Digital Earplug Featuring Combined Noise Dosimetry and Electrocochleography: a Proof of Concept.

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1 Introduction

Noise-induced hearing loss (NIHL) refers to a type of hearing loss caused by prolonged exposure to loud sounds, as is the case for persons evolving in noisy work environments. Continuous exposure to high noise levels can damage structures within the cochlea, specifically the inner ear hair cells, leading to a gradual and irreversible loss of hearing sensitivity. However, NIHL is preventable when using appropriate hearing protection devices and implementing proper safety measures to reduce exposure to loud sounds.

In recent studies [1, 2], electrocochleography (ECochG) has demonstrated the capability to detect auditory nerve damage associated with impaired speech perception that might result from excessive noise exposure. ECochG, an electrophysiological measure, records inner ear electrical potentials generated in response to acoustic stimulation, providing valuable insights into the impact of noise on the auditory system. In-ear noise dosimetry is a developed technique [3] which measures with precision the effective amount of noise a person has been exposed to throughout the day. To enhance hearing conservation practices in work environments, an approach integrating individual measures of noise exposure and early auditory nerve damage (through ECochG) could be used to detect degradation of hearing much sooner. This paper presents a proof of concept for an earpiece, dubbed eCoGeers, featuring concurrent noise dosimetry and ECochG.

2 Methods

The proposed method is based on the study from Pinsonnault-Skvarenina et al. (2023) [4]. The purpose is to ensure the quality of the data capture made possible with the eCoGeers Hardware and Software, which was designed and developed by the co-authors. To this aim, electrocochleography responses have been measured using a clinical gold standard system. The capability of the eCoGeers to detect this signal was assessed.

2.1 Experimental measurement of ECochG in clinical settings

Following the approach presented in [4], the clinical ECochG measures were recorded using a Smart EP Intelligent Hearing System (IHS, Miami, FL, USA) on one subject. ER-3A earphones transmitted 100 μs clicks at a presentation rate of 11.1 Hz and alternating polarity at 85 dBnHL, via silicone tubing. A 3.3 Hz–5,000 Hz passband filter was used, and the gain was adjusted to 100 000. Six trials containing 2,000 responses each were performed to obtain a grand average waveform. From the peak of the waveform, the pre-synaptic summating potential (SP) and wave I (AP) amplitudes were recorded and correlated with the pre-stimulus baseline. While the AP peak was recognized as the highest point between 1 and 2 msec after stimulus onset, the SP peak was defined as the highest point around 1 msec following stimulus onset. Additionally, latencies for the SP and AP were obtained.

2.2 eCoGeers Hardware & Software Acquisition System Design

eCoGeers Hardware

In order to measure the electrophysiological responses, the prototype eCoGeers was developed. The device is based on a prior hardware platform named CochlEEG and developed at the *ÉTS-EERS Industrial Research Chair in In-Ear Technologies* (CRITIAS) laboratories. The CochlEEG unit features a low-Noise, 8-channel, 24-Bit Analog-to-Digital Converter (ADC) for biopotential measurements and integrates the ADS1299 (Texas Instruments, Dallas, TX, USA) chip. The eCoGeers' device features a Teensy4.1 (PJRC, Portland, Oregon, USA) microcontroller unit (MCU). The MCU retrieves electrical potentials from the ADS1299 ADC and transmits them to the UART serial port. To the electronic hardware, a pair of earpiece is wired where each one features a foam eartip with an embedded gold-plated foil electrode and a circum-aural Ag/Ag-Cl reference electrode. By incorporating two audio shields equipped with an SGTL5000 (NXP, Eindhoven, Netherlands) 16-bit audio ADC/DAC, the eCoGeers hardware has the capability to record four channels. These channels are set aside for future audio functionalities, such as generating audio click stimuli for ECochG measurements performed on participants.

eCoGeers Software

The Teensyduino library, an open-source framework based on the Teensy MCU platform, served as the engine for the eCoGeers software. It is used to make the Teensy 4.1 microcontroller unit easier to control when high-level programming in C++ is used. The MCU reads the electrophysiological data from the ADS1299 ADC via the serial connection at an 8kHz sampling rate on 6 channels. The Universal Serial Bus (USB) protocol, which enables dependable data transfer and simple

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connection to a computer, is used by Teensyduino to simplify serial communication.

