International Journal of Health Sciences and Research
www.ijhsr.org ISSN: 2249-9571

Original Research Article

Effect of Noise on Acoustic Change Complex

Ganapathy M K, Manjula P

Electrophysiology Lab, Department of Audiology, All India Institute of Speech and Hearing, Manasagangothri, Mysore, India.

Corresponding Author: Ganapathy M K

Received: 11/07/2016 *Revised: 27/08/2016* *Accepted: 29/08/2016*

ABSTRACT

Speech has dynamic acoustic properties such as amplitude modulation, spectral modulation and periodicity change. The consequence of noise on the auditory system could be variable due to such changes within the ongoing speech signal. To study this Acoustic Change Complex (ACC) were recorded with background speech spectrum shaped noise. The ACC were recorded for speech stimulus and two tonal complex stimuli. The tonal complex stimuli comprised of one with amplitude change and the other with spectral change. The obligatory N1-P2 (onset response) and $N1^1$-$P2^1$ (change response) latency and amplitude were analyzed. The cortical responses showed significant amplitude reduction as well as prolonged latency for encoding of both onset and change responses. Also, the results showed variable effect of noise on onset and change responses. With these outcomes it may be inferred that the effect of noise varies within the ongoing signal as speech signal has dynamic acoustic cues.

Key words: Acoustic Change Complex (ACC), speech spectrum shaped noise, Central Auditory Evoked Potential (CAEP), Signal to noise ratio (SNR).

INTRODUCTION

The noise is one of the common degradation factors that affect speech recognition. The effect of noise on speech is variable as speech has dynamic and rapidly changing acoustic cues. Benkí, (2003) [1] reported that consonants are difficult to recognize when compared to vowels in presence of background noise. This is because speech signals have dynamic acoustic properties such as enhanced spectral envelop for vowels, amplitude modulation, periodicity change, etc. Meyer, Dentel, & Meunier, (2013) [2] described that the acoustic variations aid in speech recognition even after acoustic information of the signal has been degraded by noise. Also Peters et al., (1998) [3] found that spectral and temporal dips help individuals with normal hearing to understand speech in noise. This indicates that the effects of noise on rapidly changing acoustic cues are variable and the processing of acoustic cues may vary with noise.

The Cortical Auditory System (CAS) is constantly processing necessary auditory information and filtering the unwanted noise. The obligatory Cortical Auditory Evoked Potential (CAEP) can be used as a non-invasive tool to study the ability of CAS to encode signals in noise. The CAEP is the electrical activity recorded for auditory stimulus from the auditory area in cortex which gives information about cortical encoding of onset [4] and/or onset of change within an ongoing acoustic stimulus (Ostroff, Martin, & Boothroyd, 1998; Martin & Boothroyd, 1999). [5] These can be elicited from simple tone pips, [6] speech and also complex auditory stimuli (Martin &

Boothroyd, 1999; Skoe & Kraus, 2010). [7] Various studies have been carried out to understand the effect of noise on CAEPs. Whiting, Martin, & Stapells (1998) [8] studied the effect of broadband noise on CAEP. The results showed a significant decrease in amplitude of CAEP (N1, N2 and P3) at signal to noise ratio (SNR) ≤ 0dB, and latencies prolonged with SNR ≤ 20 dB. They reported that the latencies of CAEP are more sensitive for broadband noise. Most of the ERP studies on effect of noise on CAEP responses indicate reduced amplitude and prolonged latencies when compared with responses obtained in quiet (Kaplan-Neeman, Rabin, Henkin, & Muchnik, 2006; Billings, Bennett, Molis, & Leek, 2011; Mccullagh, Musiek &Shinn, 2012). [9] On the contrary, at low levels of background noise the obligatory CAEP amplitude was increased (Alain et al., 2009; Papesh et al., 2015; Parbery-Clark et al., 2011). [10,11,12] The present study aimed at understanding the CAEP at high noise levels.

The obligatory P1-N1-P2 responses can be recorded for stimuli such as tone burst [13,14] or clicks [15] or speech stimuli. [16] For a complex stimuli with acoustic change at ≥ 80 ms within an ongoing stimulus (Ganapathy, Narne, Kalaiah, & Manjula, 2013) [17] will elicit multiple overlapping P1-N1-P2 complex in response. The acoustic changes in the stimulus can be in terms of amplitude or spectrum of a sustained tone (Näätänen and Picton, 1987; Yingling and Nethercut, 1983) [18,19] or acoustic changes within a complex sound such as speech (Martin and Boothroyd, 1999;Kaukoranta et al., 1987). [20,21] This multiple overlapping potential has been termed as the acoustic change complex (ACC). [5] The ACC has been successfully recorded for a range of acoustic change/s in individuals with normal hearing, [21] users of cochlear implant [22] and hearing aid, [23] in young children [24] and in individuals with auditory neuropathy. [25,26] Further, the ACC has good test-retest reliablity [16] and has a significant difference between stimuli. [27] Thesemerits indicate that ACC can be reliably usedas a tool to study the cortical encoding of stimuli in background noise with rapidly changing acoustic cue/s within an ongoing stimulus.

Although CAEPs have been studied in background noise, there is a paucity of literatureon effects of noise on cortical encoding for change/s within an ongoing stimulus. Hence, the present study was carried out to examine the effect of broadband noise on the change/s within an ongoing stimulus. To study this, the ACC were recorded in quiet and in background noise for speech (one) and non-speech stimuli (two) with amplitude change and spectral change. TheACC were obtained from adults with normal hearing as ageing or hearing loss may show increased variablity due to their additional processing deficits. [28,29] These results of the listeners with normal hearing may be useful in interpreting forthcoming data from individuals with hearing deficits.

MATERIALS AND METHODS

The aim of the research was to study the effect of noise on ACC for speech and complex tonal stimuli. The electrophysiological test was carried out at different signal to noise ratio (SNR) to understand the neurophysiology of central auditory system (CAS) in background noise.

Participants

The ACC was recorded from thirty individuals (15 males and 15 females) in the age range from 18 to 28 years, with a mean age of 22.8 years. It was ensured that all the participants had normal hearing sensitivity bilaterally viz., pure-tone thresholds ≤15 dBHL at octave frequencies from 250 Hz to 8 kHz; normal middle ear functioning viz., A-type tympanogram and presence of acoustic reflex at 1 kHz in both ears; and no history of any neurological and/or otological problems. All participants provided informed consent.

Stimuli

Two sets of stimuli were used to record ACC, complex tonal stimuli and speech stimulus. These were individually presented in quiet and in the presence of background noise at different SNRs.

Complex tonal stimuli

Two tonal stimuli were generated, one with amplitude change and the second with spectral change using MATLAB (2009).

Complex tonal stimulus with amplitude change was created by combining a series of pure tones of 1000 Hz in which the root mean square (rms) amplitude changed at approximately the mid-point (at 160 ms) by 3 dB. The waveform of the stimuli is shown in Figure 1. To avoid spectral splatter, the stimulus was gated using raising cosine function for rise/fall time of 10 ms. The total duration of the stimulus was 350 ms and the amplitude change was introduced at 160 ms from the onset of the stimulus.

