

A Recording System for the Study of Tinnitus Through Auditory Evoked Potentials

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Abstract— Tinnitus is a consciously experienced ‘ringing’ sensation in the auditory system, which occurs without the presence of an actual auditory stimulation. The study of tinnitus has resulted in a number of speculated mechanisms and suspected origins in the auditory pathway, however a definite model for this phenomenon has not been confirmed. In the majority of cases, external acoustic stimulation masks the tinnitus sensation and the offset of tinnitus is preceded by the complete withdrawal of acoustic stimulus. This paper describes a research effort to study the neurological expressions of tinnitus by analyzing Auditory Evoked Potentials (AEP). The signals constituting the evoked response are many times smaller than the surrounding EEG signals. The paper describes the methodology and the instrument design to overcome this problem. The study concentrates in the analysis of AEP signals during silence, as well as the transitional nature of the AEP in order to identify possible EEG correlates of tinnitus.

Index Terms—Auditory Brainstem Response (ABR), Auditory Evoked Potential (AEP), Tinnitus.

I. INTRODUCTION

Tinnitus is reported by many individuals as a ringing, buzzing or hissing noise experienced when located in a quiet environment. For many individuals this noise is loud enough to cause emotional stress, hearing impairment and even psychological trauma. Studies in this area have not been able to identify a definite location within the neuro-auditory pathway as responsible for the tinnitus perception. Several research studies suggest that the cause of tinnitus may be widely distributed within the auditory system. However, based on noticeable differences in the nature of perception of tinnitus experienced by many individuals, tinnitus occurrences can be classified into two groups: Peripheral Tinnitus and Central Tinnitus. Peripheral Tinnitus is assumed to originate from the peripheral nervous system and cochlea, while Central Tinnitus is assumed to originate in the Auditory Cortex. Temporary presence of Tinnitus may be experienced from sudden acoustic, mechanical or barometric trauma. Persisting forms of Tinnitus are most commonly associated with disorders or damage in the inner ear or neuro-

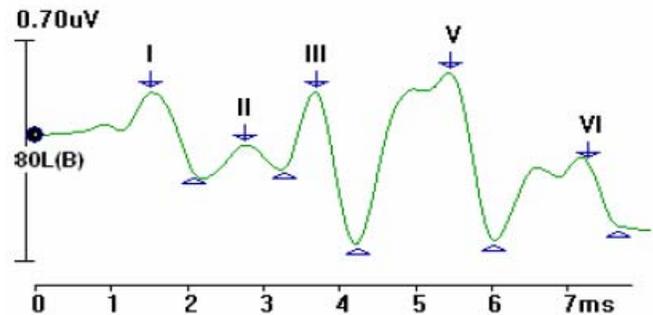


Fig. 1. A typical AEP waveform used for basic audiometric screening (courtesy of Intelligent Hearing Systems, <http://www.ihsys.com>).

auditory pathway [11]. Symptomatic expressions of Tinnitus have been associated with neural or otological dysfunctions or degenerations such as, Age Related Hearing Loss[1], Noise Induced Hearing Loss[1], Meniere’s disease, Multiple Sclerosis and Acoustic Neuroma. Neurological aspects of tinnitus have been extensively studied mostly through animal models. Studies related to the efferent nervous system controlling the inner hair cells [9] show sufficient evidence of Tinnitus being related to spontaneous neural activity. The pitch of tinnitus in noise induced hearing loss frequently correlates with the characteristic frequency of the firing rate of neurons innervating the inner hair cells of noise-damaged regions[4]. Tinnitus has been reported following surgery of the eighth nerve [3,12]. Different types of destructive surgery including neurectomy failed to improve or abolish Tinnitus [8].

II. RESEARCH GOALS

The instrument described in this paper has been developed in order to identify neural activity that might be correlated with Tinnitus, by analyzing the Auditory Evoked Brainstem Response. The skin measurements of Electroencephalogram (EEG) potentials are contributed by the superposition of numerous synaptic potentials originating in different regions of the brain. The contributors in scalp EEG measurements are classified according to their spectral significance as the alpha, beta and gamma components. Typical scalp EEG magnitudes range between 5-200 μ V.

Evoked potentials are electrical signals that result from neural activity which occurs in response to an experimental stimulus. Auditory Evoked Potentials (AEPs) originate along the neural pathway in response to appropriate acoustic stimuli.

