A BIOINSTRUMENTATION SYSTEM FOR THE IDENTIFICATION OF EEG CORRELATES OF TINNITUS

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ABSTRACT

Tinnitus is the spontaneous 'ringing' sensation within the auditory system reported by many individuals, which currently can only be diagnosed by behavioral response. Studies in this area have yet to identify definite mechanisms or sites associated with the generation of this sensation. The tinnitus sensation is typically reported to be prominent during silence. In addition, the complete withdrawal of auditory stimulus usually precedes the onset of the tinnitus sensation. This paper describes the conceptualization, integration and testing of an experimental instrument, developed to observe Auditory Evoked Potentials (AEPs) in order to identify possible EEG correlates of tinnitus. The instrumental setup permits the study of AEP responses during silence, as well as to observe the transitional nature of the AEP.

INTRODUCTION

Tinnitus is categorized as a disorder of the auditory system. Tinnitus patients report a spontaneous ringing, hissing or humming sensation in the ear(s) or inside the head. Tinnitus may be experienced temporarily due to the exposure to sudden mechanical or barometric trauma. Perceiving forms of tinnitus are known to be associated with damage or dysfunction in the neuro-auditory pathway [1]. Symptomatic expressions of tinnitus have been associated with neural or otological dysfunctions or degenerations such as, Age Related Hearing Loss[2], Noise Induced Hearing Loss[2], Meniere's disease[3], Multiple Sclerosis [4] and Acoustic Neuroma [5].

PREVIOUS STUDIES

Previous research in the study and modeling of tinnitus suggests that it is reasonable to consider that the generation of tinnitus involves several structures, which might be widely distributed over the whole auditory system. The neurological aspects of tinnitus were investigated by different groups. 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[6]. Tinnitus has been reported following surgery of the eighth nerve [7,8]. Different types of destructive surgery including neurectomy failed to improve or abolish tinnitus [9]. Studies related to the efferent nervous system controlling the inner hair cells [10] show sufficient evidence of tinnitus being related to spontaneous neural activity.

RESEARCH GOALS

Instrumental methods to demonstrate objective evidence of tinnitus have been difficult to develop. The group of Colding-Jorgensen, et al. claimed to have performed an objective test using auditory evoked magnetic fields [11,12]. However, extensive attempts to replicate these results have been unsuccessful [13]. 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 Potentials (AEP). The skin measurements of electroencephalogram (EEG) potentials are contributed by the superposition of numerous synaptic potentials originating in different regions of the brain.

Evoked potentials are electrical signals that result from neural activity, which occurs in response to an experimental stimulus. Auditory Evoked Potentials originate along the neural pathway in response to appropriate acoustic stimuli. AEP magnitudes are typically below 10 μV, with a characteristic wave shape composed of several peaks. The AEP magnitudes are considerably smaller in magnitude than other background EEG components (5-200 μV). 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 Figure 1.

Two types of stimuli are used in AEP studies: 'click' and 'tone pip' [14]. 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.

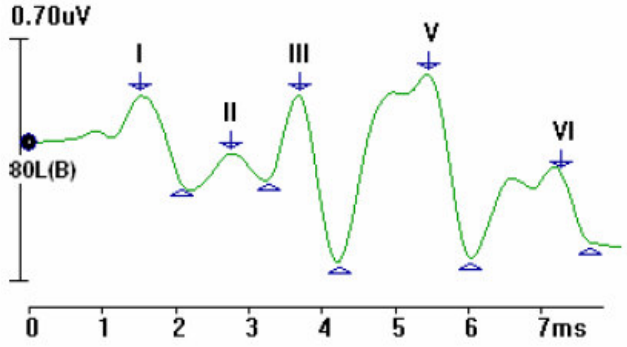

Figure 1. Typical AEP waveform used for basic audiometric screening (Courtesy: Intelligent Hearing Systems, Corp.)

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. Due to the experimental and explorative nature of the study, the instrument design was required to have the following futures:

1) High sampling rate / high resolution samples, compared to standard clinical measurements
2) Capability to compensate for different signal delays, according to different experimental configurations, to faithfully mark the time axis zero points in the AEP measurements

3) An open ended software and hardware architecture with highly configurable trigger and synchronization methods
4) Versatility to configure different types of signal processing modules for offline and runtime processing
5) Capability to record AEP measurements for variable and prolonged periods
6) Compatibility of the instrument to run with different types of acoustic stimulations
7) Reconfigurable triggering and time-stamping signals
8) Reconfigurable measurement parameters such as cutoff frequencies, gain, attenuation and delay for different signals

The following sections describe the design of an AEP measuring instrument developed with those performance goals and capable of recording AEPs for more than one second, at high sampling rates.

