Effect of Examined Persons Weight on the Acoustic Noise Produced by an Open-air NMR Imager

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Abstract. *The paper analyzes how influenced the weight of lying examined person in the scanning area of the open-air magnetic resonance imaging equipment on properties of an acoustic noise produced by mechanical vibration of the gradient coils system. This noise signal exhibits harmonic character, so it is suitable to analyze its properties in the spectral domain. Obtained results of will be used for precision of noise reduction of recorded speech signal during phonation for the human vocal tract modeling in an NMR imager.*

Keywords: Acoustic noise, Spectral analysis, NMR imaging.

1. Introduction

Magnetic resonance imaging (MRI) devices are also used for non-invasive MR scanning of vocal tract spaces of subjects for speech configuration or in phonation position of their resonant cavities for each vowel enables to develop the three-dimensional (3D) computer models of the human vocal tract [1]. To obtain the 3D vocal tract model with good quality the synchronicity between image and audio acquisition must be ensured as well as a good signal-to-noise ratio must be achieved [2]. The MRI device consists of a gradient coil system that produces three orthogonal linear fields for spatial encoding of a scanned object. The noise is produced by these gradient coils due to rapidly changing Lorentz forces during fast switching inside the weak static field B_0 environment [3]. This process subsequently propagates in the air a progressive sound wave received by the human auditory system as a noise [4]. Due to its harmonic nature and the audio frequency range, the produced acoustic noise of this device can generally be treated as a voiced speech signal. Therefore it can be recorded by a microphone and processed in the spectral domain using similar methods as for the speech signal analysis.

To investigate the transmission of noise signal originated of the plastic holder in the MRI device scanning area, as well as the magnetic filed homogeneity the measurement arrangement consisting of the testing phantom inserted in the scanning RF coil is usually used [2]. The situation changes when the testing person lies in the scanning area and the holder of the lower gradient coils is loaded with his/her weight. The motivation of this work was to analyze how influenced the weight of testing person on properties of the acoustic noise signal produced by mechanical vibrations of the gradient coils of the MRI equipment. Obtained results will be used to devise an improvement of the developed cepstral-based noise reduction method [5] in the speech recorded during 3D MR scan of the human vocal tract.

2. Spectral Properties of the Acoustic Noise Signal

The basic as well as the supplementary spectral properties are usually determined from the frames (after segmentation and widowing). To obtain the smoothed spectral envelope, the mean periodogram can be computed by the Welch method. For detailed analysis the nearest region of interest (ROI) is better to determine. In addition, the spectral distances D_{RMS} of analysed envelopes can be calculated and the position F_{max} of maximum difference ΔP_{max} can be determined for further comparison. Obtained values are subsequently analysed, the basic statistical parameters (minimum, maximum, mean, standard deviation) are calculated.

3. Subject and Experiments

The analyzed open-air MRI equipment E-scan OPERA contains also an adjustable bed which can be positioned in the range of 0 ÷ 180 degrees, where the 0 degree represents the left corner near the temperature stabilizer device [6] – see principal angle diagram of the MRI scanning area in Fig. 1a. This noise has almost constant sound pressure level (SPL) and consequently it can be easily subtracted as a background. Due to the low basic magnetic field B_0 (up to 0.2 T) in the scanning area of this MRI machine, any interaction with the recoding microphone must be eliminated. As the noise properties depend on the microphone position, the optimal recording parameters (the distance between the central point of the MRI scanning area and the microphone membrane, the direction angle, the working height, and the type of the microphone pickup pattern) must be found. The chosen type of the scan MR sequence together with the basic scan parameters – repetition time (TR) and echo time (TE) – have significant influence on spectral properties of the generated noise signal. The realization of the acoustic noise measurement experiments consists of two phases:

1. Mapping of the level of the SPL in the MRI neighbourhood by measurements of:
   - directional pattern per 12.5 degree of the acoustic noise on the MRI neighborhood in distances of {45, 60, and 75 cm} from the central point of scanning area with a testing phantom (see Fig. 1a),
   - noise SPL at directions {30, 90 and 150 degrees} in distance of 60 cm with different testing persons lying in the scanning area of the MRI device.
2. Recording of the noise signal during execution of a MR scan sequence using:
   - the test phantom only placed in the middle point of the scanning area (see Fig. 1b),
   - different testing persons lying in the scanning area of the MRI device (see Fig. 1c).