AEP magnitudes are typically below $10 \mu\text{V}$, with a characteristic wave shape composed of several peaks. The AEP magnitudes are considerably smaller in magnitude than other background EEG components. Therefore a synchronized averaging technique is utilized to enhance the AEP responses in contrast to the background EEG. AEPs are commonly used for basic audiometric evaluation. This type of general study of Auditory Brainstem Response (ABR) observes a series of positive to negative going peaks occurring within about 10 mS after stimulus onset. A Typical ABR response is shown in Fig. 1.

Two types of stimuli are used in AEP studies: ‘click’ and ‘tone pip’ [7]. The click stimulus is a brief rectangular pulse of 50-200 μS duration. The pip stimulation is a tone burst which is used to evaluate the frequency-specific sensitivity of an individual. The click stimulus provides a gross estimate of hearing sensitivity. The rapid onset of the click provides good neural synchrony, eliciting an AEP with accurate temporal clarity of the associated neural activity.

ABR measuring instruments designed for general audiometric screening generate 17-20 clicks per second, recording up to 20 mS of post stimulus response. In the intended experiment, the major objective is to record prolonged AEP responses generated by clicks, in order to observe the transitional nature of the AEP waveforms, well into the silent period. This research will investigate and identify characteristic differences in prolonged AEP patterns between individuals reporting Tinnitus and individuals with healthy hearing. The following sections describe the design of an AEP measuring instrument capable of recording AEPs for more than one second, at high sampling rates.

III. HARDWARE CONFIGURATION

The instrument designed for the AEP measurements involves hardware and software integration. The hardware consists of a National Instruments Daqpad-6052E [6] Data Acquisition System, a TDT HS4 Biological Amplifier [10] with a DB4 control module, a headphone distribution amplifier and a Personal Computer. The software has been developed for control and signal processing purposes using the Matlab Data Acquisition Toolbox TM [5]. A simplified model shown in Fig. 2 illustrates the layout of the functional components.

The National Instruments Daqpad-6052E data acquisition system is configured to digitize three analog channels. Two of the channels record the ipsilateral and contralateral AEP waveforms respectively. The third channel is configured to record the stimulus fed back through one channel of the front end bio-amplifier. This third channel, which is part of the ‘stimulus monitor’, provides a temporal reference to stimulus onset, which is used to adjust the trigger position with reference to the acoustic stimulus. The sampling rate chosen

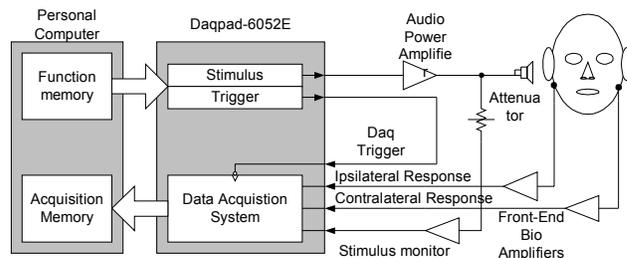


Fig. 2. Schematic layout of the functional components in the instrument design.

for this application is 44,100 samples per second with a resolution of 16 bits. The Daqpad provides a TTL compatible input to initiate data acquisition. Data acquisition starts at the falling edge of the trigger signal.

The National Instruments Daqpad-6052E provides two channels of analog output, which function at 44.1KHz with 16 bit resolution. One of these channels delivers the acoustic stimulus. This output is fed into a headphone distribution amplifier. One output channel from this amplifier drives an earphone to deliver the acoustic stimulus. Another output from the distribution amplifier is fed into one of the channels of the bio-amplifier in order to estimate the time lag caused by the front end bio-amplifier. The headphone distribution amplifier provides isolation, load balancing and independent amplitude control of individual channels. The remaining Daqpad analog output channel is used to generate the trigger signal to initiate the data acquisition process. The TDT bio-amplifier is composed of a front-end ‘head stage’ and a back-end ‘control module’. The two subunits are connected via optical fiber for safety and noise immunity. The bio-amplifier is configured with a 5Hz high-pass filter and a 5KHz low-pass digital filter. These filters introduce a fixed delay in the AEP readings when time aligned and compared with the stimulus. Therefore a lag correction method becomes necessary for proper alignment with the stimulus time reference. The gains for the AEP channels are set to 50,000 V/V. The stimulus is fed into a third channel, which is part of the stimulus monitor pathway, via a 60dB attenuator. The gain for this channel is set to the minimum, which is 100 V/V. This arrangement is made so that it is possible to estimate the time lag caused by the bio-amplifier. This information is used to delay the triggering of the data acquisition process, so that an accurate click reference is available at the first sample of each acquired data frame.