Complex tonal stimulus with spectral change was created by combining a series of equal amplitude pure tones of 1000 Hz followed by 2000 Hz. To have a smooth transition and to avoid large spectral splatter at the region of change in spectrum, a 20 ms rising linear chirp, which started at1000 Hz and ended at2000 Hz was introduced. The tonal complex stimuli had duration of 350 ms and spectral change was introduced at 160 ms from the onset of the stimulus. To avoid abrupt onset and offset, the stimulus was gated using raised cosine function for rise/fall time of 10 ms. The spectrogram of the complex tonal with spectral change is as shown in Figure 1.

The stimuli were digitized at 12 bits and a sampling rate of 22,050 per second was used. They were presented to the participants after analog to digital conversion, monaurally via ER-3Ainsert earphones of the AEP recording system.

Speech stimuli

The consonant-vowel (CV) syllable /sa/, an alveolar fricative, spoken by an adult male native speaker of Kannada, was used as speech stimulus. The CV syllable was used to record the ACC because, the onset of frication elicits P1-N1-P2 complex, and further the change from frication to vowel elicits another P1-N1-P2 complex, i.e., ACC (Tremblay, Friesen, Martin, and Wright, 2003). The recording of the speech stimulus was carried out in a sound treated room using a dynamic microphone, placed at a distance of 10 cm from the lips of the speaker, at a sampling frequency of 44.1 kHz and 16 bit analog-to-digital converter. The recorded syllable was analyzed and edited using waveform editing software, Adobe Audition 1.5, to maintain duration of 350 ms. The waveforms of the CV syllable /sa/ used in the study are shown in Figure 2.

To study the ACC in presence of noise, the non-speech and speech stimuli were presented in quiet and in the presence of speech spectrum shaped noise in background. The speech spectrum shaped noise was of 2000msduration and was synthesized by randomizing the phase of Fourier of the CV syllable and non-speech stimuli used in the study (Figure 3). The CV syllables and the tone complex stimuli were presented continuously at +5, 0 and -5 signal to noise ratio (SNR) relative to the peak amplitude of the noise.

The speech stimulus /sa/ and two complex tonal stimuli were presented at 80 dBSPL in homogenous train with simultaneous continuous noise (speech spectrum shaped noise) added to the background at varying SNRs (+5, 0 and -5). The presentation levels of the stimulus and background noise were calibrated by measuring the peak amplitude (A-weighted) using the sound level meter (Larson Davis System 824 SLM).

Procedure for recording ACC

The CAEPs were recorded in an acoustically treated room. The NeuroScan Stim 2 (Ver 4.4) was used to present the stimulus and the NeuroScan Syn Amps^2 data acquisition system was used to record the EEG. NeuroScanStim2 is a computer based system which controls the stimulus presentation and delivers an external trigger to the NeuroScan Syn Amps^2 data acquisition system. The stimuli were presented to the ear of the participant through ER-3A insert earphones. The speech stimulus /sa/ and two non-speech complex stimuli were presented at 80 dBSPL in quiet and in noise (+5, 0 and -5 SNR). An inter-stimulus interval of 800 ms from offset of the stimulus to the onset of the next stimulus was used and the presentation order within condition was randomized across participants.

The participants were seated comfortably in a reclining chair and were instructed to minimize the head and body movements. The electrode sites were cleaned up with Nu-prep abrasive gel. The disc type Ag-AgCl electrodes were placed along with Ten-20 conduction paste at the recording sites. The non-inverting electrodes were placed on Cz, C3, C4 and Fz based on 10-20 system (Jasper, 1958). The reference/inverting electrode was placed on the ipsilateral mastoid and the ground electrode was placed on the contralateral mastoid. It was ensured that the impedance was ≤5 kOhms at all electrode sites and inter-electrode impedance was ≤2 kOhms for recording the EEG and the ACC. The online EEG was recorded using NeuroScan Syn Amps[2] data acquisition system at an analog-digital sampling rate of 1000 Hz. The EEG was online band-pass filtered from 0.1 to 100 Hz (12 dB/octave roll-off) and all channels were amplified with a gain of x2010. The recording was carried out twice for each stimulus to ensure replicability and reliability of the response. All the recordings were carried out in quiet and with simultaneous continuous background noise (+5, 0, -5 SNR) for speech and two complex tonal stimuli. For each recording, the stimulus was presented 250 times. While recording the ACC, the participant watched a muted movie played through a battery operated lap-top computer kept at a distance of 2 meters away from the participant. This was done to ensure cooperation from the participants enabling them to sit quietly for the whole duration of recording, which took approximately 1 hour and 30 minutes for recording the ACC for the two sets of stimuli. Breaks were provided to the participants whenever necessary.

Waveform analyses

The recorded EEGs were analyzed offline. The continuous EEGs were epoched with the time window consisting of a 100 ms pre-stimulus period and 800 ms post-stimulus time. The epoched responses were baseline corrected and off-line band pass filtered from 0.1 to 30 Hz (12 dB/octave roll-off, zero phase-shift FIR filter). The trials that were greater than ±50 were rejected from averaging. The remaining sweeps were averaged. As the evoked waveforms at Cz were large and clear than at other electrode sites the waveforms were analyzed at Cz. From the averaged response the latency and peak-peak amplitude N1-P2 and $N1^1$-$P2^1$ were measured and tabulated. The peak latency was calculated from stimulus onset (i.e., 0 ms) to the point of most positive and negative peak in the pre-selected time window, based on grand average waveform for each stimulus. The latency and amplitude values of each N1, P2, $N1^1$ and $P2^1$ response were determined by agreement of three qualified audiologists who served as judges. Each judge used grand average waveforms to determine peaks for the given condition. Instances where the judges could not agree on specific peak values the latency and amplitude value for the peak were excluded from the data. This was seen when SNR was reduced and the component peaks approached the CAEP noise floor. The peaks N1 and P2 correspond to the onset response that reflects the change in acoustic energy from silence to onset of the stimulus and the $N1^1$ and $P2^1$ reflects the response to the onset of the change within the ongoing stimulus.

Statistical analyses

A repeated measures analysis of variance (ANOVA) was carried out on amplitude and latency measures of each component of the evoked response (N1, P2, $N1^1$ and $P2^1$). Further one-way ANOVA was carried out on latency and amplitude measures of each component of the evoked responses between stimuli in each condition viz., quiet and SNR.

RESULTS

The latency and amplitude measures of the CAEPs for speech stimuli and two tonal complex stimuli were tabulated and Shapiro-Wilk test was performed to know the distribution of data. The results revealed no significant difference ($p>0.05$) of peak latency and amplitude in quiet and at different SNRs indicating that the data were normally distributed. The results analyzed using SPSS are given below.

Onset and change response of cortical potentials for speech stimuli in quiet and in background noise (with +5, 0 and -5 dB SNR):

The Figure 4 shows the grand averaged waveform for speech stimulus /sa/ at Cz in quiet and three SNRs (+5, 0 and -5). It is seen from the figure that in quiet, the stimulus /sa/ elicited N1 and P2 response for onset of frication /s/ and $N1^1$ and $P2^1$ for detection of change within the stimulus i.e., from /s/ to /a/. At +5 and 0 dB SNR, the onset and change responses were obtained. At -5 dB SNR, only the change response was seen.

