Significance of Snoring and Other Sounds Appearing during the Night based on the ECG

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Abstract

Presented study demonstrates that there is a significant difference in sound spectrum between snoring, normal breath and obstructive apneas which is correlated with ECG signal. It is possible to use sound spectrum analysis as a supplementary method to determine the obstruction site for patients with obstructive sleep apnea syndrome (OSAS) or other disturbances during the night. Correlation between acoustic and ECG analysis might be one of the screening methods allowing early assessment of the severity of various sleep disorders. Several differences have been found between people showing typical snoring symptoms and subjects with some other common sleep syndromes. The acoustic characteristics of snoring sounds and its variability can be fully described using the time domain, by sound intensity and pitch and the frequency domain, using representative formant frequencies, shape and energy ratio measurements. Sounds appearing during the night, in conjunction with ECG monitoring, allow convenient subject assignment to categories described with the level of snoring severity.

1. Introduction

Recorded, correct breathing signal was used as a standard for comparison with the signals indicating the disorder. The development of the data was carried out in MATLAB. Recordings were processed using STFT (Short Term Fourier Transform). To compare some properties of the sounds during sleep, a set of parameters was extracted. Feature classification of snoring sounds and ECG parameters allow classification according to the level of SAHS (sleep apnea-hypopnea syndrome) of people who have sleep disorders. The ECG recordings were used to acquire patterns of heart rate variability (HRV) in the time domain. The typical tachogram and its main parameters were calculated: SDNN, RMSSD, p50nn, SDi SDANN. All parameters were determined for 2.5, 5 or 10 min time periods, representingd short and long-time variability respectively [1,2,3].

2. Methods: data acquisition

Signals appearing during the night were analyzed using two previously described methods: acoustic and ECG signals analysis. Comparison of breath, snoring or apnea were conducted using both methods, indicating their equivalence in the assessment. At this stage the following acoustic signals have been analyzed using the STFT analysis:

- typical breathing pattern with length of about 2 seconds each,
- apnea signals including rapid 2 second inhalations,
- snoring signals 2 seconds in length (during this time one entire respiratory cycle was recorded: inhalation and exhalation).

All acoustic analysis was based on ECG recordings. All samples have been taken from one subject, during different stages of sleep. Normal breathing signal has been taken as the basal signal, whereas apnea and snoring signals have been considered as key for analysis. Snoring and apnea signals have been filtered using a high-pass filter with cut-off frequency set at 200Hz. Mentioned signals have components in the removed range but they overlap with noise frequencies (strong noise band detected in every recording), therefore it was decided to filter these component out in order to raise the readability of the signals. Analyzed signals can have local maxima (even quite significant) in the cut-off region, but their amplitudes could be only approximated due to the significant noise, even with filtration. Only signals of normal breath were not filtrated, since their frequency band significantly overlaps with the noise band [4,5,6].

2.1. Acoustic signal Normal breath signals

From the time spectra of the analyzed signals it can be concluded that breathing, despite being a random signal, bears the characteristics of stationarity, since its characteristics are similar in different points of time. It is difficult for example to distinguish the breathing phase based on either time or frequency points alone. Assumption about the signal stationarity can also be confirmed by the similarity between the two analyzed samples (time domain amplitude, frequency bands, format values). Signal stationarity justifies analysis performed only in the frequency domain. The signal of breathing in the time domain resembles a deformed sinus curve, so its frequency domain representation is also similar – simple, consisting of only a few remaining components in the low frequency band. The graph of the spectral power density leads to the conclusion that the vast majority of the signal energy falls at the low frequency range (below 5000Hz). Maxima (formants) fall at the following frequencies:

- 1st formant: 1855Hz,
- 2nd formant: 3160Hz
- 3rd formant: 3460Hz;

(these values are the average, all of the formants throughout the all samples in whole analysis). These values are similar, as is their variability over time for both runs.

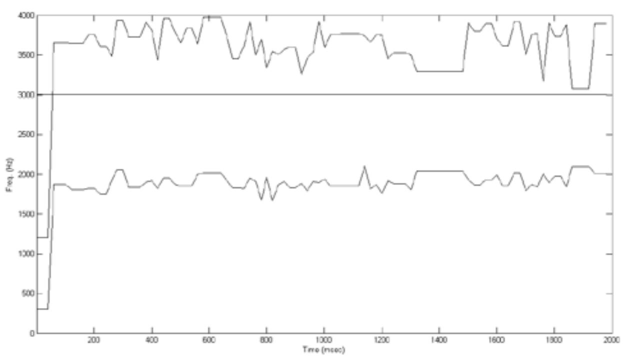

Figure 1. Normal breath – Formant frequency.

