Effect of stimulus phase reversal on the 20-35 Hz frequency component of the AEP.

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***Abstract*—Auditory evoked potentials (AEP) have been recorded to investigate the effect of phase reversal of the stimulus presentation. Acquisition of the Middle Latency Response (MLR) for both homophasic and antiphasic cases was obtained by epoch averaging 500 trials of in-phase and 500 trials of out-phase EEG. An epoch was defined as the EEG data between 20 ms to 100 ms after the presentation of stimuli. The MLR was segmented by a trigger signal synchronized to the onset of the stimuli. The homophasic stimulus was a 1000 Hz Blackman windowed pure tone with a duration of 18 ms followed by 200 ms silence. The antiphasic stimulus was identical except for the phase of the stimulus. The stimuli were presented as blocks of 10 antiphasic tones followed by 10 homophasic tones for a total of 1000 tones.**

The comparison of the MLR responses upon presentation of homophasic and antiphasic stimuli showed there is electrophysiological evidence of binaural processing in the 20-35 Hz dominant frequency component.

I. Introduction

Event-related potentials (ERPs) are a series of voltage changes caused by an evoked neural activity [1]. Auditory evoked potentials (AEP) are time-locked events caused by a sound stimulus. They are the electrophysiological reaction to a sound and also reflect the function of the auditory pathway. AEP can be elicited by a number of different stimuli such as short duration clicks (100 to 500 ms) [2] and sinusoidal amplitude modulated tones [3]. The electrophysiological response in the form of AEPs are captured by an electroencephalogram (EEG).

The raw EEG signal has amplitudes in the range of μV with an extremely poor signal-to-noise ratio (SNR). The central nervous system (CNS) creates spontaneous random bioelectric activity in the absence of sensory stimulation which can be recorded using scalp electrodes. Spontaneous EEG components are not consistent with the onset of the stimuli, and elicit a significantly larger potential than the AEPs. This can mask the underlying neural processes related to the stimulus induced event potentials. Spontaneous EEG signals can be created by attention changes, language processing and perception [1].

Trigger-synchronized averaging is a common technique used to significantly improve the SNR [2]. This method involves synchronizing a short rectangular pulse signal to the beginning of the duration of the stimulus. By doing this, the time of the onset of the stimulus can be accurately recorded. This information is then used to segment the data to create a series of epochs, which contain the AEPs which are of interest and other spontaneous EEG components. The non event-related potentials are not consistent in onset and therefore, when averaged, the amplitude of non-related potentials decreases relative to time and phase locked potentials elicited by the stimuli.

The extracted AEP signals consist of a number of characteristic waves depending on duration after the onset. The conventional analysis of the AEP is mainly concerned with the measurement of amplitude and latencies of particular peaks [2].

AEPs have been used in both clinical [4] [5] and research [2] settings for studying and analysing the auditory system. Depending on the onset time and the progression of the potentials, they can be classified into four categories:

- electrocochleography
- the brainstem response
- the mid-latency response, and
- the long-latency response.

Electrocochleography (ECoG) is the measurement of potentials generated by presynaptic activity in hair cells and the compound action potential of the cochlear nerve. The time duration for the ECoG potentials is up to 10 ms after stimulation [6]. The brainstem response is concerned with electrical activity in the brainstem and cochlear nerve up to 20 ms after stimulation. The mid-latency and long-latency cortical responses are related to the primary and secondary auditory cortical areas in the central auditory pathway. MLRs typically range between 20-70 ms and LLRs up to 500 ms post-stimulation. MLR and LLRs can be measured through surface electrodes on the scalp [7].

This study focuses on the AEP present in the MLR 20 ms to 100 ms post-stimulation. The AEPs are elicited by the repeated presentation of homophasic and antiphasic Blackman-windowed pure tone stimuli. The AEP is extracted from the EEG recording using a trigger-synchronized epoch averaging procedure. The mid-latency response was measured from the cerebral cortical position Cz. A Fourier analysis was

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conducted on the averaged epochs to determine frequency components of the AEP for homophasic and antiphasic stimuli. Peak detection was performed to extract the position of the dominant frequency component of the AEP in the 18 Hz to 35 Hz range.

II. Experimental Method

The experimental procedure, along with subject selection, preliminary hearing testing, the creation of audio stimuli used to elicit the AEP, and the hardware will be presented in this section.