Latency of N1, P2, $N1^1$ and $P2^1$ for /sa/

The latency of N1, P2, $N1^1$ and $P2^1$were measured and analyzed in quiet and in background noise. From Figure 4, it can be seen that both onset and change responses are elicited in quiet, +5 and 0 dB SNR. At +5 and 0 dB SNR, the onset and change responses are present but with prolonged latencies. At -5 dB SNR, only the change response is seen with latency prolonged and morphology of the $N1^1$ and $P2^1$ being marginally poorer in comparison with waveforms in quiet and in noise at +5 and 0 dB SNR. The mean and standard deviation of the onset and change responses for speech stimulus /sa/ are as shown in Figure 5.

A repeated measure ANOVA was performed to ascertain if the mean latency shift of N1, P2, $N1^1$ and $P2^1$ was significant in quiet and in background noise. The result revealed a significant main effect of background noise on latency of N1 [$F(2, 58) = 389.279$ $p<0.001$], P2 [$F(2, 58) = 469.049$ $p<0.001$], $N1^1$ [$F(3, 72) = 252.279$ $p<0.001$] and $P2^1$ [$F(3, 72) = 630.305$ $p<0.001$]. Post-hoc Bonferroni pair-wise comparison was performed to determine if the mean shift in latency of N1, P2, $N1^1$ and $P2^1$reached statistical significance. The result revealed significant difference ($p<0.001$) in latency of N1, P2, $N1^1$ and $P2^1$ between quiet, +5 dB SNR and 0 dB SNR.

Peak to peak amplitude of N1-P2 and $N1^1$-$P2^1$for /sa/

Peak to peak amplitude (N1-P2 and $N1^1$-$P2^1$) were tabulated and analyzed in quiet and in background noise. From Figure 4, it can be noted that the amplitude decreased with increase in noise level. Further, it is seen that at -5 dB SNR, N1 and P2 response, viz., onset response of frication, was absent. The effect of noise on mean amplitude for onset and change response is as shown in Figure 6.

The repeated measures ANOVA was carried out to assess if the mean shift in peak-peak amplitude of N1-P2 and $N1^1$-$P2^1$ were significant across different SNRs. The results revealed a significant main effect in the N1-P2 amplitude [$F(2, 58) = 18.15$ $p<0.001$) at different SNRs. Bonferroni pair-wise comparison revealed a significant difference ($p<0.001$) in amplitude of N1-P2 for increase in SNR. The repeated measure ANOVA for amplitude of $N1^1$-$P2^1$ showed a significant main effect [$F(3, 72) = 7.245$ $p<0.001$]. The Bonferroni pair-wise comparison revealed significant difference ($p<0.001$) except for $N1^1$-$P2^1$amplitude between 0 and -5 dB SNR.

Onset and change response for tonal stimuli with amplitude change in quiet and in background noise (+5, 0 and -5 dB SNR):

The grand averaged waveform for tonal complex stimulus with amplitude change recorded at Cz in quiet and three SNRs (+5, 0 and -5) are shown in Figure 7. From the figure, it can be observed that the stimulus in quiet condition and in three SNRs elicited N1 and P2 response for onset and N1^1 and P2^1 for detection of change within the stimulus, i.e., amplitude change. The changes in morphology, latency and amplitude were seen with increase in SNR.

Latency of N1, P2, N1^1 and P2^{1}for tonal stimulus with change in amplitude

Then mean and SD of latency of N1, P2, N1^1 and P2^1 in quiet and in background noise are as shown in Figure 8. From the figure, it can be seen that the onset (N1 and P2) and change response (N1^1 and P2^1) latencies are systematically delayed with increase in SNR.

In order to ascertain the mean latency shift of N1, P2, N1^1 and P2^1 in quiet and in background noise, repeated measures ANOVA was performed. It revealed a significant main effect of background noise on latency of N1 [F (3, 72) = 708.288 p<0.001], P2 [F (3, 72) = 925.292 p<0.001], N1^1 [F (3, 72) = 487.331 p<0.001] and P2^1 [F (3, 72) = 654.497 p<0.001]. Bonferroni pair-wise comparison was performed to determine if the latency shift reached statistical significance. The result revealed a significant difference (p<0.001) in latency of N1, P2, N^{1}and P2^1 between quiet and at different SNRs.

Peak to peak amplitude of N1-P2 and N1^1-P2^{1}for tonal stimulus with change in amplitude

From Figure 7, it can be seen that the amplitude of the response is reduced with decrease in SNR. The mean and SD of the peak-peak amplitude obtained for tonal complex stimulus with amplitude change is as shown in Figure 9. It can be noted that the peak-peak amplitude of N1-P2 and N1^1-P2^1 systematically reduced with decrease in SNR.

The result of repeated measures ANOVA showed a significant main effect of SNR on peak-peak amplitude of N1-P2 [F (1, 24) = 111.817 p<0.001] and N1^1-P2^1 [F (3, 72) = 35.607 p<0.001]. A Bonferroni pair-wise comparison was performed to see whether the mean shift in peak-peak amplitude reached significance. The N1-P2 amplitude revealed a significant difference (p<0.001) in amplitude at different SNR. Whereas, N1^1-P2^1 amplitude also showed significant difference (p<0.001) except between 0 and -5 dB SNR.

Onset and change response for tonal stimuli with spectral change in quiet and in background noise (+5, 0 and -5 dB SNR):

Figure 10 shows the grand average waveform of tonal complex stimulus with spectral change at Cz in quiet and three SNRs (+5, 0 and -5). It is seen from Figure 10 that the tonal complex stimulus in quiet condition elicited N1 and P2 response for onset of 1 kHz and N1^1 and P2^1 for detection of change within the stimulus, i.e., for the onset of 2 kHz. For the tonal complex stimuli at +5, 0 and -5 dB SNR the onset and change responses were obtained. There were changes in morphology, latency and amplitude.

Latency of N1, P2, N1^1 and P2^{1}for tonal stimulus with spectral change:

Then mean and SD of latency of N1, P2, N1^1 and P2^1 in quiet and in background noise is as shown in Figure 11. From the figure it can be seen that with decrease in SNR, the latency of onset (N1 and P2) and change (N1^1 and P2^1) responses are systematically delayed.

To assess if the mean latency shift of N1, P2, N1^1 and P2^1 in quiet and in background noise reached significant level, a repeated measures ANOVA was performed. It revealed a significant main effect of back noise on latency of N1 [F (3, 72) = 594.906 p<0.001], P2 [F (3, 72) = 668.985 p<0.001], N1^1 [F (3, 72) = 461.299 p<0.001] and P2^1 [F (3, 72) = 357.628 p<0.001]. The Bonferroni pair-wise comparison was performed to determine whether these mean shift in latency reached statistical significance. The result revealed a significant difference (p<0.001) in latency of N1, P2, N1^1 and P2^1 between quiet and at different SNRs.