HARDWARE CONFIGURATION

The instrument designed for the AEP measurements involves hardware and software integration. The hardware consists of a National Instruments Daqpad-6052E [11] Data Acquisition System, a TDT HS4 Biological Amplifier [12] 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 Matlab Data Acquisition Toolbox ™ [13]. A simplified model shown in Figure 2 illustrates the layout of the functional components.

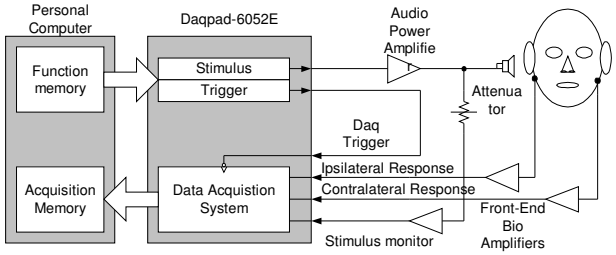

Figure 2. Schematic layout of the functional components in the instrument design.

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 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 and a 5KHz low-pass digital filters. These filters introduce a fixed delay in the AEP readings when time aligned and compared with the stimulus. Therefore, a lag correction method (described below) becomes necessary for proper alignment with the stimulus time reference.

The gains for both AEP channels are set to 50,000 V/V. The stimulus is fed into the 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.

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 of 44100 samples each. During the calibration process, the click sequence and trigger sequence are re-aligned in the buffers, to counter the measured bio-amplifier delay, as shown in Figure 3. To measure this delay, a calibration stimulus is issued, fed back through the bioamplifier, and recorded, observing its delay. In the final calibrated sequence, the falling edge of the trigger is retarded by the same number of samples as the measured delay. This repositioning ensures that the time axis '0' point in the calibrated measurements is aligned with the stimulus (Figure 3).

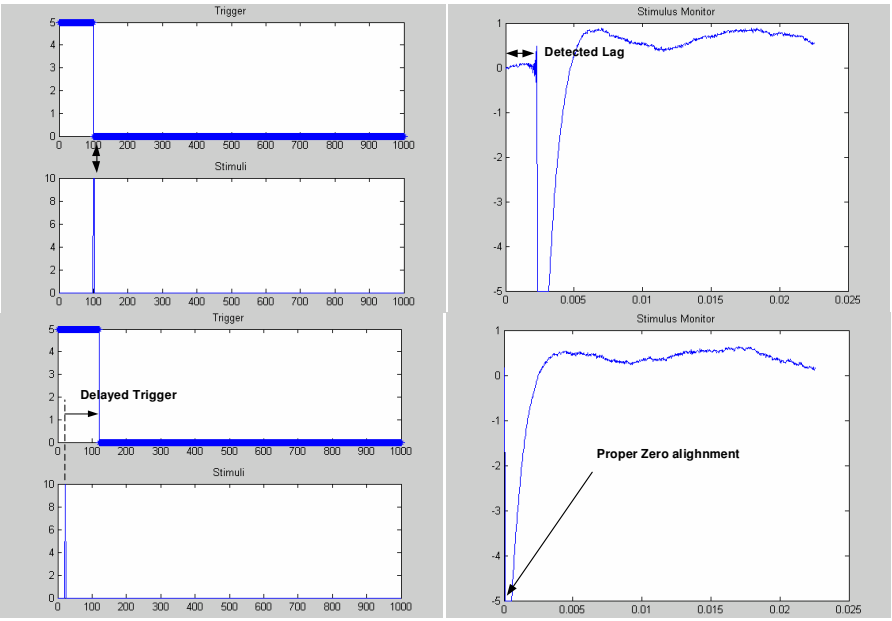

Figure 3. Calibration method for lag detection and zero alignment. Top: pre-calibration, Bottom: post-calibration.

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 (Figure 4), so that the operator can observe the results in progress.

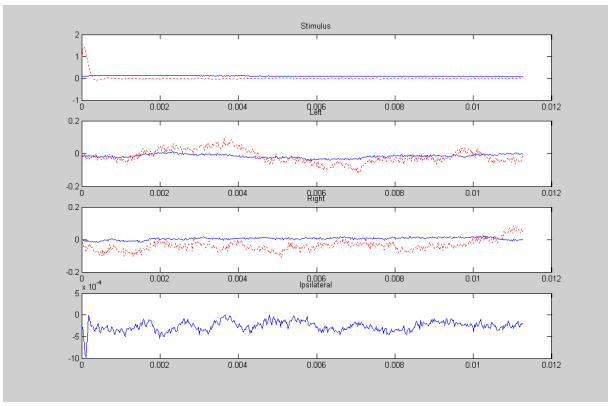

Figure 4. Screen capture of the operator interface. From top to bottom: Stimulus monitor, Left AEP, Right AEP and Averaged Ipsilateral AEP