A. Subjects

7 Subjects participated voluntarily in the experiment. The subject age ranged between 18 to 35 based on approved ethics clearance. The median subject age was 24 years. The subjects answered a questionnaire to establish whether they had any current or pre-existing hearing problems. Subjects who had a healthy otological history were asked to take part in a hearing test. The hearing test was conducted according to the relevant Australian Standards (AUS/NZ 3200, 1591 and 1269; AS IEC 60645-1:2000).

B. Hearing test

The hearing test consisted of stimuli being presented to the subject and the acknowledgment of the subject hearing the stimuli. Pure tones of rising decibel intensities were transmitted to one ear until the person signaled that they have heard the tone. This process was duplicated for all the frequencies that were tested. The sequence was then repeated for the other ear. For this research, the frequency range was tested was from 20 Hz to 8 kHz.

The hearing test was conducted in a sound isolation booth with a sound pressure level measured by a Extech 407738 sound level meter as well below 30 dB. The two computers used for capturing and sending data were placed outside the room. Digital audiometer professional software was used to conduct the hearing test.

Criteria were established to select subjects for EEG recording. Subjects who reported no past or current significant hearing problems and had a normal hearing range based on the hearing test were selected for the experiments. Normal hearing was defined as a difference of no more than 20 dB between the ideal hearing threshold and the subject's actual hearing threshold [8]. Subjects with a difference greater than 20 dB based on the hearing test were excluded from the experiment. No otological observations were taken prior or during the experiments. If a subject volunteered any indication of a current otological condition, they were excluded from the experiment.

C. Hardware

The process used for EEG capture is shown in Figure 1. EEG data was recorded from the cortical position Cz by gold

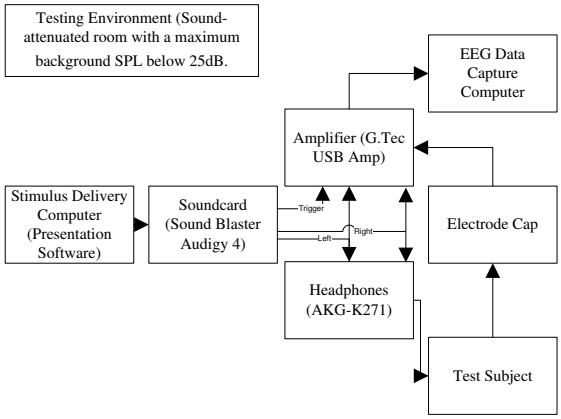

Fig. 1. The EEG capture process.

plated electrodes. The measured potentials were sampled at 4.8 kHz using a G.Tec USB biosignal amplifier (Guger Technologies OG, Austria). The G.Tec amplifier had a 24-bit resolution with simultaneous sampling of all channels. It consists of four blocks with four channels, a ground and reference for each block to eliminate the interference from each recorded signal. The audio stimulus was presented with a Creative SoundBlaster Audigy 4 soundcard and AKG-K271 circumaural headphones.

The AKG-K271 headphones were calibrated at a sound pressure level of 60dB. This was achieved with a sound level meter paired with a coupler to simulate the sound being played through the headphones and entering the ear.

D. Audio Stimuli

The auditory test stimuli that have been selected for this research has been derived from [10]. The core specifications of the stimulus are unchanged, however a slight adaption to the silence duration, increased to 200 ms has been applied to allow sufficient time for the brain to rest between each stimulus iteration. The event potential is assumed to end well into the late-latency response stage. The frequency of interest to be tested is 1,000 Hz. This frequency is relevant because most conversation occurs around this range. The stimulus utilised is a Blackman-windowed sinusoid with a duration of 18 ms. This duration was chosen as the MLR is classified as 20-100 ms post-stimulus, therefore, the stimulus does not overlap with the interested region. The sequence of stimulus presentation was a block of 10 antiphasic stimuli followed by a block of 10 homophasic stimuli for a until 500 out-phase and 500 in-phase related event potentials were captured.

E. EEG Recording

Subjects were asked to devote one hour of their time for the experiment. This included filling out the questionnaires, consent forms, a hearing test and the recording of EEG.

Participants were seated in a sound-attenuated room with lights and electrical devices switched off to reduce any possible interference. Subjects were told about EEG artifacts and their potential sources. The subjects were explicitly instructed to remain relaxed during the experiment and to limit any unnecessary movement during the presentation of the stimuli.