IV. SOFTWARE

The software for the system has been implemented in Matlab. The major functions performed by the program are: Device initialization, control, calibration, data transfer and real-time signal processing. A ‘Function Memory’ is created to store two data buffers, used to generate the click and trigger sequences encoded at 16 bit resolution of 44100 samples each. During the calibration process, the click

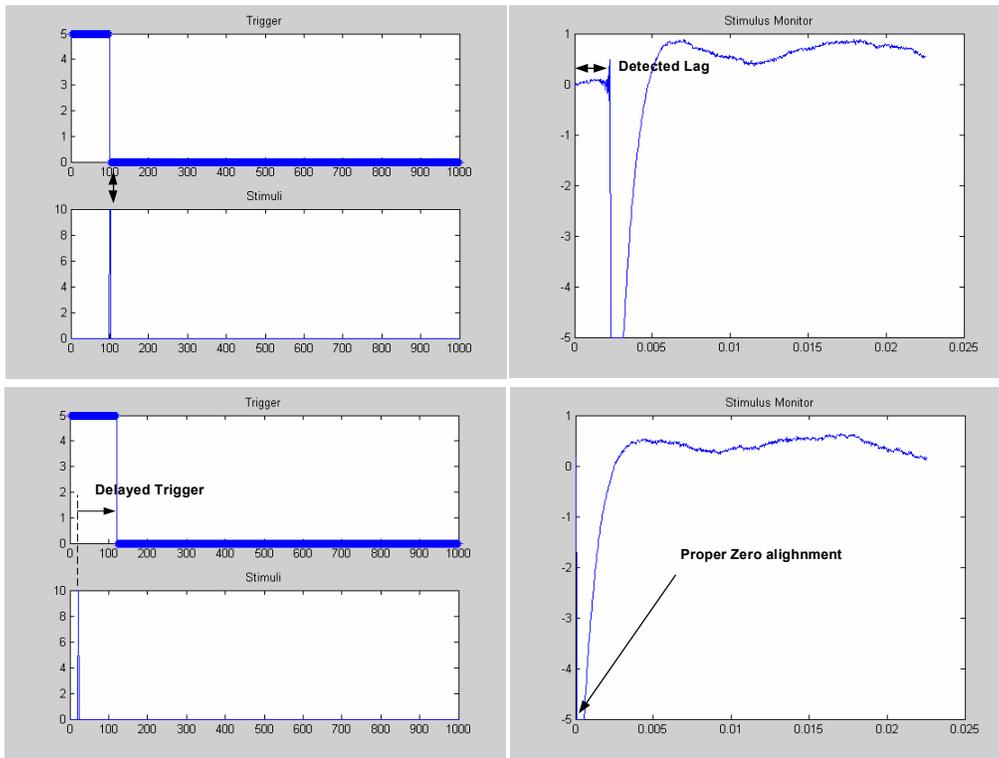


Fig. 3. method for lag detection and zero alignment. Top: pre-calibration, Bottom: post-calibration.

sequence and trigger sequence are re-aligned in the buffers, to counter the measured bio-amplifier delay, as shown in Fig. 3. To measure this delay, the click and trigger sequences are aligned at the same temporal position and streamed into the Daqpad. Data acquisition starts immediately upon receiving the trigger, however, the click fed back through the stimulus monitor channel is delayed due to the lag introduced by the bio-amplifier. This delay is measured and in the final calibrated sequence, the falling edge of the trigger is retarded by the same number of samples as the measured delay. As illustrated in Fig. 3, this repositioning ensures that the time axis '0' point in the calibrated measurements is aligned with the stimulus.

After calibration, the AEP measurement begins. During the AEP recording session, each trial acquires a desired duration of AEP readings. All trials in a particular session sample the same duration of AEP response. The Acquisition Memory can be configured to hold three channel samples for up to 10 seconds, sampling at 44100 samples per second. Multiple trials, synchronized to their corresponding stimuli, are recorded in each measurement session. Each frame of acquired data channels is aligned with the previous frame and accumulated point by point. Measurements are usually taken in sessions of 512 or 1024 stimuli (trials). Upon the completion of each trial, the newly acquired response is incorporated to update the average response, which is presented on screen in real time, so that the operator can observe the results in progress. Fig. 4 shows the real-time measurement window available to the operator. The

calibration process is performed only once per setup.

V. AEP RECORDINGS

Fig. 5 shows an example of long latency measurements showing two 1-second responses, averaged from 1024 trials each. AEP sessions are saved in files containing the three channel time-synchronized averaged readings and other critical data such sampling rate, subject information, etc. Fig. 6 and 7 show 18 mS AEP measurements comparing the responses between two subjects. The responses shown in Fig. 6 were measured from a subject with healthy hearing. The AEPs shown in Fig. 7 were acquired from a Tinnitus subject. Some clear differences are apparent in the long latency regions of these sample recordings.

