An Auditory Evoked Potential Measurement System to Study Tinnitus

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Abstract

Tinnitus is a consciously experienced 'ringing' sensation in the auditory system, which, so far can only be diagnosed by behavioral response. The study of Tinnitus has resulted in a number of speculated mechanisms and suspected origins within the human auditory pathway. A definitive model for this phenomenon is yet to be formulated. 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. Therefore, the objective of our research is to facilitate the study of the Auditory Evoked Potential (AEP) response during the silent period that ensues simulation, as well as to observe the transitional nature of the AEP. This paper describes the conceptualization, integration and testing of an experimental instrument setup for observing AEP, in order to identify possible EEG correlates of tinnitus.

1. Introduction

Tinnitus is described as a disorder by which a person perceives a spontaneous auditory sensation in the absence of a true acoustic stimuli. A 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 auditory-neural pathway [10]. 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. Tinnitus occurrences can be classified into two groups: Peripheral Tinnitus and Central Tinnitus. There is noticeable difference in the perception of these two types of Tinnitus. Peripheral Tinnitus is assumed to originate from the peripheral nervous system and cochlea, while Central Tinnitus is assumed to originate in segments of the auditory neural pathways beyond the cochlea.

2. Neurological Activity and Tinnitus

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 have been 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[3]. Tinnitus has been reported following surgery of the eighth nerve [2,11]. Different types of destructive surgery including neurectomy failed to improve or abolish Tinnitus [7]. Studies related to the efferent nervous system controlling the inner hair cells [8] show sufficient evidence of Tinnitus being related to spontaneous neural activity.

3. 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 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 0.5-4 mV.

Evoked potentials are electrical signals reflecting neural activity that 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 μV, with a characteristic wave shape composed of several peaks. The AEP signals 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

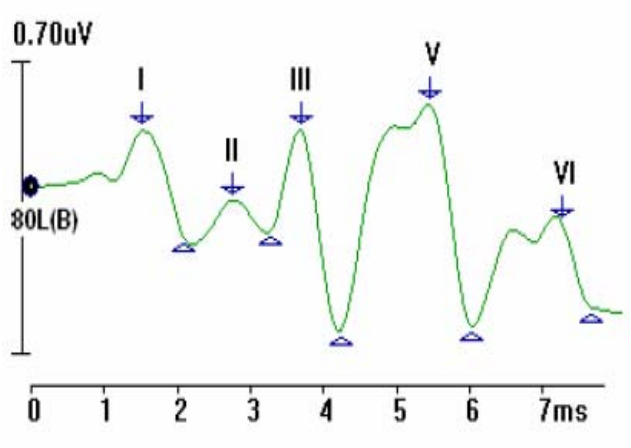

Figure 1. A typical AEP waveform used for basic audiometric screening (Courtesy of Intelligent Hearing Systems, http://www.ihsys.com).

(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' [6]. 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.

4. Hardware Configuration

The instrument designed for the AEP measurements involves hardware and software integration. The hardware consists of a National Instruments Daqpad-6052E [5] Data Acquisition System, a TDT HS4 Biological Amplifier [9] with a DB4 control module, a headphone distribution amplifier and a Personal Computer. The software has been

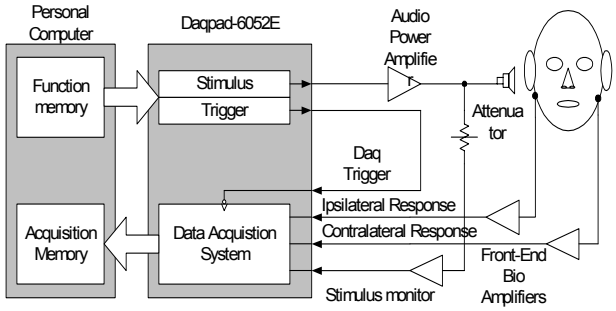

Figure 2. Schematic layout of the functional components in the instrument design.

developed for control and signal processing purposes using Matlab Data Acquisition Toolbox ™ [4]. A simplified model shown in Figure 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 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 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