Standard placement of scalp electrodes followed the international 10-20 system [11]. Electrodes were placed in the Cz position, on the left earlobe and on the forehead. The electrode sites were cleaned with Theodor-Korner-Apotheke abrasive electrode gel to remove the hair, a Medi-Swab, and Nihon-Kohden Elefix paste was applied to increase conductivity. The electrode caps were filled with Medi-Trace EEG Solution and then attached to the electrodes sites with medical tape and a head cap. The left earlobe was used as a reference and the forehead ground. Inter-electrode impedance was monitored for all three electrodes to ensure it was <5 kΩ for the experiments to prevent poor quality EEG data [12]. All electrical wires were shielded to prevent crosstalk. AKG-K271 headphones were placed over the head cap and inter-electrode impedance was checked again.

The g.DAQ Recorder software was used to check the impedance of the electrodes and determine if the EEG channels are recording correctly. This software was also used for data capturing at a rate of 4.8 kHz. The recorded signal was a raw EEG signal. No online filtering was performed.

III. Signal Processing

As discussed in Section I, the raw data needs to be processed to enhance the underlying EEG signal. All recorded EEG data were stored on an external hard-drive. Signal processing was performed offline. The software package used to process the data was MATLAB R2008b.

The Cz electrode was recorded on a single channel, the sound stimuli played to the left and right ears had a channel each, and the final two channels contained the trigger signals for the left and right ears. The trigger signals were synchronized to the beginning of the sound stimuli played in the other two channels. Rectangular pulses of very short duration were used as trigger signals. These signals captured the time when the sound stimuli are played in the other channels.

The trigger signals were detected in MATLAB by a difference method. The location of the steepest derivative was calculated for each trigger. These points correlated with the beginning of each epoch. The raw data was segmented based on the position of the trigger signals to produce 500 in-phase and 500 out-phase trials.

Trigger-synchronized epoch averaging was used for both in-phase and out-phase EEG data. This boosted the SNR by enhancing the amplitude of the underlying EEG signal and decreasing the amplitude of the noise.
A Fast Fourier Transform (FFT) was performed on the averaged epoch similar to the analysis in [13]. The dominant peak found in the 18-35 Hz frequency range was extracted using peak detection. The magnitude was determined using the real and imaginary components of the FFT derived complex expression.

IV. Results & discussion

TABLE I
Out-phase amplitude and frequency.

Subject Number	Out-phase Amplitude (μV)	Out-phase Frequency (Hz)
1	0.9193	23.4375
2	1.377	23.4375
3	1.053	23.4375
4	0.3678	30.4688
5	0.2969	23.4375
6	0.4008	30.4688
7	0.2021	30.4688

TABLE II
In-phase amplitude and frequency.

Subject Number	In-phase Amplitude (μV)	In-phase Frequency (Hz)
1	0.6097	23.4375
2	1.011	23.4375
3	0.6361	21.09375
4	0.3270	21.09375
5	0.2694	35.1563
6	0.4307	25.7813
7	0.2406	23.4375

TABLE III
Amplitude Difference.

Subject Number	Amplitude Difference (Out-In) (μV)
1	0.3096
2	0.3659
3	0.4171
4	0.0408
5	0.0275
6	-0.03
7	0.0315

The dominant 20-35 Hz frequency component of the MLR AEP is tabulated in Table I & II.

Table III shows the positive amplitude difference of frequency components in this range for out-phase stimuli compared to in-phase stimuli. When the subjects were exposed to antiphasic stimuli, the amplitude of the 20-35 Hz frequency component was larger compared to exposure to homophasic stimuli. Out of the subjects measured, 6 out of 7 demonstrated a higher amplitude in this frequency range when presented with antiphasic stimuli.

Figure 2, 3 and 4 show a visual comparison of the relevant sinusoidal component from the out-phase and in-phase MLR, based on the Fourier analysis. The complex expression for

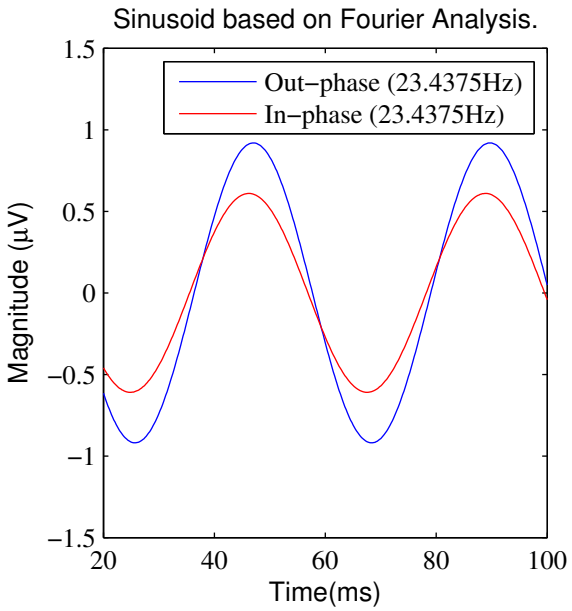

Fig. 2. Subject 1: Sinusoid based on the complex number extracted from the Fourier analysis.