- Apnea signals with rapid inhalations

Apnea signals with rapid inhalations can be classified as non-stationary signals, since their characteristics change depending on the selected time point. All analyzed samples of this type are similar to each other in terms of amplitude and duration of sudden inspiration, the characteristics of the time - frequency, the energy distribution of the signal and the formant values and their variability in time. On this basis, we can say that the acoustic characteristics of the induced apnea and sudden inspiration are characteristic features of each subject. These signals last an average of 400 to 800 ms and are characterized by much greater amplitudes compared to the normal, quiet breathing (normal inhalation has on average of 400dB volume intensity, while sudden breath volume intensity can reach up to 10000dB), and a more complex frequency structure. On the basis of the frequency spectra it can be shown that during sudden inspiration much more components are involved when compared to the case for calm breathing, and that many more components of the medium-and high-band frequencies are present (there are even components reaching 15000Hz with quite significant amplitudes, whereas the frequency range of quiet inspiration does not extend beyond 5000Hz). Furthermore it can be seen that the high-frequency component of these signals increase over time, reaching a maximum at mid-length of inspiration, and then begins to decrease. Power spectral density plots confirm the richer structure of the signal, because more local energy maxima and greater energy distribution of the more significant components between higher frequencies can be seen compared with normal respiration. Mean values of the first three formants of signals from this group are as follows:

- 1st formant: 340Hz,
- 2nd formant: 2030Hz
- 3rd formant: 3590Hz

These values are similar to each other regardless of the phase of sleep, perhaps depending on the patient. Some signals from this group seem to have an even richer structure than the others, a conclusion made based not only on the graphs, but also looking at the formant frequencies that are slightly different from their counterparts. This is due to the fact that the apnea preceding the inhalation took longer (about 15 seconds) than the other apnea episodes. Thus, we conclude that the signal characteristics of sleep apnea with a sharp breath depend not only on the patient and the possible diseases or anatomical/physiological differences, but also on the duration of apnea incidents. The time domain plot also show that following the rapid inspiratory stage there is an acoustic silence phase lasting around several hundred milliseconds preceding the return to normal breathing (due to the applied signal filtering it was not possible to exactly determine its duration).

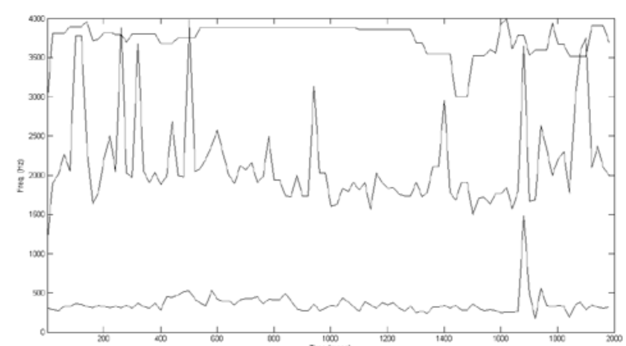

Figure 2. Apnea – formant frequency.

- Snoring signals

Snoring signals are non-stationary because their properties change over time. Based on the time plots of analyzed =signals, their duration in each case was similar and averaged 1.5 seconds. Signals however, showed great variation of amplitude relative to each other (up to 2000, 3000 or even 5000dB for the maximum values). Compared to normal breathing, snoring amplitude showed considerable variability in time (normal respiration amplitude is approximately constant and also much lower - only 400dB). Comparing the snoring and calm breathing signals in the time domain, it can be said that in the latter it is difficult for us to distinguish individual respiratory cycles, while in snoring signals these are very clear. This is mainly due to the overlapping of the signal frequency bands of normal breathing with noise, making extraction of the signal solely responsible for breathing difficult. When analyzing the characteristics of snoring one should be aware, that mainly the inspiratory phase is analyzed, as in this stage soft tissues are stimulated to vibrate the oropharynx. Characteristics of exhalation for the most part already fall at frequency bands of normal breathing, and therefore vanish in the noise. Hence the gap in the snoring sounds signal, that consists of the exhaust and the interval between following respiratory cycles. Frequency spectra show the complexity in all the signals, with a clear and specific formant structure of components at low, medium and high frequencies (of up to 15000Hz, only the last signal contains components to about 10000Hz), with the largest part of the lower frequencies (for comparison – for normal breathing, only low-frequency components up to 5000Hz are present). We are able to distinguish much more formants than in the normal respiration signal. The amplitude of components do not vary considerably over time; we can only conclude that there is a slight attenuation at the beginning and end of a single respiratory cycle, especially in the higher frequency components. Graphs of the spectral power density show numerous energy peaks that fall into similar components for all three samples. Interestingly, each of these reveal even one maximum that falls above 15000Hz. This is an important observation, taking into account that the last maximum has the smallest maximum energy input for each signal, and therefore are rarely repeated. Hence the conclusion that the test signals of the patient's snoring, even taken at different stages of sleep and apparently different from each other, have a very similar structure in the frequency domain. This can also be seen looking at the first three formant values, that confirm the findings based on the power spectral density plots. Their average values are as follows:

- 1st formant: 350Hz,
- 2nd formant: 1890Hz
- 3rd formant: 3530Hz,

Graphs of spectral power density for normal breathing are much less varied. These have only just 2-3 formants, while snoring signals exhibit much more formants and these are a lot clearer and appear at more widely spaced frequencies.