2.3 Signal acquisition and analysis

The signal that was sent to eCoGeers was generated using the grand average waveform of Section 2.1. The signal was upsampled to 48 kHz in order to be transmitted through the sound card to the device. 40 ms segments were created and looped over 600 times. The signal was transmitted at the same amplitude as it was recorded 0.55 microVolts. The eCoGeers device recorded the signal with a samping rate of 8 kHz. Continuous data was epoched every 40 ms corresponding precisely to the beginning of each new loop. Epochs were baselined at t0. Epochs that were dominated by noise were eliminated if there maximal amplitude was above 8 standard deviation, about 8 percent of the epochs were rejected. Data was then band pass filtered between 60 and 2000 kHz. The grand average waveform was the computed.

3 Results

Figure 1 shows the grand average waveform recorded by eCoGeers of a signal characteristic of an ECochG potential emitted at the low amplitude of ± 0.55 microvolts. After processing and averaging, the waveform recorded is clear enough to identify the relevant potentials for ECochG measurements. The SP and AP peaks were found at the same latencies as the original signal.

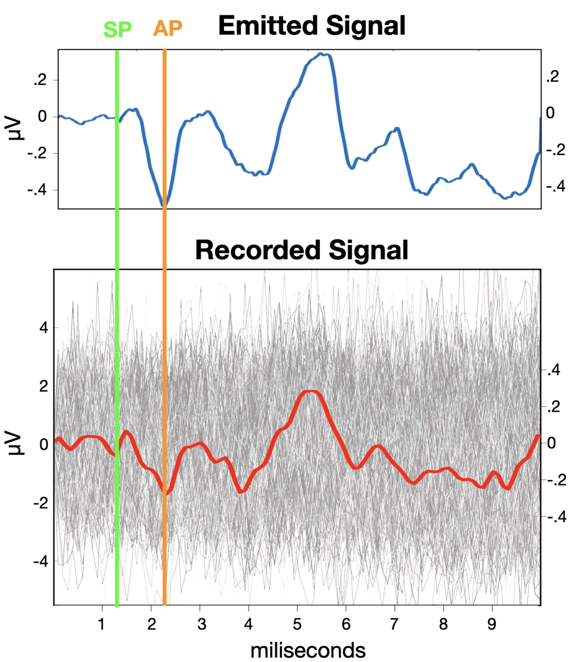

Figure 1: Recordings of the ECochG. Top plot is what was sent to eCoGeers, bottom plot is what the eCoGeers recorded (right axis refers to the red trace representing the average of 400 trials)

4 Discussion

The corresponding responses between the ECochG template and the eCoGeers recorded signal at 0.55μV shows that the device can successfully extract low-level voltage of an ECochG response from the electrical noise floor when extracting grand average waveforms.

Electrocochleography combined with in-ear dosimetry holds a great promise as an effective approach for hearing loss prevention. In a previous study [3], instrumentation and algorithms have been developed for measuring in-ear noise exposure. This method is important in order to precisely quantify noise exposure instead of approximating noise levels delivered to the cochlea with hearing protection. Added to electrocochleography, this new approach could lead to a better understanding of auditory damages, as we could correlate data of in-ear noise exposure throughout the day with auditory impairment.

Further research is needed to ensure the eCoGeers's autonomy and ready to use state. We anticipate that limits of the electric floor noise could be potential challenges in the future.

5 Conclusions

The results obtained on the eCoGeers device demonstrate the capacity of this device to record electrocochleography and dosimetry. The eCoGeers device could ultimately be used to detect damage to auditory nerve fibers following noise exposure with electrocochleography after necessary further advancements and real-world validation studies. Together this hearable technology could be used to protect the wearer against loud sounds, monitor real-time noise exposure and detect auditory damage. The wearer could then be alterted to this hearing degradation and react accordingly, thereby effectively improving occupational noise-induced hearing loss prevention programs.

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