1.82	0.00	1.32	2.74	0.03	2.06	3.96	0.06	3.22	5.90	0.12	5.05	8.88	0.18	6.50	10.52

Parameter	Noise	Mann–Whitney <i>U</i> test									
		60–65 dB		65–70 dB		70–75 dB		75–80 dB		80–85 dB	
		<i>Z</i>	<i>p</i>	<i>Z</i>	<i>p</i>	<i>Z</i>	<i>p</i>	<i>Z</i>	<i>p</i>	<i>Z</i>	<i>p</i>
Sharpness	PS	−0.18	0.859	−1.56	0.119	−3.70	0.000	−76.89	0.000	−6.11	0.000
	UARS	−5.99	0.000	−28.86	0.000	−0.07	0.944	−64.26	0.000	−87.45	0.000
	OSAS	−12.39	0.000	−5.94	0.000	−2.69	0.007	−0.54	0.589	−0.36	0.719
Roughness	PS	−16.45	0.000	−22.64	0.000	−20.71	0.000	−13.30	0.000	−22.15	0.000
	UARS	−26.99	0.000	−68.79	0.000	−40.05	0.000	−58.41	0.000	−55.94	0.000
	OSAS	−16.87	0.000	−15.55	0.000	−15.05	0.000	−14.32	0.000	−7.41	0.000
Loudness	PS	−22.71	0.000	−34.42	0.000	−38.47	0.000	−41.80	0.000	−55.03	0.000
	UARS	−17.11	0.000	−35.76	0.000	−21.37	0.000	−43.20	0.000	−29.73	0.000
	OSAS	−14.80	0.000	−13.89	0.000	−13.45	0.000	−13.84	0.000	−9.06	0.000

The data describe an increase of the specific psychoacoustic parameter under increasing SPL level for the different snoring noises. The results of the Mann–Whitney *U* test are given as *Z* and *p* values. Snoring noises of primary snoring (PS), snoring at upper airway resistance syndrome (UARS) and obstructive sleep apnea syndrome (OSAS) are given

*MD* median, *M* mean, *SD* standard deviation

of values. Therefore, the obtained statistical data need to be interpreted carefully.

## Results

### Frequency analysis (FFT) under rising *L*<sub>peak</sub>

There was no change in the peak intensity of the FFT under rising *L*<sub>peak</sub> (65–85 dB) in all the three snoring samples.

### Psychoacoustic analysis under rising *L*<sub>peak</sub>

#### Loudness

Under rising *L*<sub>peak</sub> (dB), the snoring sample “OSAS” revealed a lower loudness than the snoring samples “PS” and “UARS”. PS revealed a higher loudness, especially

under high SPL levels than UARS (*Z* and *p* values given in Tables 1, 2). The increase in loudness for PS and UARS was more intense than for OSAS (Fig. 2).

#### Sharpness

The sharpness for PS and UARS was higher than for OSAS at all SPLs. The sharpness increased at high SPLs for PS and OSAS, whereas the sharpness of UARS tended to decrease (*Z* and *p* values given in Tables 1, 2) (Fig. 3).

#### Roughness

The roughness of all the three snoring samples increased under increasing SPLs. Sample PS revealed a greater roughness than samples UARS and OSAS (*Z* and *p* values given in Tables 1, 2) (Fig. 4).

