USE OF AUDITORY STEADY-STATE RESPONSES IN MEASURING THE ATTENUATION OF HEARING PROTECTION DEVICES

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1 Introduction and objectives

Worldwide hearing loss estimates increased from 120 million people in 1995 \cite{1} to 250 million in 2004 \cite{2}. A common solution to protect workers from noise exposure consists of using hearing protection devices (HPD). Unfortunately, it is difficult to provide hearing protection using an attenuation level that is appropriate for an individual’s work environment since present methods of attenuation measurement have limitations \cite{3}. Objective measurements such as field microphone in real ear (F-MIRE) do not assess bone conducted sound. Psychophysical measurements such as real ear attenuation at threshold (REAT) are biased due to the low frequency masking effects from test subjects’ physiological noise and contain variability of measurement due to subjective responses. The present study reports an attempt to overcome the limitations of these methods through the recording of auditory steady-state responses (ASSR). Due to the time consuming nature of ASSR recording, the study was conducted using only two stimuli having 0.5 and 1 kHz carriers.

2 Methodology

Ten volunteers (8 males – 2 females) with ages from 20 to 29 and thresholds below 20 dB SPL (from 125 Hz to 8 kHz) were assessed. A typical experimental procedure included four steps:

2.1 Step 1: Custom earplugs molding

Each experiment started with the molding of the custom earplugs used throughout the recordings for each subject. In selecting the earplugs, we were sensitive to the fact that, when a subject is wearing earplugs, the stimulation levels must be adjusted to ensure that the sound pressure levels in a subject’s ear canals are approximately the same in both open and occluded conditions. Accordingly, attenuation at 500 Hz and 1 kHz should be moderate (e.g. 10-20 dB) and stimulation levels should not exceed about 75 dB SPL. This ensured, in case of bad fit, that a subject would not be exposed to an excessive noise level. Lastly, due to the somewhat long duration of the experiment (e.g. 90 minutes), the earplugs should be comfortable.

Sonox Self-Fit™ earplugs are suitable for this experiment. These are fitted to the user’s ear by injecting medical-grade silicon between a rigid core and an expandable membrane. The earplugs are designed to include an inner bore of constant length and diameter that permits the temporary insertion of a microphone probe and the permanent insertion of a passive acoustical filter. We used, a brown-colored filter, in the set of filters provided by Sonomax, which provides an attenuation of 10 dB at 500Hz and 15 dB at 1 kHz.

2.2 Step 2: REAT measurements

The REAT method is commonly considered as the “gold standard” and is included in many worldwide standards. REAT calculates HPD attenuation as the difference between open-ear and occluded-ear hearing thresholds for human subjects. REAT measurements were conducted according to ISO 4869-1:1990 standards by using the LabVIEW™ based “REAT MASTER™” Nelson Acoustics software which is an automatic Bekesy audiometer program designed to provide a stimulus and track responses for sound field hearing threshold determination in both normal and occluded conditions. Stimuli used to conduct REAT measurements were warble tones at 0.5 and 1 kHz computer generated and presented via a Sennheiser headphone.

2.3 Step 3: F-MIRE measurements

The F-MIRE method calculates the noise reduction (NR) as the difference between the residual SPL in the ear canal and the external SPL, measured simultaneously by two miniature microphones positioned inside and outside the ear-plug. F-MIRE measurements were conducted by using “SONOPASS™” software which measures the NR and then applies compensation factors to provide an effective individual attenuation rating. The stimulus used to conduct F-MIRE measurements was a computer generated pink noise that was presented at 85 dB SPL via a speaker in frontal incidence.

When using Sonomax Self-Fit™ Hearing Protectors, sound can travel to the middle ear along two paths: a solid path and an air path. The first path corresponds to the sound going through the HPD material itself and the second path corresponds to the sound going through the filter. During F-MIRE measurements, the microphone is plugged into the hole for the filter and the HPD is “full-blocked”. The

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measured attenuation reflects the reduction of sound through the HPD. If the filter is not a full-block filter (as with brown filter), the software decreases the attenuation value to match that of the filter. For that reason, F-MIRE results should be the same for each individual. Since the F-MIRE method cannot measure the real attenuation of the ear plug with a filter, the F-MIRE measurements realized in this study have been used to verify the conformity of the custom HPD and to provide an initial prediction of the REAT.

2.4 Step 4: ASSR recordings
ASSRs are electrophysiological responses [4], recorded from the human scalp, evoked by one or more carrier frequencies (F c) that are each amplitude-modulated at a specific frequency (F m). In practice, if the subject hears such a stimulus, a peak will appears in the EEG frequency spectrum of the subject at F m. Since amplitudes and phases of ASSR are quite well correlated with the intensity of stimulation, it may be possible to measure earplug-attenuation by recording ASSRs using both normal and occluded conditions. ASSR recordings and stimuli generations were conducted by using the LabVIEW™ based “MASTER SYSTEM™” Rotman Research software. Stimulus characteristics are reported in Table 1.

3 Results and discussion
ASSR-based “physiological” attenuation has been calculated as the average difference between the normal and occluded conditions using linear least-square regression of ASSR amplitude and phase data. As seen on Figure 1, the amplitude-based estimate of attenuation computed with the highest stimulation levels (A 1) is substantially the same as the one computed with the lowest stimulation level (A 2). This attenuation effect was not as consistent in the phase data (lower graphs of Figure 1). This finding suggests that physiological attenuation seems to be more accurate when calculated from the amplitude rather than phase of the ASSR.

Physiological attenuation estimates were expected to be different from REAT-based attenuation results, because we used supra-threshold stimulation levels to deter any low-frequency masking effect. However, Wilcoxon tests failed to show any statistical difference between REAT and ASSR results (p value > 0.1). This suggests that the effect of low-frequency masking may not be as large an influence as previously assumed.

Although other electrophysiological methods have been adapted in the past for measuring the attenuation of HPD [5], no study has considered using ASSRs. The present study seeks to ascertain whether it is possible to objectively measure the attenuation of HPD using ASSRs collected in the same subject both with and without protectors. The results are encouraging: we successfully measured the attenuation in every volunteer who participated but further research, using an extended frequency range, should be done to explore this hypothesis.

<table>
<thead>
<tr>
<th>Stimulus</th>
<th>F c</th>
<th>F m</th>
<th>AM%</th>
<th>Open</th>
<th>Occluded</th>
</tr>
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<tbody>
<tr>
<td>#1</td>
<td>500 Hz</td>
<td>40 Hz</td>
<td>100 %</td>
<td>45 to 65 dB (10 dB step)</td>
<td>55 to 75 dB (10 dB step)</td>
</tr>
<tr>
<td>#2</td>
<td>1 kHz</td>
<td>41 Hz</td>
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Table 1: Characteristics of the amplitude-modulated tones used in the ASSR experiment, for both normal and occluded condition.

Figure 1: Grand mean ASSR amplitude (upper plots) and phase (lower plots) as a function of stimulation intensity, at 0.5 (left plots) and 1 kHz (right plots). Occluded results are represented by the red curves and normal results, by the blue curves. The linearity of the responses is represented by the black dotted lines. The «physiological» attenuations have been calculated as the mean difference between the two curves (A= 0.5*[A1+A2]).

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References