Peak to peak amplitude of N1-P2 and N1^1-P2^{1}for tonal stimulus with spectral change

From Figure 12, it can be seen that the amplitude of the response is reduced with decrease in SNR. The mean and SD of the peak-peak amplitude obtained for tonal complex stimulus with amplitude change is as shown in Figure 12. It can be noted that the mean peak-peak amplitude of N1-P2 and $N1^1$-$P2^1$ reduced with decrease in SNR.

The result of repeated measures ANOVA showed a significant main effect of SNR on peak-peak amplitude of N1-P2 [F (3, 72) = 51.166 p<0.001] and N11-P21 [F (3, 72) = 22.508 p<0.001]. A Bonferroni pair-wise comparison was performed to see whether the mean shift in peak-peak amplitude reached significance. The result revealed a significant difference (p<0.001) of N1-P2 with increase in SNR. For $N1^1$-$P2^1$, the analysis showed a significant difference at different SNR except between 0 and -5 dB SNR.

Effect of stimuli on onset and change response at different SNRs:

Statistical analysis was carried out to study if the latency and amplitude of the obtained responses varied across stimuli at different SNRs.

Effect of stimuli on latency of N1 response in quiet, +5, 0 and -5 dB SNR:

One-way ANOVA was carried out to ascertain if the mean latency of N1 varied across stimuli (/sa/, tonal complex stimulus with amplitude change and tonal complex stimulus with spectral change). The result showed no significant main effect on N1 latency across stimulus in quiet [F (4, 145) = 6.692 p>0.05], +5 dB SNR [F (4, 145) = 7.765 p>0.05] and 0 SNR [F (4, 145) = 3.385 p>0.05]. Further, independent samples t-test was performed to find out whether there was a significant difference in latency at -5 dB SNR between the tonal complex stimulus with amplitude change and spectral change. The result showed no significant difference in the mean N1 latency between the two tonal complex stimuli at -5 dB SNR [t (48) = 4.593 p>0.05].

Effect of stimuli on latency of P2 response in quiet, +5, 0 and -5 dB SNR:

To analyze if the mean latency of P2 varied across stimuli, viz., /sa/, tonal complex stimulus with amplitude change and tonal complex stimulus with spectral change, one-way ANOVA was carried out. There was no significant main effect on P2 latency across stimulus in quiet [F (4, 145) = 1.303 p>0.05], +5 dB SNR [F (4, 145) = 2.711 p>0.05] and 0 dB SNR [F (4, 145) = 3.58 p>0.05]. The independent samples t-test was performed to find out whether there was significant difference in mean latency at -5 dB SNR between tonal complex stimulus with amplitude change and spectral change. The result showed no significant difference in the mean P2 latency between the two tonal complex stimulus at -5 dB SNR [t (48) = 0.707 p>0.05].

Effect of stimuli on latency of $N1^1$ response in quiet, +5, 0 and -5 dB SNR:

To analyze if the mean latency of $N1^1$ varied across stimuli, viz., /sa/, tonal complex stimulus with amplitude change and tonal complex stimulus with spectral change, one-way ANOVA was carried out. The result showed significant main effect on $N1^1$ latency across stimulus in quiet [F (4, 145) = 77.42 p<0.001], +5 dB SNR [F (4, 145) = 136.927 p<0.001], 0 dB SNR [F (4, 145) = 340.785 p<0.001] and -5 dB SNR [F (4, 120) = 127.184 p<0.001]. A Bonferroni pair-wise comparison was performed to see whether the mean shift in latency in quiet and across SNR reached significance. The result showed no significant difference in the mean $N1^1$latency between the tonal complex stimulus with amplitude change and tonal complex stimulus with spectral change in quiet and at various SNR. Further, the result revealed a significant difference between speech stimulus /sa/ and the two non-speech stimuli in quiet, at different SNRs.

Effect of stimuli on latency of $P2^1$ response in quiet, +5, 0 and -5 dB SNR:

One-way ANOVA was performed to assess if the mean latency of $P2^1$ varied across stimuli, viz., /sa/, tonal complex stimulus with amplitude change and tonal complex stimulus with spectral change. The result showed significant difference of $P2^1$ latency across stimulus in quiet [F (4, 145)

= 68.652 $p<0.001$], +5 dB SNR [$F(4, 145) = 94.184$ $p<0.001$], 0 dB SNR [$F(4, 145) = 52.487$ $p<0.001$] and -5 dB SNR [$F(4, 120) = 58.888$ $p<0.001$]. To assess whether the mean shift in latency in quiet and at various SNR reached significance, a Bonferroni pair-wise comparison was performed. The result showed significant difference in the mean P2[1]latency between the two tonal complex stimuli and speech stimuli /sa/ in quiet and at different SNRs. Further, the result revealed no significant difference between the two tonal complex stimuli in quiet and at different SNRs.

Effect of stimuli on peak-peak amplitude of N1-P2 in quiet, +5, 0 and -5 dB SNR:

To analyze if the mean peak-peak amplitude of N1-P2 varied across stimuli, viz., /sa/, tonal complex stimulus with amplitude change and tonal complex stimulus with spectral change, one-way ANOVA was carried out. The result showed no significant main effect on peak to peak amplitude of N1-P2 latency across stimulus in quiet [$F(4, 145) = 1.016$ $p>0.05$], +5 dB SNR [$F(4, 145) = 4.507$ $p>0.05$] and 0 dB SNR [$F(4, 145) = 3.366$ $p>0.05$]. Independent samples t-test was performed to find out whether there was a significant difference in mean latency at -5 dB SNR between tonal complex stimulus with amplitude change and tonal complex stimulus with spectral change. The result showed no significant difference in the mean peak to peak amplitude of N1-P2 between the two tonal complex stimulus at -5 dB SNR [$t(48) = 0.67$ $p>0.05$].

Effect of stimuli on peak-peak amplitude of N1[1]-P2[1] in quiet, +5, 0 and -5 dB SNR:

The mean peak-peak amplitude of change responses (N1[1]-P2[1]) were analyzed using One-way ANOVA to assess if the mean varied across stimuli. The result showed no significant difference of N1[1]-P2[1] amplitude across stimulus in quiet [$F(4, 145) = 0.270$ $p<0.001$], 0 dB SNR [$F(4, 145) = 24.75$ $p<0.001$] and -5 dB SNR [$F(4, 120) = 12.771$ $p<0.001$]. The result showed significant difference of peak-peak amplitude at +5 dB SNR [$F(4, 145) = 7.75$ $p>0.05$]. To assess whether the mean shift in latency at +5 dB SNR reached significance, Bonferroni pair-wise comparison was performed. The result showed a significant difference only in the mean peak to peak amplitude of N1[1]-P2[1]between speech stimulus /sa/ and tonal complex stimulus with amplitude change at +5 dB SNR.