**Table 2** Statistical analysis of the psychoacoustic parameters

Parameter	SPL (dB)	Analysed samples per noise ( $N = 30,000$ )									Mann–Whitney $U$ test					
		PS			UARS			OSAS			PS–UARS		PS–OSAS		UARS–OSAS	
		MD	M	SD	MD	M	SD	MD	M	SD	Z	$p$	Z	$p$	Z	$p$
Sharpness	60	1.66	1.22	0.85	2.03	1.49	0.91	0.01	0.67	0.79	–83.07	0.000	–90.30	0.000	–122.70	0.000
	65	1.67	1.24	0.83	2.02	1.50	0.91	0.04	0.75	0.83	–87.87	0.000	–80.60	0.000	–120.03	0.000
	70	1.68	1.26	0.80	1.98	1.48	0.88	0.1	0.80	0.85	–89.72	0.000	–73.39	0.000	–115.55	0.000
	75	1.66	1.27	0.77	1.95	1.50	0.81	0.2	0.82	0.85	–103.51	0.000	–68.05	0.000	–137.89	0.000
	80	1.82	1.92	0.33	2.04	2.05	0.14	0.31	0.83	0.85	–78.85	0.000	–150.25	0.000	–196.74	0.000
	85	1.82	1.95	0.37	1.89	1.45	0.85	0.39	0.84	0.85	–16.61	0.000	–149.40	0.000	–115.68	0.000
Roughness	60	14.98	28.13	30.54	5.42	7.12	6.62	0.09	6.61	14.09	–60.68	0.000	–94.05	0.000	–66.82	0.000
	65	19.26	33.91	35.04	9.04	9.22	7.68	0.33	10.08	18.65	–67.17	0.000	–89.35	0.000	–47.69	0.000
	70	26.00	43.25	41.83	20.08	16.04	10.69	1.03	14.45	24.24	–63.12	0.000	–91.36	0.000	–56.45	0.000
	75	33.21	52.86	48.33	24.45	19.28	12.08	2.82	19.63	31.89	–77.26	0.000	–93.98	0.000	–43.33	0.000
	80	38.14	58.92	51.78	29.93	24.65	14.57	7.63	26.90	45.31	–69.15	0.000	–89.55	0.000	–41.95	0.000
	85	46.40	65.81	53.25	36.40	31.23	18.08	13.08	29.83	52.15	–73.77	0.000	–107.60	0.000	–56.67	0.000
Loudness	60	1.77	2.20	2.19	1.56	2.55	2.84	0.00	0.78	1.77	–6.81	0.000	–89.35	0.000	–94.70	0.000
	65	2.62	3.01	2.88	2.08	3.19	3.45	0.00	1.29	2.68	–0.05	0.962	–84.08	0.000	–83.54	0.000
	70	4.58	4.88	4.45	4.09	5.63	5.70	0.03	2.06	3.99	–5.83	0.000	–87.52	0.000	–89.50	0.000
	75	8.03	8.20	7.21	5.46	7.28	7.21	0.06	3.19	5.86	–16.81	0.000	–92.38	0.000	–82.28	0.000
	80	11.93	12.04	10.32	8.94	11.49	11.03	0.12	5.07	8.93	–19.63	0.000	–114.51	0.000	–106.78	0.000
	85	21.12	21.06	17.40	16.24	20.15	18.88	0.21	6.46	10.48	–23.20	0.000	–128.72	0.000	–98.43	0.000

The data describe the difference between the three different snoring noises under increasing SPLs. The results of the Mann–Whitney  $U$  test are given as  $Z$  and  $p$  values. Snoring noises of primary snoring (PS), snoring at upper airway resistance syndrome (UARS) and obstructive sleep apnea syndrome (OSAS) are given

$MD$  median,  $M$  mean,  $SD$  standard deviation

*Psychoacoustic fingerprint*

Merging the psychoacoustic parameters “loudness”, “sharpness” and “roughness”, a three dimensional diagram can be created. The curves of the snoring samples differ from each other and create a psychoacoustic fingerprint of the specific noise (Fig. 5).

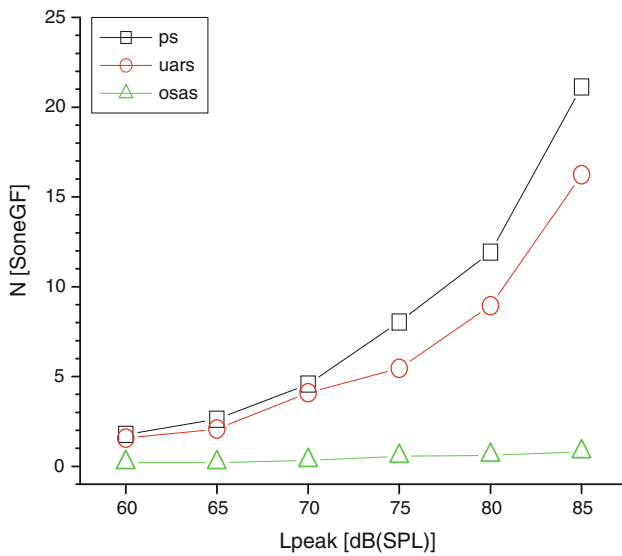
**Discussion**

The present results demonstrate that the perception of snoring sounds depends on various psychoacoustic parameters. Although the sound pressure levels are equal for the three investigated snoring samples, the psychoacoustic parameters “loudness”, “sharpness” and “roughness” alter under increasing sound pressure levels. These individual changes in psychoacoustic parameters enable the creation of “acoustic fingerprints” of snoring sounds to identify specific types of snoring and to evaluate the degree of annoyance.