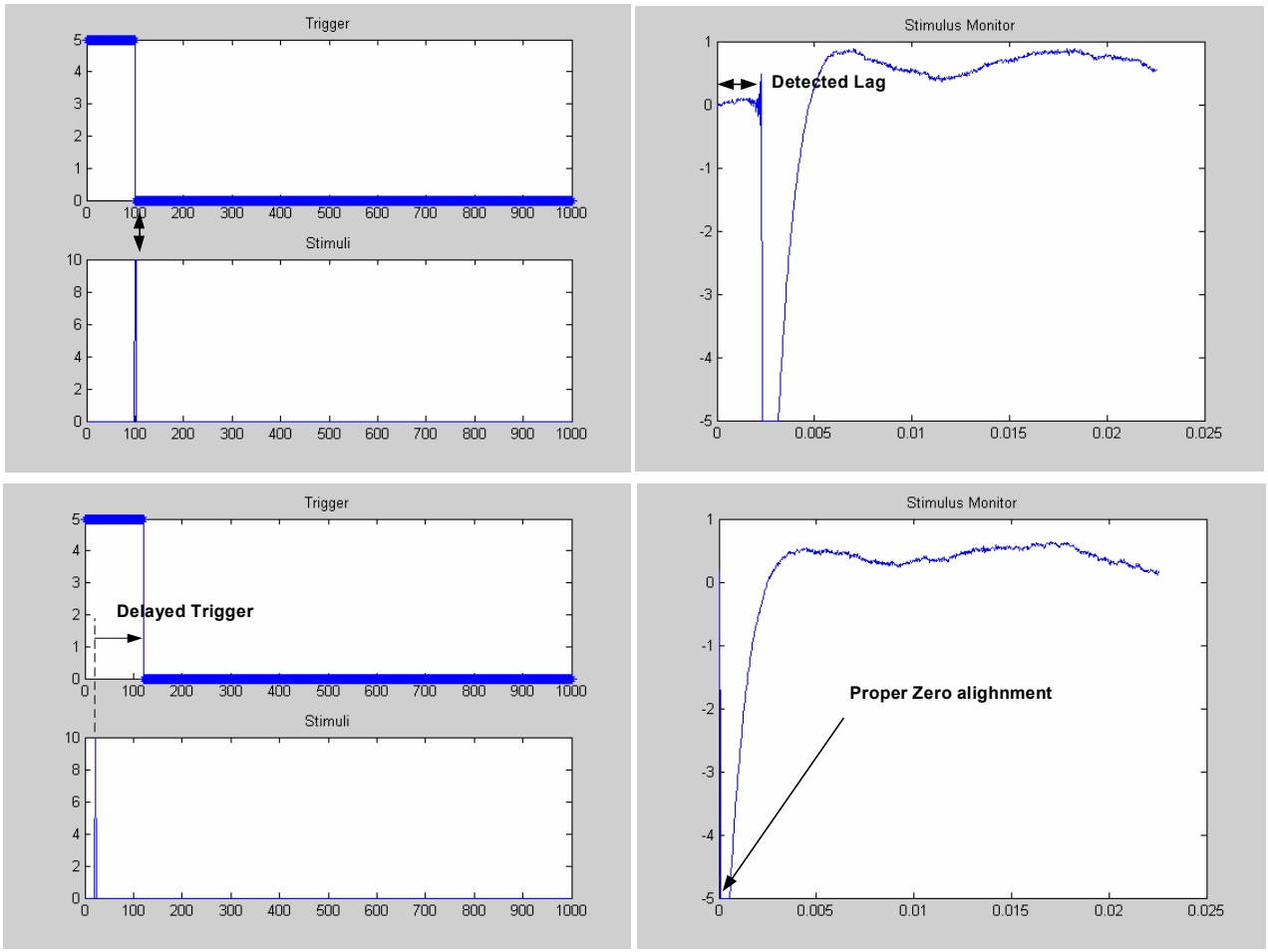

Figure 3. Calibration method for lag detection and zero alignment. Top: pre-calibration, Bottom: post-calibration

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.

5. 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 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, 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 Figure 3, this repositioning ensures that the time axis '0' point in the calibrated measurements is aligned with the stimulus. This calibration process is performed once per setup.

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).