Measurement of the noise SPL was realized by the measuring device DT 8820, the resulting graph of the directional pattern for three measuring distances is presented in Fig. 2a. The mean SPL values obtained with the help of male/female examined persons and water phantom for three positions of DT 8820 device are shown in Fig. 2b. In the second part of our experiment, the noise signal was parallel recorded (at sampling frequency of 16 kHz) with the help of the Behringer PODCAST STUDIO equipment connected to a separate personal computer. The recording microphone was located in the distance of 60 cm, horizontally in the positions of 30, 90, and 150 degrees (the bed with the examined person at 180 degrees in all cases) and vertically in the middle between both gradient coils. By this way collected noise database consists of the records from six testing persons (3 male + 3 female) that were lying in the MRI scanning area (with the approximate weights as it is shown in Table 1), and using only the water phantom (WP) with a holder.

Table 1. The approximate weights of the testing persons/object used in our experiment.

Person/object	JP (Male1)	TD (Male2)	LV (Male3)	AP (Female1)	BB (Female2)	ZS (Female3)	XX (WP)
Weight [kg]	78	75	80	53	50	55	0.75

The measurement and recording was realized during execution of the MR sequence SSF-3D (with setting of TE=10 ms, TR=45 ms) that is often used for the 3D MR scans of the human vocal tract [5]. By this way obtained noise signals were subsequently processed as follows:

- visual comparison of determined spectral envelopes in the full frequency range of 0 ÷ f_s / 2 (0-8k) and for the sub-ranges of 0 ÷ 2.5 kHz (0-2k), and of 2 ÷ 6 kHz (2-6k);
- determination of the spectral distances D_{RMS} between the envelopes calculated from acoustic noise obtained with using of an individual person and/or the testing phantom;

- localization of frequency position F_{max} of the maximum spectral difference ΔP_{max} within the low-frequency band of 0 ÷ 2.5 kHz – see an example in Fig. 3;
- basic statistical analysis of the achieved values – see the mean values in Table 2 and the box-plot of the basic statistical parameters in Fig. 4.

Fig. 1. An arrangement of noise SPL measurement (a) and noise recording in the MRI Opera using the testing water phantom (b), and a lying examined person (c).

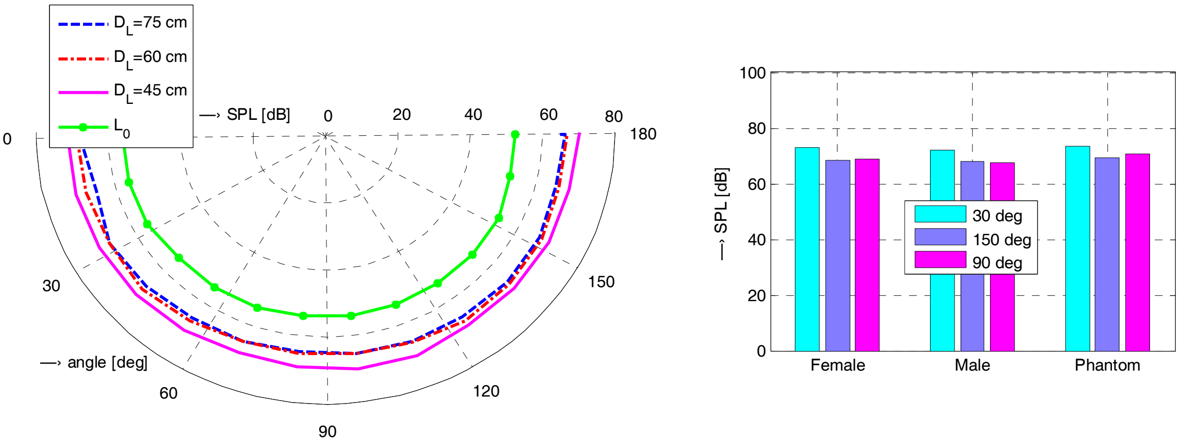

Fig. 2. Directional pattern of the noise source together with the background noise L_0 for three distances using a water phantom (left); the noise SPL values for selected three positions of DT 8820 device (right).