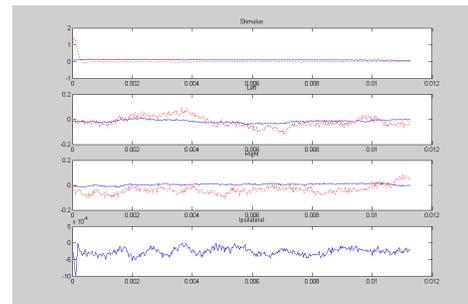


Fig. 4. Screen capture of the operator interface. From top to bottom: Stimulus monitor, Left AEP, Right AEP and Averaged Ipsilateral AEP.

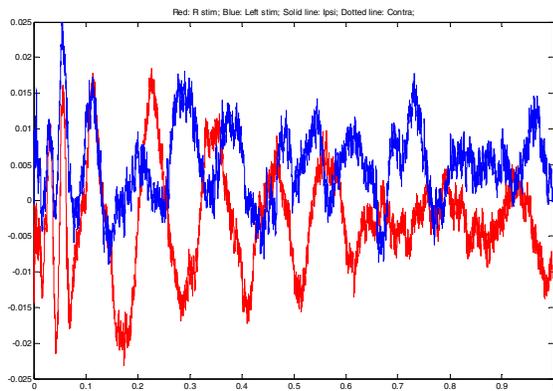


Fig. 5. Ipsilateral AEPs of 1 second recordings, 1024 trials.

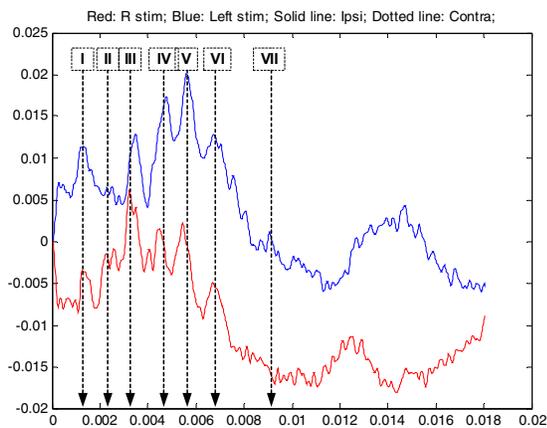


Fig. 6. AEP recordings from a subject with healthy hearing: Left (blue) and Right (red) AEP recordings averaged from 1024 trials with peaks I through VII identified. The clicks were presented in the right ear.

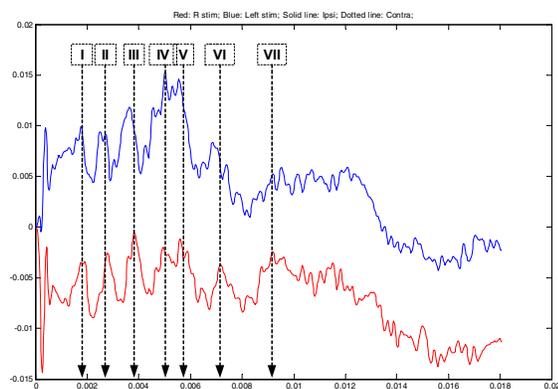


Fig. 7 AEP recordings from a subject with Tinnitus: Left (blue) and Right (red) AEP recordings averaged from 1024 trials with peaks I through VII identified. The clicks were presented in the right ear.

VI. CONCLUSION

The investigation of EEG related to tinnitus requires analysis of the AEP signals including long latency features. Regular AEP measurement instruments for audiometric screening are limited in their capabilities to record these features. Therefore, it was necessary to develop a AEP measurement system featuring extensive flexibility and configurability to study the EEG correlates of tinnitus.

This paper presented the conceptual development, software and hardware integration for the AEP measurement setup. It utilizes off-the-shelf components and the software was developed on a PC platform in Matlab. The paper describes the methodology for instrument delay measurement and lag compensation, which ensures proper zero time axis calibration.

The measurements shown as example in this paper demonstrate the capabilities of the instrument setup. The recording period, sample rate and resolution of the AEP recordings made using the prototype demonstrate promising implications in further analytical techniques for identifying EEG correlates of tinnitus. Our immediate goal is to investigate the potential decomposition of these responses using sequential application of Prony's method, which has been used to analyze other forms of evoked potentials [12].

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