

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

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1 Introduction and objectives

Worldwide hearing loss estimates increased from 120 million people in 1995 [1] to 250 million in 2004 [2]. A common solution to protect workers from noise exposure consists of using hearing protection devices (HPD). An important parameter about HPD is the wearing time, since it can decrease the effective protection provided by HPD [3]. However, the recommended wearing time for limiting exposure to noise is not always respected. The occlusion effect (OE) is one of the reasons often given to justify the non-use of HPD: the occlusion of the ear canal induced a modification of the wearer's voice perception, which creates a discomfort that sometimes brings people to remove their HPD. Present methods of OE measurement have limitations. Objective measurements using microphone do not assess bone conducted sounds directly transmitted to the cochlea. Psychophysical measurements at threshold 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), which has been adapted from the methodology used in previous work for the measurement of HPD attenuation [4]. Due to the time consuming nature of ASSR recording, the study was conducted using only two stimuli having 250 and 500 Hz carriers, chosen in the low frequency range (below 1000 Hz) where the greatest positive OE is expected. ASSR results were compared to the results obtained with a subjective psychophysical method.

2 Method

2.1 Participants

Eight men with ages from 22 to 26 and hearing thresholds below 20 dB SPL (from 125 Hz to 8 kHz) were assessed. A typical experimental procedure included two steps:

2.2 Step 1: Psychophysical measurements

The psychophysical OE for each subject was measured on three trials during a single visit to the laboratory. Each trial consists of a paired open and occluded threshold, the order being counterbalanced across subjects. The hearing protectors, a pair of 3M™ foam earplugs with a 10mm insertion depth, were refitted by the experimenter for each

trial. The test signals consisted of bone-conducted pure tones at 250 and 500 Hz presented to a Radioear B-81 [5] bone vibrator which was coupled to the forehead by an elastic headband with approximately 400 to 450 g of force. For both stimuli, the level of the first presentation was 30 dB HL. The level of each succeeding presentation was determined by the preceding response. After each failure to respond to a signal, the level was increased in 1-dB steps until the first response occurred. After the response, the intensity was decreased 10 dB and another ascending series was started. The minimum number of responses needed to determine each BC threshold was three responses out of five presentations at a single level.

2.3 Step 2: Physiological measurements (ASSR)

ASSRs are electrophysiological responses, recorded from the human scalp, and often evoked by one or more carrier frequencies (F_c) that are amplitude-modulated at a specific frequency (F_m). In practice, when a subject is exposed to such a stimulus, spectral power of the EEG frequency spectrum of the subject that is related to the stimulus will be manifest at F_m , and may also appear at its harmonics [6]. Since amplitudes of ASSR are quite well correlated with the level of stimulation, it may be possible to measure the

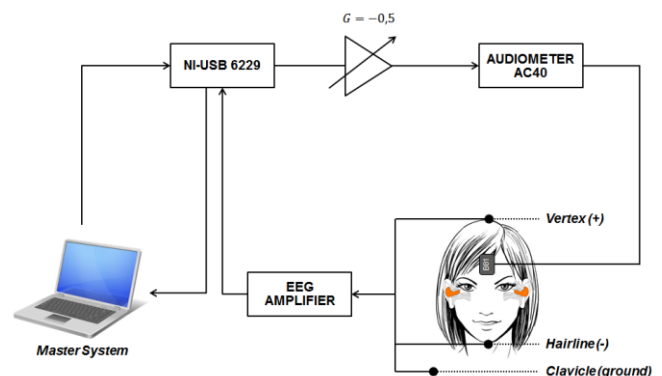


Figure 1: Overview of the experimental setup of ASSR recording. All components are monitored by a single PC. The stimulation signals from the DA output of the NI-USB 6229 board are attenuated by an operational amplifier with a gain of -0.5, so that they may be delivered to the "tape input" of the audiometer, which enables the operator to adjust the levels of stimuli delivered by the bone vibrator. In parallel, ASSRs are scalp-recorded on the electrodes (placed between vertex (+) and hairline (-), with clavicle as a ground) and are then amplified by an EEG amplifier, before reaching the AD input of the data acquisition board. Data is processed online through the MASTER SYSTEM software.

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Stimulus	F_c	Stimulation levels	F_m	AM%	FM%
#1	250Hz	0 to 20 dB _{HL} (10 dB step)	40Hz	100 %	25%
#2	500Hz	20 to 40 dB _{HL} (10 dB step)			

Table 1: Characteristics of the amplitude-modulated tones used in the ASSR experiment. The same stimulation levels were used for both normal and occluded condition.

occlusion effect 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. The setup used for the recording of ASSR is illustrated on Figure 1.

Results and discussion

ASSR-based “physiological” OEs were calculated as the average difference between the occluded stimulation levels and their unoccluded equivalents that would be obtained for the same amplitudes, which were calculated using the linear least-squares regression performed on unoccluded data. An example is illustrated in Figure 2, on the plot of the 250 Hz amplitudes for subject #1.

Physiological OEs estimates were expected to be different from psychophysical OEs, because electrophysiological assessments of hearing threshold are not biased by the low-frequency masking effect. However, results suggest that the effect of low-frequency masking may not be as large an influence as previously assumed for frequencies below 500 Hz (87.5% of subjects at 500Hz, and 25% of subjects at 250 Hz had physiological OEs that were greater than psychophysical OEs).

Although ASSRs have been adapted in the past for measuring the threshold to bone-conduction stimuli [7], no study has considered using ASSRs as a method to evaluate the OE induced by wearing HPD. The present study seeks to ascertain whether it is possible to objectively measure the OE of HPD using ASSRs collected in the same subject both with and without protectors. The results are encouraging: we successfully measured the OE in every volunteer who participated but further research, using an extended frequency range, should be done to explore this hypothesis.

Acknowledgments

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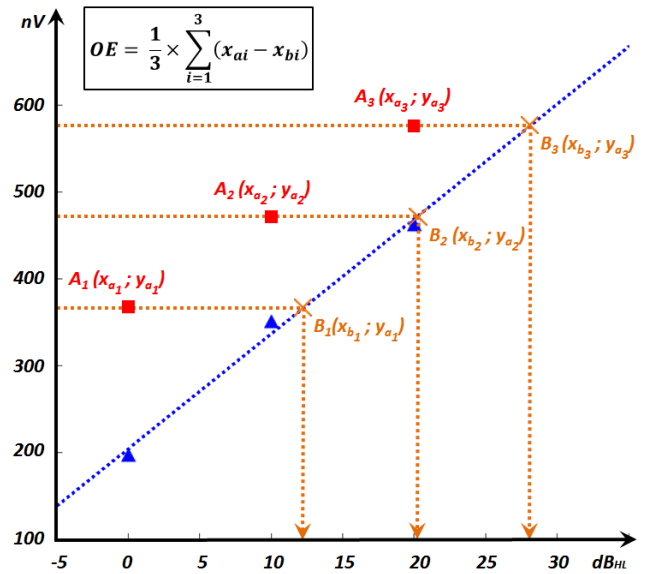


Figure 2: Example of calculation of the physiological OE from ASSR amplitudes as a function of stimulation intensity at 250 Hz, in the case of subject #1. Occluded condition results are represented by the red “■” markers and unoccluded condition results by the blue “▲” markers. The blue dotted straight line was obtained from linear last squares regression for the unoccluded condition.

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