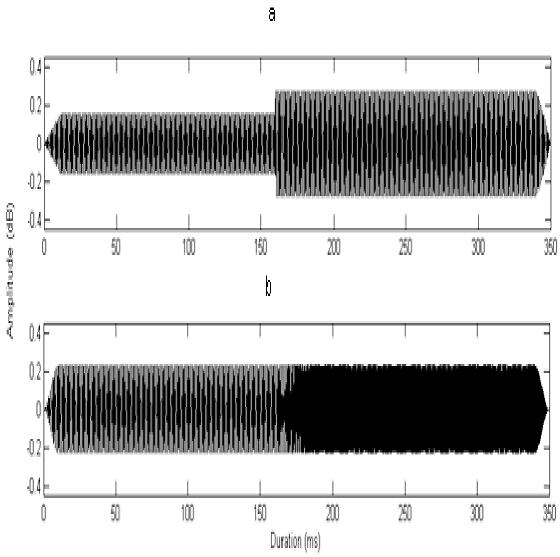

Figure 1: Acoustic waveform of complex tone with a total duration of 350 ms (a) pure tone of 1000 Hz with change in amplitude and (b) equal amplitude pure tones of 1000 Hz followed by a 2000 Hz. The change in amplitude and spectrum is at 160 ms.

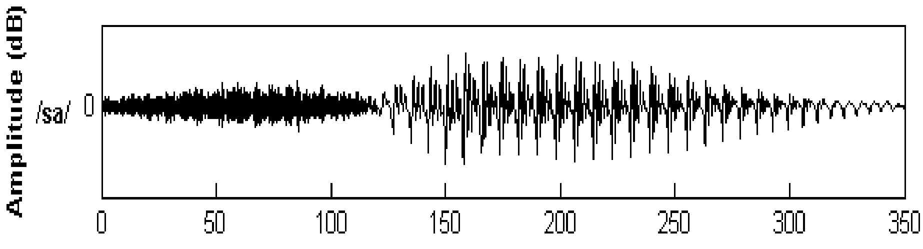

Figure 2: The acoustic waveform of consonant-vowel syllable /sa/. The duration of consonant /s/ is 120 ms, and duration of vowel /a/ is 230 ms.

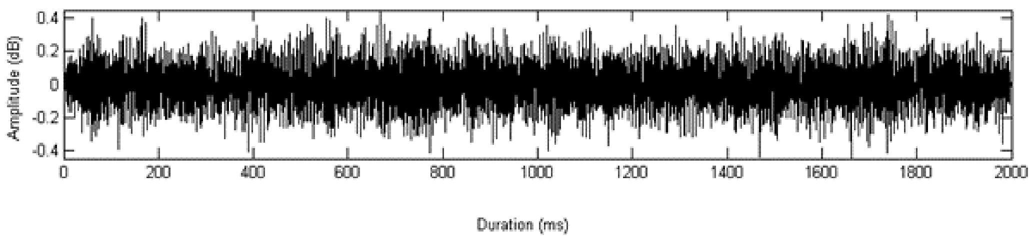

Figure 3: The speech spectrum shaped noise used to study the cortical response in background noise.

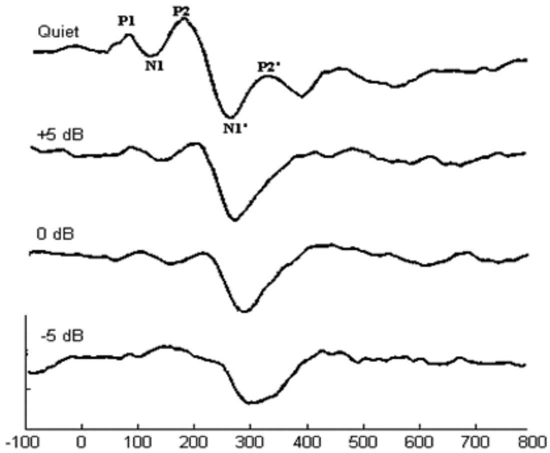

Figure 4: Grand averaged waveform of speech stimulus /sa/ at Cz in quiet and three SNRs (+5, 0 and -5).

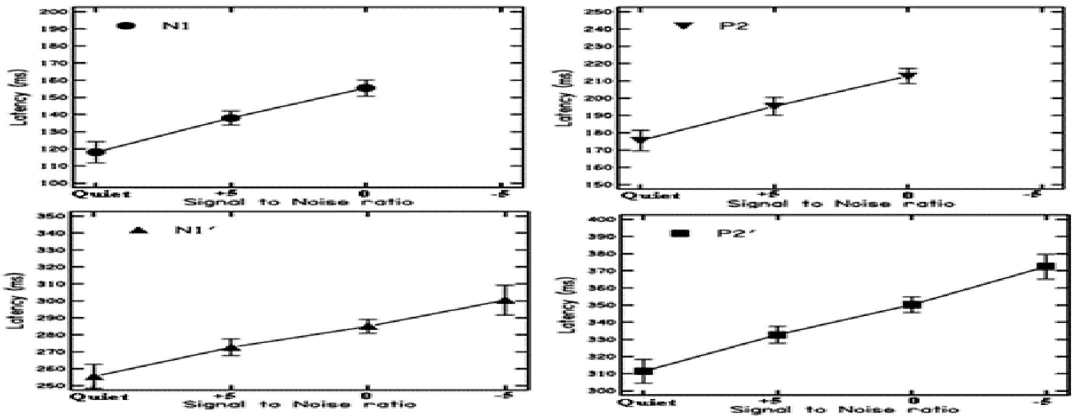

Figure 5: Mean and standard deviation of latency of onset (N1, P2) and change response (N1[1] and P2[1]) for speech stimulus /sa/ in quiet and three SNR's (+5, 0 and -5)

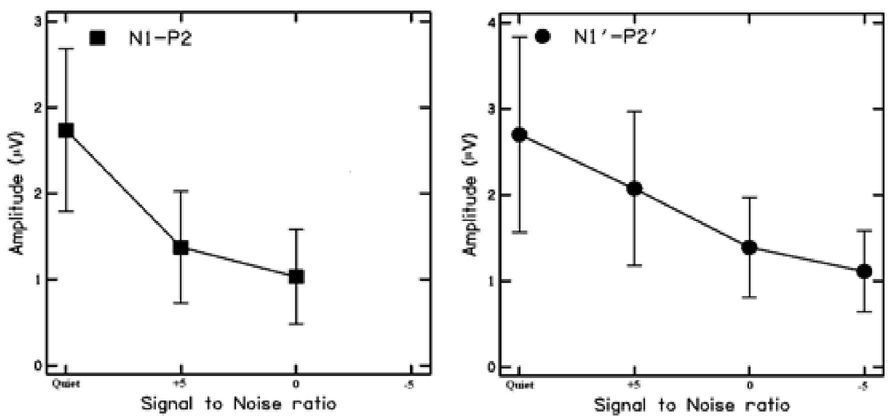

Figure 6: Mean and standard deviation of peak to peak amplitude of onset (N1-P2) and change response (N1[1]-P2[1]) for speech stimulus /sa/ in quiet and three SNR's (+5, 0 and -5)

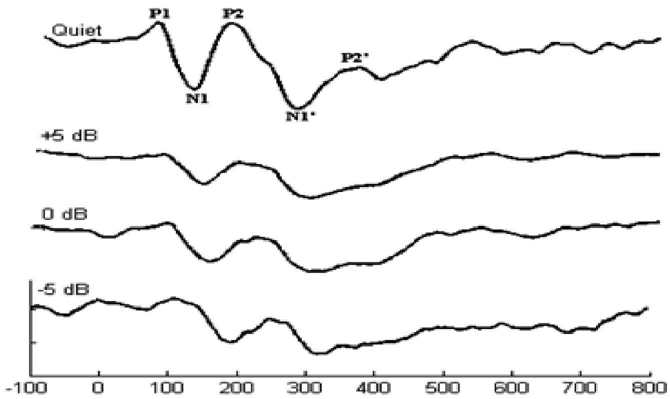

Figure 7: Grand averaged waveform of tonal stimulus with change in amplitude at Cz in quiet and three SNRs (+5, 0 and -5).