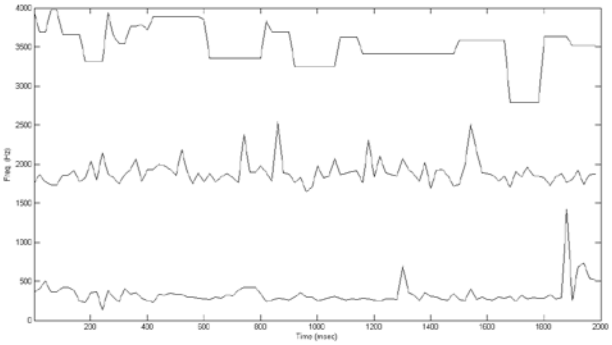

Figure 3. Snoring – formant frequency.

2.2. ECG – heart rate viability

During the sleep the heart rate variability is solely controlled by the autonomic nervous system. Short-time and long-time variability indexes are low during the sleep. Long-term variability is stable during the night, but short-term variability may increase depending on many factors e.g. motion, respiratory obstructions or during the REM phase. HRV-based estimation of the subject’s condition is not enough, therefore support from other methods in detection of sudden status changes is required such as acoustic analysis[7]. All HRV parameters are calculated on ‘normal-to-normal’ (NN) inter-beat intervals (or NN intervals) caused by normal heart contractions paced by sinus node depolarization.

The typical tachogram and its main parameters were calculated: SDNN, RMSSD, p50nn, Sdi, SDANN.

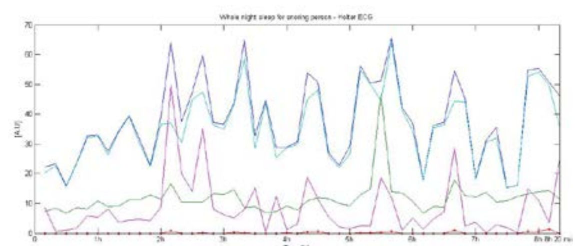

Figure 4. Overnight tachogram (all parameters) for snoring person.

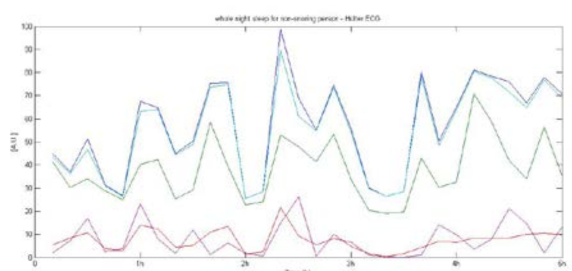

Figure 5. Overnight tachogram (all parameters) for non-snoring person.

SDNN is the most representative parameter of HRV. HRV could indicate SDNN values among many other parameters of HRV analysis. Thus low HRV means low SDNN, which indicates reduction in dynamic complexity. Healthy people have more irregular and complex HRV signal. Decrease in HRV has received increasing attention as a prognostic indicator of risk associated with a variety of chronic diseases, behavioral disorders, mortality and aging.

The clinical meaning of the decrease in SDNN is as follows:

- Weakened Autonomic Nervous System - ability to keep homeostasis,
- lowered coping ability to various emotional/physical stressors,
- general weakness of health.

RMSSD - this parameter is associated with the electrical stability of heart influenced by the parasympathetic nervous system activity. Decrease in RMSSD (below 10) accompanied by lowered SDNN (less than 20) has been associated with a higher risk of cardiac disease development.

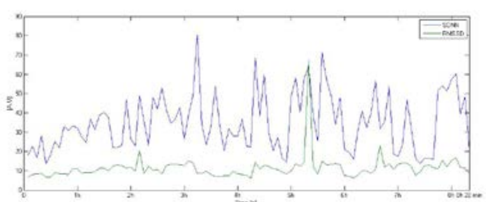

Figure 6. Overnight tachogram SDNN/RMSSD for a snoring person,

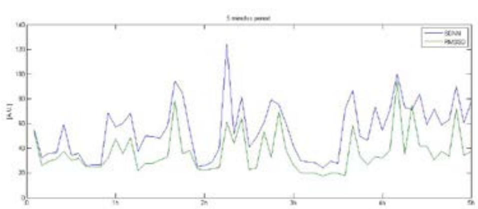

Figure 7. Overnight tachogram SDNN/RMSSD for non-snoring person,

Figures 6 and 7 show how HRV changes for sample snoring and non-snoring subjects. It is clear that the SDNN and RMSSD parameters are lower for snorers in comparison with non-snoring subjects.

Based onwhole night observations and recordings for snoring subject it can be observed that there are two episodes of very loud snoring (between 2nd and 3rd hour and between 5th and 6th hour). Decreasing Holter parameters are in correlation with decreasing snoring sound parameters from acoustic analysis. Following snoring episodes rapid decline in values of parameters indicating apnea during sleep can be observed, which is in correlation with parameters determined using acoustic analysis.

4. Conclusion

In this paper two methods for measuring the signal appearing during the night are described - acoustic analysis of sleep sounds and electrocardiography (ECG). The simultaneously acquired acoustic and ECG signals were used to define signals during sleep. The information from synchronized recording of acoustic effects and the ECG signal partly overlap, giving an opportunity to improve accuracy of diagnosis. Results indicate that the aspect of sleep analysis can be extended using a combination of these methods proposed in this paper.

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