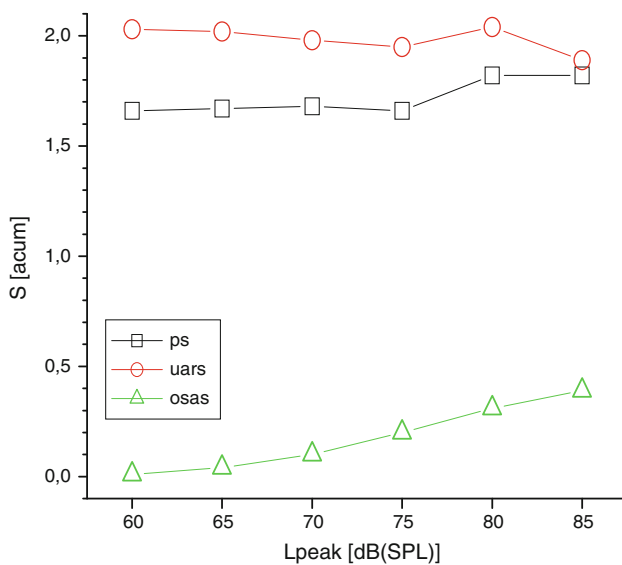
The frequency analysis by fast Fourier transformation (FFT) has been described as a method to investigate snoring sounds in the recent two decades [1, 6, 8, 10, 31, 32].

According to several authors, it seems to be possible to distinguish between palatal and tongue based snoring as the two major sources of origin of snoring. In general, the differences base mostly on the dominant frequency spectra of the snoring sounds. Palatal snoring is reported to consist of low frequency spectra (80–300 Hz), whereas tongue based snoring reveals predominately higher frequency spectra (1,000–4,000 Hz) [1, 3, 8, 10, 34]. Despite these efforts, a precise acoustical discrimination between different snoring sounds is still not possible in somnological standard diagnostic procedure. Moreover, the degree of annoyance of specific snoring sounds is not possible to determine the means of FFT.

The use of psychoacoustic parameters is predominately present in environmental acoustic investigations like studying traffic noise, aircraft noise and occupational environments to describe the degree of annoyance of a specific noise [13, 25, 29, 30]. In medical use, psychoacoustic analysis of sounds has been only reported in few cases although the use of psychoacoustic parameters seems to be an adequate tool to classify a specific noise. Nielsen et al. [19] investigated mechanical heart valve noises according to their annoying potential to the listener and found the

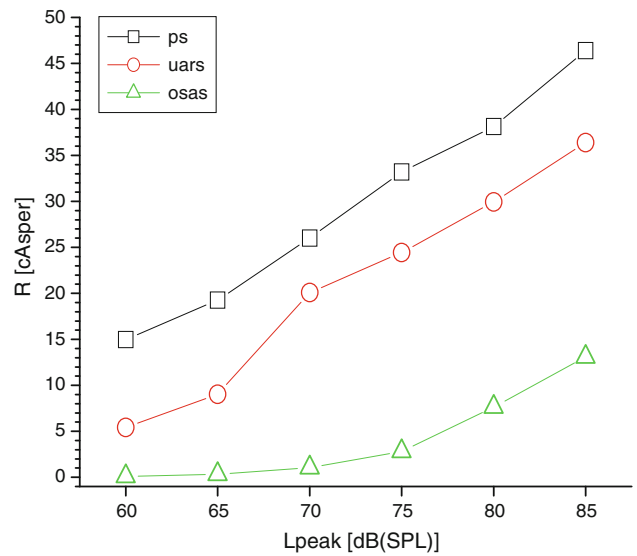


**Fig. 2** Alteration of the psychoacoustic parameter “loudness” under increasing sound pressure levels. All snoring samples show an increase in loudness (y axis) under increasing SPLs (x axis). The loudness of sample OSAS was lower than samples PS and UARS and increased to a lower extent (median values of the specific sample shown; *black PS, red UARS, green OSAS*)