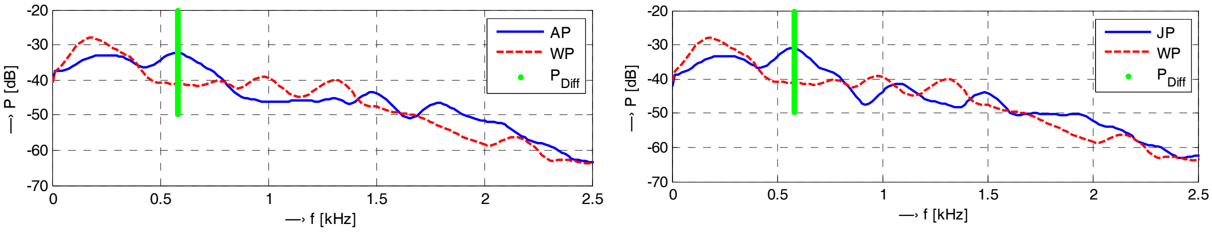

Fig. 3. Differences of spectral envelopes in the low frequency band up to 2.5 kHz for: female person (AP) to phantom (WP) – left, and male person (JP) to phantom (WP) – right; microphone at 90 degrees.

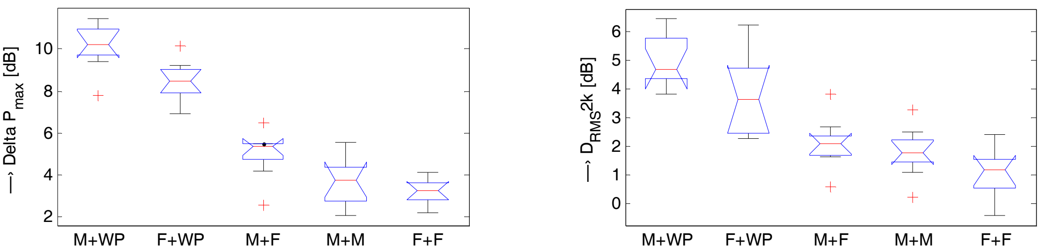

Fig. 4. Box-plot of basic statistical parameters of the spectral envelope differences within the low frequency band up to 2.5 kHz: ΔP_{max} at frequency F_{max}.= 576 Hz (left), spectral distances D_{RMS} 0-2k (right); tested pairs of: Male + WP, Female + WP, Male + Female, Male + Female, Female + Female; joined values for all there microphone positions at 30, 90, and 150 degrees.

Table 2. Comparison of mean values of the basic spectral properties of acoustic noises for the tested pairs of male/female persons and water phantom (WP) inserted in the scanning area of the MRI device.

Tested pairs *)	F_{max} **[Hz]**	ΔP_{max} **[dB]**	D_{RMS} **0-2k [dB]**	D_{RMS} **2-6k [dB]**	D_{RMS} **0-8k [dB]**
Female + WP	575	8.95	4.18	2.78	3.55
Male + WP	577	9.81	4.34	3.85	4.25

*) The noise signal recorded at 90 degree.

4. Discussion and Conclusion

Results of performed measurement of the noise SPL distribution in the MRI equipment neighbourhood help to find the sub(optimal) placement of the pick-up microphone for the next acoustic noise recording experiment. The mean values of the SPL obtained with the help of male/female lying person and water phantom for three tested locations show that no significant differences exist; however, the maxima were obtained for the microphone position at 90 degree – opposite to the face of the examined person. At the position of 0 degree the influence of the MRI temperature stabilizer can be superimposed as an additive noise with normal distribution, and finally the microphone position at 150 degree is unnatural from the point of the lying person. In all cases, the measurement confirms a principal influence of under load of the MRI plastic cover by a person lying on the produced acoustic noise. As documents achieved the mean values in Table 2 and the basic statistical parameters in Fig. 4, the weight of lying persons also effected on the spectral properties of the generated noise. From the spectral envelopes can be determined frequencies (positions), where is the noise spectrum supressed or increased in dependence on the acting weight of the examined person.

Obtained results will serve to create databases of initial parameters (such as the bank of noise signal pre-processing filters) very useful in an experimental practice – when it is often occurs, that the basic parameter setting of the used scanning sequence as well as the other scanning parameters must be changed depending on the currently tested person.

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