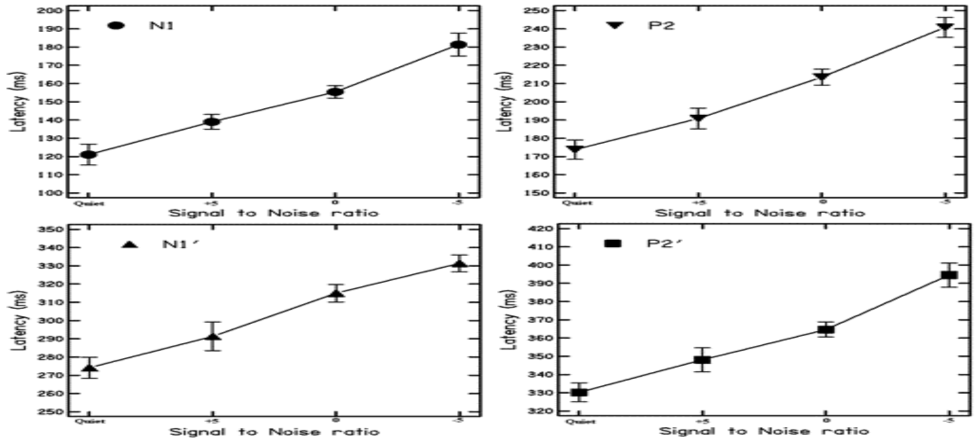

Figure 8: Mean and standard deviation of latency of onset (N1, P2) and change response (N1[1] and P2[1]) for tonal stimulus with change in amplitude in quiet and three SNR's (+5, 0 and -5)

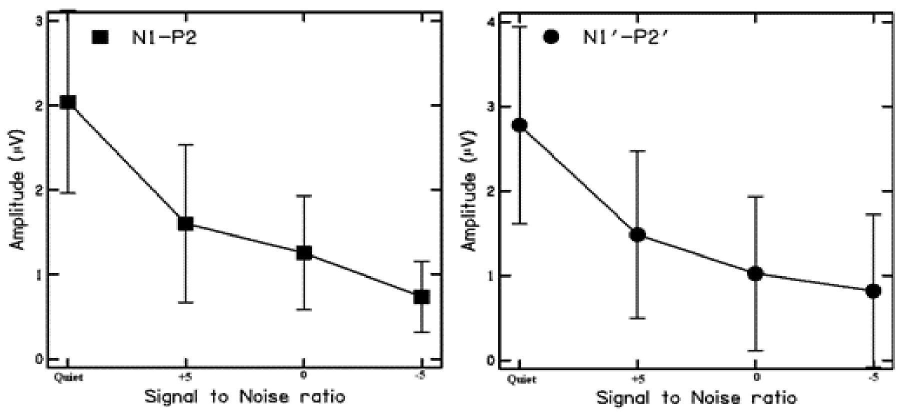

Figure 9: Mean and standard deviation of peak to peak amplitude of onset (N1-P2) and change response (N1[1]-P2[1]) for tonal stimulus with change in amplitude in quiet and three SNR's (+5, 0 and -5)

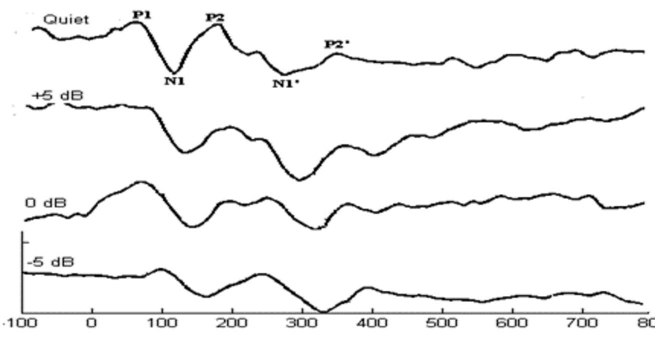

Figure 10: Grand averaged waveform of tonal stimulus with spectral change at Cz in quiet and three SNRs (+5, 0 and -5).

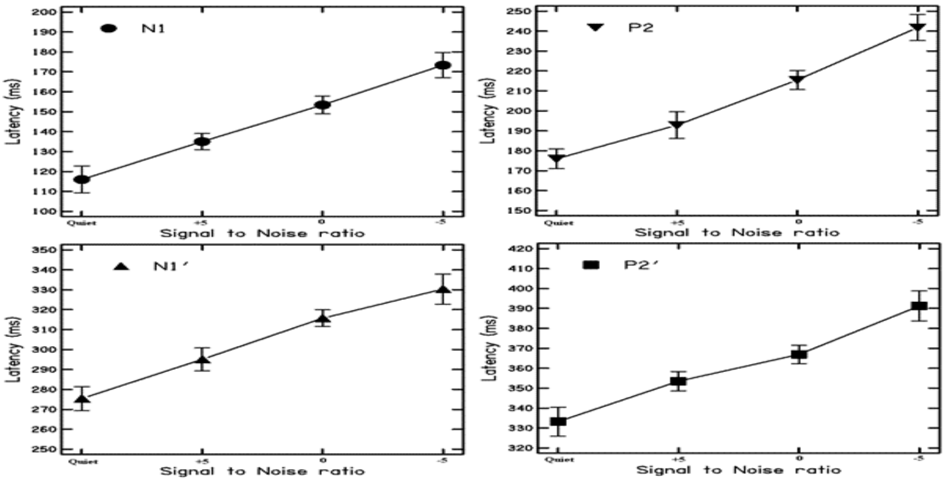

Figure 11: Mean and standard deviation of latency of onset (N1, P2) and change response (N1[1] and P2[1]) for tonal stimulus with spectral change in quiet and three SNR's (+5, 0 and -5)