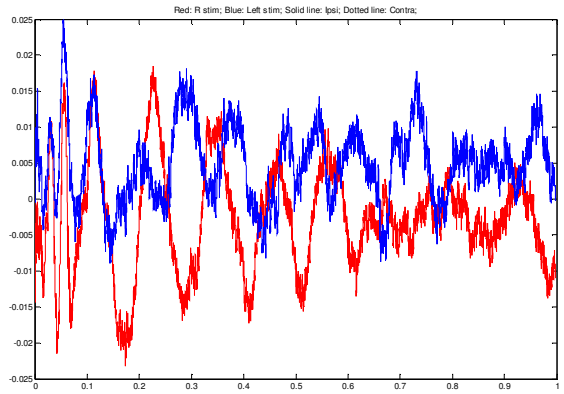

Figure 5. Ipsilateral AEPs of 1-second recordings, 1024 trials

AEP RECORDINGS

Figure 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. Figure 6 shows 18 mS AEP measurements comparing the responses between two subjects. The left frame shows AEPs measured from a subject with healthy hearing. The AEPs in the right frame were acquired from a tinnitus patient. Some differences are apparent in the medium latency regions of these sample recordings.

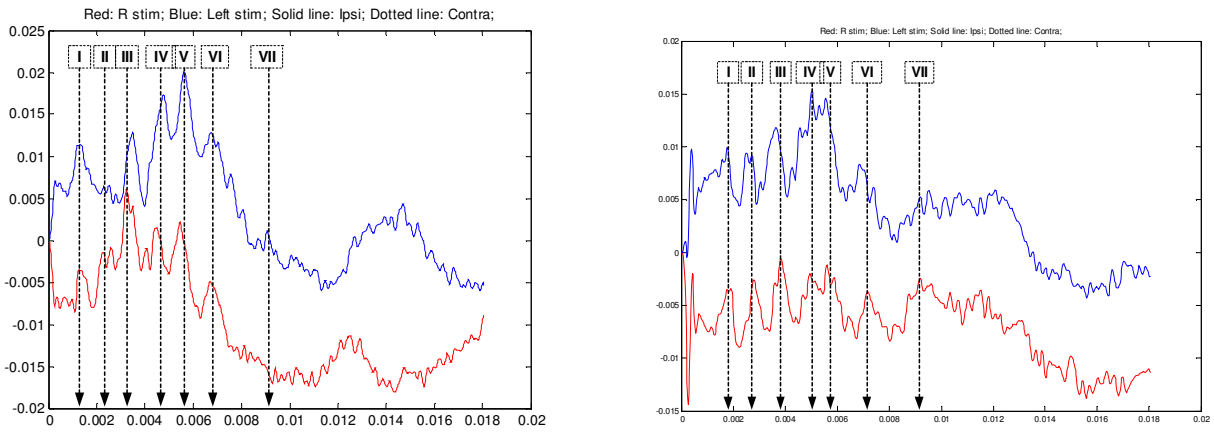

Figure 6. Averaged (1024 trials) AEP recordings form a normal-hearing subject (left frame) and a Tinnutus subject (right frame), with peaks I–VII identified. The upper and lower traces show the ipsilateral AEPs from the left and right ears respectively.

CONCLUSION

In order to study possible EEG correlates of tinnitus it was required to develop a bioinstrumentation system which offers an open architecture that is highly configurable, robust, and offers high accuracy in timing and AEP measurements, including the long latency features which are beyond the recording capabilities of conventional audiometric screening instruments. The instrumentation system software is based on Matlab, which provides a powerful means for signal processing and statistical analysis during runtime or offline. In addition, Matlab provides a versatile interface for instrument control and configuration. Because of the integration of Matlab in this system, the trigger and acoustic stimulation functions can be generated through the theoretical implementation of mathematical concepts, which means that the stimulus functions are not only limited to click and pip, but can be extended to experimental stimulation waveforms. Similarly time locked evoked responses can be averaged in real time using experimental transform domains. The graphical data presentation features also provide innovative diagnostic presentation schemes, which may present a powerful graphical indicator of tinnitus related activity.

The sample records collected with the system and illustrated in this paper confirmed the capability of this prototype to acquire records with the required characteristics of sampling rate and length. In fact, some interesting differences in the long latencies of records from tinnitus and non-tinnitus subjects seemed to be emerging already. Current availability of this prototype will enable the acquisition of data from a larger number of subjects, towards the definition of algorithms to quantify the differences in these responses. In addition, due to its open architecture and designed flexibility, this bioinstrumentation setup is likely to find other additional applications in the area of evoked response research.

ACKNOWLEDGMENTS

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