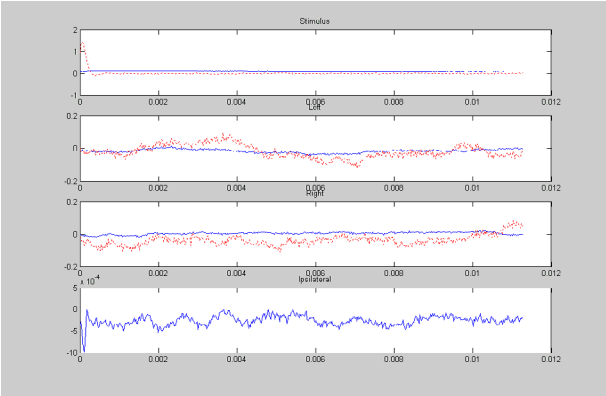

Figure 4. Screen capture of the operator interface. From top to bottom: Stimulus monitor, Left AEP, Right AEP and Averaged Ipsilateral AEP.

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. Figure 4 shows the real-time measurement window available to the operator.

6. 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. Figures 6 and 7 show 18 mS AEP measurements comparing the responses between two subjects. The responses shown in Figure 6 were measured from a subject with healthy hearing. The set of AEPs in Figure 7 were acquired from a Tinnitus patient. Some clear differences are apparent in the mid-latency regions of these sample recordings.

7. Conclusion

In order to explore the potential correlates of Tinnitus in EEG signals, it was necessary to develop an instrumental setup for the measurement of auditory evoked responses, including their long latency features which are beyond the recording capabilities of conventional audiometric screening instruments.

This paper presented a conceptual development and hardware and software integration of such a recording system. The prototype discussed utilizes off-the-shelf bio-amplifiers and data acquisition equipment controlled by purpose specific software written in Matlab. Particular care was applied to measure and compensate for the lag introduced by the bio-amplifier used, in digitized evoked potential responses.

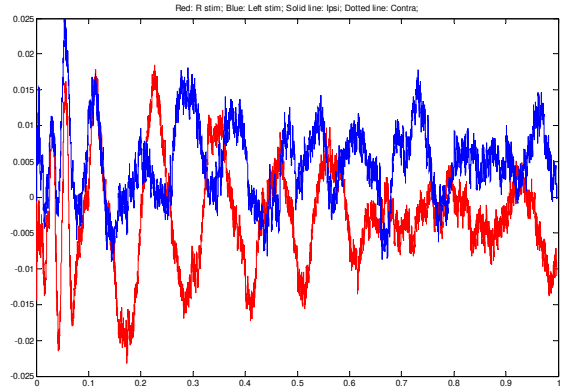

Figure 5. Ipsilateral AEPs of 1 second recordings, 1024 trials.

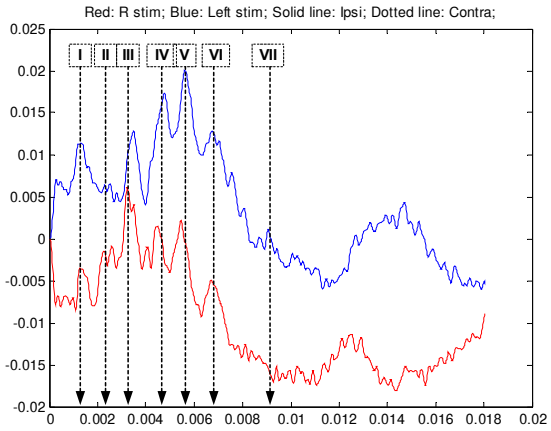

Figure 6. Recordings from a normal-hearing subject: Left (upper trace) and Right (lower trace) Ipsilateral AEP recordings averaged from 1024 trials with peaks I through VII identified.

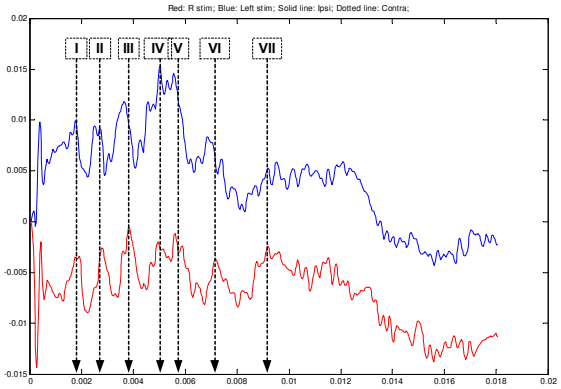

Figure 7. Recordings from a Tinnitus subject: Left (upper trace) and Right (lower trace) Ipsilateral AEP recordings averaged from 1024 trials with peaks I through VII identified.

The sample records collected with the system and illustrated in this paper confirmed the capability of this prototype to acquire AEPs with the required characteristics of sampling rate and length. In fact, some interesting differences in the mid-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.

8. Acknowledgements

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