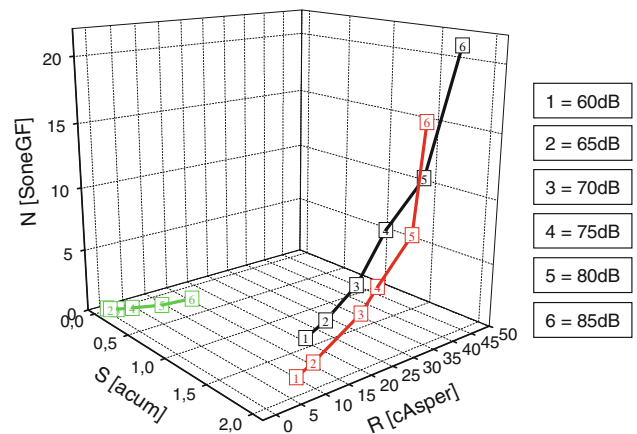


**Fig. 3** Alteration of the psychoacoustic parameter “sharpness” under increasing sound pressure levels. Snoring samples PS and UARS revealed a high level of sharpness (y axis) for all SPLs (x axis), whereas the sharpness of sample OSAS increased under rising SPLs. The sharpness of sample OSAS was lower than sample PS and UARS (median values of the specific sample shown; *black PS, red UARS, green OSAS*)

loudness and sharpness of the valve noises, which are crucial for the degree of annoyance. Haderlein et al. [7] used psychoacoustic parameters for the evaluation of speech quality of tracheoesophageal substitute voices after laryngectomy.



**Fig. 4** Alteration of the psychoacoustic parameter “roughness” under increasing sound pressure levels. The roughness (y axis) of all three samples increased under increasing SPLs (x axis). Sample PS revealed a greater roughness than sample UARS and OSAS (median values of the specific sample shown; *black PS, red UARS, green OSAS*)



**Fig. 5** Three dimensional plot of the psychoacoustic parameters “loudness”, “sharpness” and “roughness”. A psychoacoustic “fingerprint” of the three different snoring sounds is demonstrated. The SPL is given as *outlined number* of the respective snoring sound. x axis: sharpness, y axis: loudness, z axis: roughness (*black PS, red UARS, green OSAS*)

Despite encouraging results in other medical fields in describing the quality a specific noise, the analysis of snoring sounds by psychoacoustic parameters is still a rarely investigated field. A study by Ng and Koh [18] investigated the degree of annoyance of 13 snoring samples estimated by 25 individuals. Psychoacoustic parameters were also used to classify different snoring sounds in combination with the individual estimation of the listening person. The parameters loudness, roughness and annoyance seem to be

the best parameters to distinguish between apnoeic and non-apnoeic snoring in the cited study.

It needs to be marked that polysomnography will remain the gold standard for the detection of sleep related breathing disorders. But the use of psychoacoustic analyses might contribute to topo-diagnose the snoring noise and to evaluate the degree of annoyance of a specific noise.

According to the present data, the assumption that the loudness represents a crucial parameter for the annoyance of snoring noises can be confirmed. The loudness and roughness of the low-frequent rhythmic and high-frequent rhythmic snoring samples increase to a bigger extent under increasing SPL level compared to the high-frequent non-rhythmic sample.

By merging the psychoacoustic parameters “loudness”, “roughness” and “sharpness”, it is possible to create an “acoustic fingerprint” of a specific noise. As demonstrated in Fig. 5, the curves for each snoring noise differ in the plotted diagram. Based on those results, psychoacoustic analyses of a larger sample of snoring patients need to be performed to verify the present preliminary data in a heterogeneous group of snoring individuals.

## Conclusion

The analysis of snoring sounds by psychoacoustic parameters provides a promising approach to differentiate different types of snoring sounds. Compared to conventional methods like FFT, a more precise description is obtained by calculating “loudness”, “roughness” and “sharpness”, which cumulates in the creation of “psychoacoustic fingerprints” of the snoring sounds. Psychoacoustic analyses could be implemented in routine polysomnography for a sufficient investigation of snoring sounds and could provide an adequate tool to evaluate the annoyance by snoring noises.

**Conflict of interest** There is no conflict of interest for any of the authors.

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