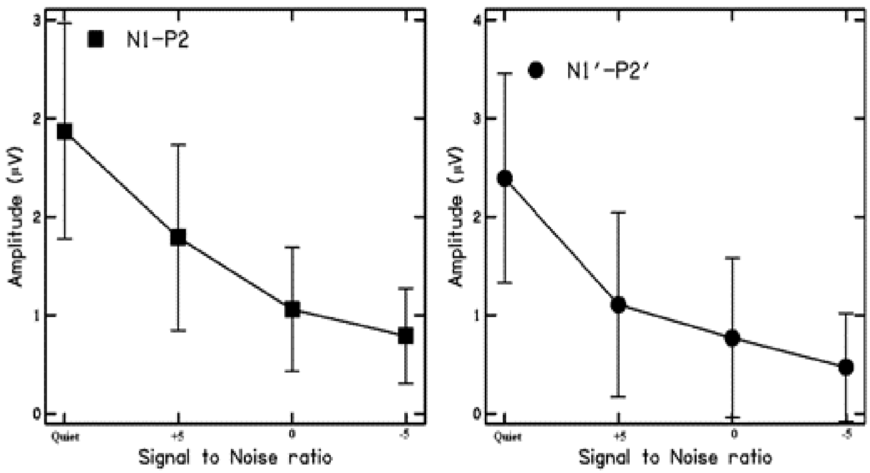

Figure 12: Mean and standard deviation of peak to peak amplitude of onset (N1-P2) and change response (N1[1]-P2[1]) for tonal stimulus with spectral change in quiet and three SNR's (+5, 0 and -5)

DISCUSSION

The study was undertaken to study the effect of speech spectrum shaped noise on rapidly changing acoustic cue/s within an ongoing stimulus, using ACC. To understand this, the ACC were recorded in background speech spectrum shaped noise for speech stimulus with spectral and amplitude change, tonal stimulus with amplitude change, and tonal stimulus with spectral change. The outcome evinced that increase in background noise resulted in significant changes in latency, amplitude and morphology of ACC.

Effect of BBN on speech stimulus /sa/:

The onset and change responses were recorded in quiet and as well in presence of background noise (Figure 4). With increase in noise levels the morphology depreciated, with significant effect on consonant /s/. No detectable onset response could be traced at -5 dB SNR. It demonstrates that noise effects the encoding of consonants prior to vowels. This finding is in agreement with behavioral study by Benkí (2003) [1] who reported that recognition of consonants is not as easy as vowels in presence of background noise. The inability of the CAS to extract information at higher noise levels could have led to decline in consonant perception. The ability of CAS to encode vowel /a/ could be attributed to its enhanced spectral and amplitude envelop. Also, in the present study, the calibration of the noise and stimulus were by measuring peak amplitude, this could have lad to effective masking of consonant which is lesser amplitude than the vowel.

Along with the change in morphology, the increase in noise levels resulted in significant decrease of amplitude and prolongation of latencies for speech evoked ACC. The mean data (Figure 5) shows systematic prolongation of latency of onset and change response with decrease in SNR. Similar effects of noise were seen for peak to peak amplitude for onset and change response except for N1^1- P2^1 amplitude between 0 and -5 dB SNR (Figure 6). The peak to peak amplitude of N1^1 and P2^1 did not show a significant difference between 0 and -5 SNR. This could also be pointing that the CAS may perhaps compensate at higher noise levels.

Effect of noise on tonal stimulus with spectral change:

The onset response N1, P2 and change response N1^1 and P2^1 were present for the tonal stimulus with amplitude change in quiet and in presence of background noise (Figure 7). The results revealed significant changes in morphology, amplitude and latency changes with increase in background noise. Both onset and change responses were present at quiet and at different SNRs (+5, 0 & -5 SNR). The results of latency showed a systematic prolongation with increase in background noise (Figure 8). The peak to peak amplitude of N1-P2 and N1^1-P2^1 decreased with increase in background noise. But as seen for speech stimuli, amplitude values of N1^1 and P2^{1}for the change response between 0 SNR and -5 SNR did not show a significant change.

Effect of BBN on tonal stimulus with spectral change:

The obligatory N1, P2 and N1^1 and P2^1 responses were elicited for the tonal stimulus with spectral change in quiet and in background noise (Figure 10). As seen for speech stimulus /sa/, similar effect of noise was seen on the recorded ACC for the tonal stimulus. Deterioration of morphology, prolongation of latency and decrease in amplitude were observed. Both onset and change responses were present till -5 dB SNR. The latency of N1, P2 and N1^1 and P2^1 (Figure 11) showed significant prolongation with increase in noise levels. The peak to peak amplitude results (Figure 12) also showed a significant decrease with increase in background noise, except between N1-P2 and N1^1-P2^1. A similar result was seen for speech stimulus and tonal stimulus with amplitude change.

Effect of noise on ACC and its implication:

The results revealed that the background noise affects both onset and change responses with prolongation of latency and decrease in amplitude. These results are in agreement with studies on CAEP recorded in background noise. [8,9,30] This indicates that the change complex shows similar pattern as that of the onset response.

The findings on between stimuli across background noise levels revealed that the N1 P2 onset response and N1^1 P2^{1}change response function as an obligatory potential reflected the encoding at cortical level for auditory stimuli. The spectral and temporal dip/s evoked the ACC in quiet and in background noise. These results warrant the use of ACC as a tool to study the rapid acoustic changes within an ongoing auditory stimulus in quiet and in the presence of background noise. However, these results may not be extrapolated on behavioral response. It was reported that even with disruption of consonant cues, recognition remained intact at -5 dB SNR. [31] This suggests that the auditory system relies on other acoustic cues in presence of background noise.

The peak latency effects were straightforward; the overall latency delayed, which indicate that background noise results in slower temporal processing. The amplitude results were complex for effect of noise; at 0 and -5 SNR change complex amplitude did not have significant change. This may be indicating that there could be underlying cortical or even sub-cortical process that assists hearing at higher background noise levels. However, with the results of the present study it was not clear, and it needs further examination.

The ACC in quiet and in presence of background noise provides insight into the processing by CAS those results in encoding of rapidly changing acoustic cues. Hence, the ACC might be considered for those clients who cannot provide accurate behavioral measures for speech audibility or discrimination in quiet and in background noise. Even though further insight is required to determine the correlation of ACC and speech sound discrimination, ACC may be used as a tool for discrimination considering the dearth of other objective tests.

The ACC has been reliably recorded in aided condition. [23] Hearing aid fitting in difficult-to-test individuals using speech perception measures may provide limited or no information. Also in individuals with hearing impairment, the acoustic cues may be inaudible, degraded or distorted in real life listening situations due to processing deficits in frequency, intensity and temporal information. [28,29] Use of ACC in quiet and in background noise can provide information on neural processes in these individuals and further to examine the extent to which amplification remediates the deficits in such individuals. Thus, ACC could be investigated for hearing aid fitting in difficulty-to-test individuals.

CONCLUSION

To conclude, the study evinced that the ACC can be used as a reliable tool to study the effect of background noise on rapidly changing acoustic stimulus and further could assist in understanding the encoding in impaired auditory system as well.

ACKNOWLEDGEMENTS

This work was supported by the grants from the AIISH Research Fund (ARF) scheme of the All India Institute of Speech and Hearing Mysore. We would like to thank the participants of the study for their patient cooperation.