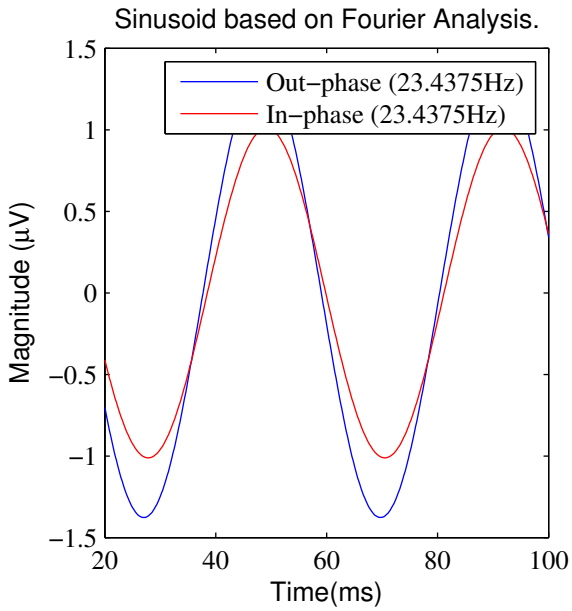

Fig. 3. Subject 2: Sinusoid based on the complex number extracted from the Fourier analysis.

the peak was converted into a pure sinusoid for comparison. The figures demonstrate a clear amplitude difference between the response to antiphasic stimuli and homophasic stimuli.

The positive amplitude difference apparent in Table III suggests there is a change in the auditory evoked potential during the mid-latency response upon the presentation of homophasic and antiphasic tones.

The amplitude difference suggests the antiphasic stimulus was perceived better than the homophasic stimulus. In addition, results obtained from a similar experiment using 500 Hz stimuli returned a positive amplitude difference in 8 out of 9 subjects. Future research related to this result is linked to approximating binaural sensitivity based on the event potential elicited by different stimuli in the mid-latency response.

V. Conclusion

Subjects with normal hearing were presented with homophasic and antiphasic auditory stimuli. The antiphasic stimulus was presented as 10 Blackman-windowed 1000 Hz sinusoidal tone with 180 degree phase reversal followed by the homophasic stimulus with 10 identical stimuli without phase reversal for a total of 500 out-phase and 500 in-phase.

The collected EEG data was processed using a trigger-synchronized epoch averaging procedure. The event potential elicited by the sound stimuli in the MLR was enhanced and a Fourier analysis demonstrated a visible amplitude difference in the 20-35 Hz frequency component of the signal. The antiphasic stimulus elicited a larger response in comparison to the homophasic stimulus for this frequency range. The

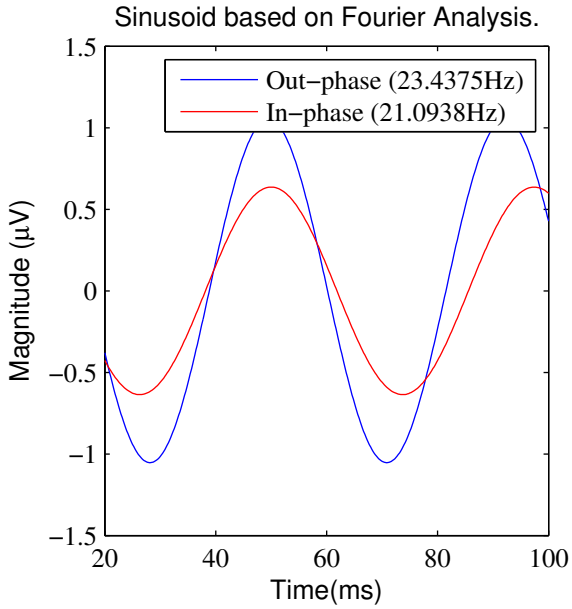

Fig. 4. Subject 3: Sinusoid based on the complex number extracted from the Fourier analysis.

higher amplitude of the response to the antiphasic stimulus is suggestive of the subject perceiving the out-phase better than the in-phase.

The findings of this research suggest there is electrophysiological evidence of binaural processing in the event-related potential elicited by homophasic and antiphasic auditory stimuli in the mid-latency response.

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