CHARACTERIZATION OF NOISE PRODUCED DURING CONTINUOUS AND SPARSE SAMPLING FUNCTIONAL MAGNETIC RESONANCE IMAGING

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1 Introduction

Noise is generated during magnetic resonance imaging (MRI) and comes from the gradient magnetic field (Lorentz forces acting on the gradient coils) and radiofrequency pulses used to generate sequences for scanning [1–3]. Characterizing this noise is complicated by the fact that sensors without any metal parts must be used, given the intense magnetic fields present in MRI. Also, the typical continuous acquisition scheme that generates continuous noise is hardly compatible with auditory-related experiments. To avoid or reduce noise during stimulus presentation, the use of headphones, sound absorbing material or even active noise cancellation have been considered. Another approach to decrease the level of the interfering noise is the implementation of less noisy MRI sequences. Sparse sampling functional MRI [4] has been suggested and involve the acquisition of imaging volumes interspersed with silent periods (i.e. no acquisition periods). This communication describes the use of optical fiber microphones to characterize the noise produced during continuous and sparse sampling functional MRI sequences. The instrumentation chain is described, along with the preliminary results obtained in terms of overall sound pressure level and time-frequency content.

2 Magnetic Resonance Imaging

MRI is a noninvasive medical imaging test that can produce highly detailed images of almost every internal structure in a living body (this can include organs, bones, muscles and even blood vessels) and help to establish diagnostics. No ionizing radiation is produced during a MRI tests (unlike X-rays), since MRI scanners create images of the body using radio waves and a large magnet (magnetic flux densities from 1.5 Tesla up to 10 Tesla are typically used). The scanner uses the effect of nuclear magnetic resonance and the differences in relaxation processes between different tissues to generate an image contrast. In parallel, functional MRI (fMRI) allows measuring brain activity since neuronal activation and cerebral blood flow are coupled (an increase in neuronal activity is followed by an increase in the flow of oxygenated blood, therefore the term Blood-Oxygen Level Dependent - BOLD - response is used). Combining functional and structural images allows linking physiological processes to the anatomical structures of the human brain and exploring neural activity with a spatial resolution of a few millimetres and a temporal resolution of several seconds (electrophysiological methods like electroencephalograms - EEG - provide on their side a poor spatial resolution, in the order of several centimeters, but a fine temporal resolution in the order of few milliseconds). MRI comes with some limitations that are linked to the noise but also the strong electromagnetic field it generates, that exclude people having metallic implants or cardiac pacemakers but also the use of sensors using ferromagnetic materials.

3 Instrumentation, data acquisition and measurements

To measure noise in a MRI, a remote microphone using a tube can be used, but this requires the use of a correction transfer function [5]. Microphones that do not include ferromagnetic parts like fiber optic microphone are also a possible solution that is here evaluated, in order to be able to perform *in situ* (and not remote) measurements. The two considered microphones are manufactured by Phonoptics and depicted in Figure 1. The Alpheus microphone has a 3 mm diameter with a 15 mm length, and a sensitivity of 0.3 mV/Pa, while the Evotis microphone has a 10 mm diameter, a 23 mm length and a sensitivity of 10 mV/Pa. The patented technology follows a light intensity modulation principle and relies on a single optical fiber with an associated conditioning unit that provides the one light source, one photo-detector and one splitter. It also features 3-level signal amplification, headphone and BNC AC outputs, SMA DC output for sensor integrity monitoring and a USB 44 kHz, 16 bit, digital output. In order

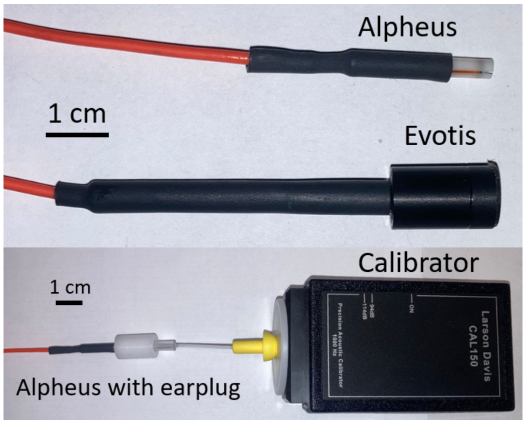

FIGURE 1 – Pictures of the optical fiber microphones.