REFERENCES

1. Benkí JR. Analysis of english nonsense syllable recognition in noise. Phonetica. 2003 Jan; 60(2):129-57.
2. Meyer J, Dentel L, Meunier F. Speech recognition in natural background noise. PLoS One. Public Library of Science; 2013 Jan 19; 8(11):e79279.
3. Peters RW, Moore BC, Baer T. Speech reception thresholds in noise with and without spectral and temporal dips for hearing-impaired and normally hearing people. J Acoust Soc Am [Internet]. 1998 Jan [cited 2015 Jun 9]; 103(1):577-87. Available from: http://www.ncbi.nlm.nih.gov/pubmed/9440343
4. Woods DL. The component structure of the N1 wave of the human auditory evoked potential. Electroencephalography and clinical neurophysiology. Supplement. 1995. p. 102-9.
5. Martin BA, Boothroyd A. Cortical, auditory, event-related potentials in response to periodic and aperiodic stimuli with the same spectral envelope. Ear Hear. 1999; 20(1):33-44.
6. Woods DL, Alain C, Covarrubias D, Zaidel O. Frequency-related differences in the speed of human auditory processing. Hear Res. 1993 Mar; 66 (1):46-52.
7. Skoe E, Kraus N. Auditory brain stem response to complex sounds: a tutorial. Ear Hear. 2010; 31:302-24.
8. Whiting KA, Martin BA, Stapells DR. The effect of broadband noise masking on cortical event-related potentials to speech sounds /ba/ and /da/. Ear Hear. 1998; 19(3):218-31.
9. Billings CJ, Bennett KO, Molis MR, Leek MR. Cortical encoding of signals in noise: effects of stimulus type and recording paradigm. Ear Hear. 2011; 32(1998):53-60.
10. Alain C, Quan J, McDonald K, Van Roon P. Noise-induced increase in human auditory evoked neuromagnetic fields. Eur J Neurosci. 2009 Jul; 30(1):132-42.
11. Parbery-Clark A, Marmel F, Bair J, Kraus N. What subcortical-cortical relationships tell us about processing speech in noise. Eur J Neurosci. 2011

Feb; 33(3):549-57.
12. Papesh MA, Billings CJ, Baltzell LS. Background noise can enhance cortical auditory evoked potentials under certain conditions. Clin Neurophysiol. 2015 Jul; 126(7):1319-30.
13. Jordan K, Schmidt A, Plotz K, von Specht H, Begall K, Roth N, et al. Auditory event-related potentials in post- and prelingually deaf cochlear implant recipients. Am J Otol [Internet]. 1997 Nov [cited 2015 Jun 9]; 18(6 Suppl):S116-7. Available from: http://www.ncbi.nlm.nih.gov/pubmed/9391625
14. Pantev C, Ross B, Fujioka T, Trainor LJ, Schulte M, Schulz M. Music and learning-induced cortical plasticity. Ann N Y Acad Sci [Internet]. 2003 Nov [cited 2015 Jun 9]; 999:438-50. Available from: http://www.ncbi.nlm.nih.gov/pubmed/14681168
15. Eggermont JJ, Ponton CW, Don M, Waring MD, Kwong B. Maturational delays in cortical evoked potentials in cochlear implant users. Acta Otolaryngol [Internet]. 1997 Mar [cited 2015 Jun 9]; 117(2):161-3. Available from:http://www.ncbi.nlm.nih.gov/pubmed/ 9105439
16. Tremblay KL, Friesen L, Martin B a, Wright R. Test-retest reliability of cortical evoked potentials using naturally produced speech sounds. Ear Hear. 2003; 24:225-32.
17. Ganapathy MK, Narne VK, Kalaiah MK, Manjula P. Effect of pre-transition stimulus duration on acoustic. Int J Audiol. 2013; 52(February 2012):350-9.
18. Näätänen R, Picton T. The N1 wave of the human electric and magnetic response to sound: a review and an analysis of the component structure. Psychophysiology [Internet]. 1987 Jul [cited 2015 Apr 1]; 24(4):375-425. Available from: http://www.ncbi.nlm.nih.gov/pubmed/3615753
19. Yingling CD, Nethercut GE. Evoked responses to frequency shifted tones: tonotopic and contextual determinants. Int J Neurosci [Internet]. 1983 Dec [cited 2015 Jun 9]; 22(1-2):107-18. Available from: http://www.ncbi.nlm.nih.gov/pubmed/6668128
20. Kaukoranta E, Hari R, Lounasmaa O V. Responses of the human auditory cortex to vowel onset after fricative consonants. Exp brain Res [Internet]. 1987 Jan [cited 2015 Jun 9]; 69(1):19-23. Available from: http://www.ncbi.nlm.nih.gov/pubmed/3436386
21. Martin BA, Boothroyd A. Cortical, auditory, evoked potentials in response to changes of spectrum and amplitude. J Acoust Soc Am. 2000; 107(4):2155-61.
22. Friesen LM, Tremblay KL. Acoustic change complexes recorded in adult cochlear implant listeners. Ear Hear. 2006; 27:678-85.
23. Tremblay KL, Billings CJ, Friesen LM, Souza PE. Neural representation of amplified speech sounds. Ear Hear. 2006; 27(1):93-103.
24. Martinez A, Eisenberg L, Boothroyd A. The acoustic change complex in young children with hearing loss: A preliminary study. Semin Hear. 2013; 34 (212):278-87.
25. Small SA, Werker JF. Does the acc Have Potential as an Index of Early Speech-Discrimination Ability? a Preliminary Study in 4-Month-Old Infants With Normal Hearing. Ear Hear. 2012; 33:e59-69.
26. Dimitrijevic A, Starr A, Bhatt S, Michalewski HJ, Zeng FG, Pratt H. Auditory cortical N100 in pre- and post-synaptic auditory neuropathy to frequency or intensity changes of continuous tones. Clin Neurophysiol. International Federation of Clinical Neurophysiology; 2011; 122(3):594-604.
27. Shetty HN, Manjula P. Effect of stimuli, transducers and gender on acoustic change complex. Audiol Res. 2012; 2:e14.
28. Festen JM, Plomp R. Relations between auditory functions in impaired hearing. J Acoust Soc Am [Internet]. 1983 Feb [cited 2015 Jun 9]; 73(2):652-62. Available from: http://www.ncbi.nlm.nih.gov/pubmed/6841805
29. Thibodeau LM. Exploration of factors beyond audibility that may influence

speech recognition. Ear Hear [Internet]. 1991 Dec [cited 2015 Jun 9]; 12(6 Suppl):109S-115S. Available from: http://www.ncbi.nlm.nih.gov/pubmed/1794637

30. Kaplan-Neeman R, Kishon-Rabin L, Henkin Y, Muchnik C. Identification of syllables in noise: Electrophysiological and behavioral correlates. J Acoust Soc Am [Internet]. Acoustical Society of America; 2006 Aug 1 [cited 2015 Jun 3]; 120(2):926. Available from: http://scitation.aip.org/content/asa/journal/jasa/120/2/10.1121/1.2217567
31. Parikh G, Loizou PC. The influence of noise on vowel and consonant cues. J Acoust Soc Am [Internet]. 2005 Dec [cited 2015 Jun 19]; 118(6):3874-88. Available from: http://www.ncbi.nlm.nih.gov/pubmed/16419830

How to cite this article: Ganapathy MK, Manjula P. Effect of noise on acoustic change complex. Int J Health Sci Res. 2016; 6(9):356-370.

****