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to be able to perform noise measurements as close as possible to the eardrum, adaptors were 3D-printed to link microphones with 3M™ E-A-R™ UltraFit™ probed test earplugs. A data acquisition program was developed to perform measurements using the direct output from the conditioning unit as a sound device. The program includes a frequency-calibration step, the acquisition and visualization of signals (as a function of time, frequency and time-frequency) and the calculation of equivalent sound levels (L_{eq}). It can be run through the Matlab interface, but a standalone version was also created. To validate the whole measurement chain, a comparison with a Bruel&Kjaer half-inch microphone connected to a Bruel&Kjaer Connect data acquisition system was performed in hemi-anechoic conditions.

4 Results

The presented results were generated using measurements made with the Evotis microphone. The acquisition computer was placed in the control room (out of the magnetic field), the microphone was calibrated in the same room and then positioned at 1 meter from the MRI coil's center. Since the optical fiber involves negligible losses, a 20-meter fiber is used and allows a convenient connection between the control room and the MRI, while preventing mechanical stress and excessive curvature on the fiber. The background noise was first measured and the estimated 1-second L_{eq} was 70 dB (re. 2e-5 Pa), and mostly linked the MRI cooling system functioning. The MRI noise was then characterized in standard acquisition mode, see Figure 2 in which raw time signal, spectrogram and $L_{eq,1s}$ are provided. As the noise generated by MRI is cyclic (see Figure 2(a)), measurement results are only shown over 3 seconds. According to the spectrogram (see Figure 2 (b)), a time-modulated harmonic and tonal high-level noise is generated. The mean L_{eq} equals 102.1 dB (re. 2e-5 Pa). MRI noise during compressed (or sparse) acquisition is finally characterized, see Figure 3. The MRI now only generate noise during 1 second at 3-second intervals. The results show that the measured L_{eq} reaches the background noise level between acquisition steps, leading to an effective 30 dB difference.

5 Conclusion and perspectives

The use of optical fiber microphones for noise measurements during MRI together and the development of a tool for convenient acquisition and processing of signals were both validated. Future works will include the presentation of various acoustic stimuli during fMRI but also using EEG, and the analysis of corresponding neuroimages and recordings to enlarge our knowledge of the auditory processes. An improved understanding of the perception of sound alarms in order to improve their design is an underlying goal.

Acknowledgments

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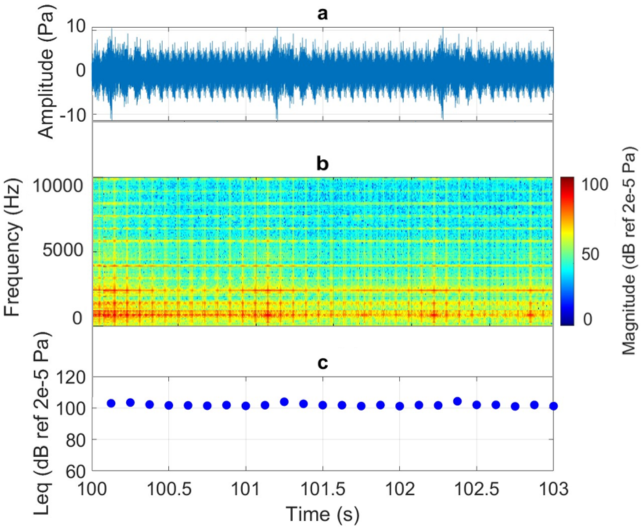

FIGURE 2 – FRMI with continuous acquisition - (a) Raw time signal ; (b) Spectrogram ; (c) 1/8-second Leq.

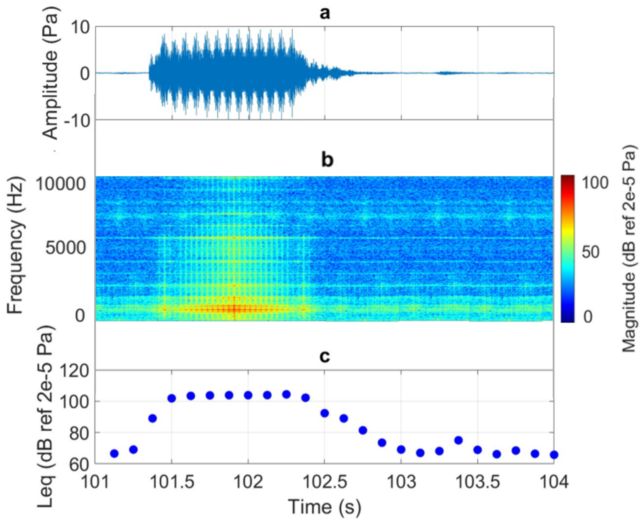

FIGURE 3 – FRMI with sparse acquisition - (a) Raw time signal ; (b) Spectrogram ; (c) 1/8-second Leq.

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