Aided Acoustic Change Complex in Individuals with Sensorineural Hearing Loss

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Abstract

Multiple overlapping P1-N1-P2 responses can be elicited in response to naturally produced speech stimulus. This overlapping neural response represents the acoustical changes within speech stimulus. These potentials are known as Acoustic Change Complex (ACC). Research evidences clearly indicates that ACC can be reliably recorded in normal hearing individuals. But, there is lack of evidences in individual with sloping sensorineural hearing loss with different duration and degree of hearing loss and its effect on unaided and aided ACC. Hence, the aim of the present study was to investigate the effect of degree and duration of sloping sensorineural hearing loss and digitally amplified speech by hearing aid on ACC. The result of the study indicated that a clear ACC can be successfully recorded in aided condition compared to unaided condition. The present study also showed that as the degree and duration of hearing loss increases, there is a change in unaided and aided ACC compared to lesser degree and duration of hearing loss.

Keywords: *Acoustic Change Complex (ACC), Sloping sensorineural hearing loss, Unaided ACC, Aided ACC.*

Introduction

Sensorineural hearing loss (SNHL) is probably the most common form of hearing loss and these type of hearing loss not only lead to elevation of threshold for detection of sound, but, also the affects the way in which sound is perceived. The perception of speech in individuals with SNHL is also dependent on the configuration of hearing loss (Coughlin, Kewely-Port & Humes, 1998; Dubno, Dirks & Schafer, 1987; Sher & Owens, 1974). In SNHL, different audiometric patterns like flat, raising, sloping etc. are evident (Pittman & Stelmachowicz, 2003). One of the most common management options for this type of permanent hearing loss are hearing aids. Hearing aids can compensate sensorineural hearing loss by amplifying sound. Despite adequate amplification of sound by hearing aid, the person with cochlear hearing loss continues to report unclear and distorted speech. The effectiveness of hearing aid in persons with SNHL also depends on the ability of the central auditory system to represent and integrate the spectral and temporal information delivered by the hearing aid, other than hearing aid related factors.

The individuals with SNHL avoid the use of hearing aids or adjust to the listening situations without the use of hearing aids. This kind of avoidance and adjustments for a longer period of time can lead to auditory deprivation (Silman, Gelfand & Silverman, 1984). Hence, there is interest in examining the neural representation (by hearing aid) of speech cues and amplified speech cues in people with hearing loss. It will be still more interesting, if it is possible to get knowledge about the different durations of hearing loss and its effect on neural representation of speech cues and amplified speech cues (by hearing aid) in people with hearing loss.

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The P1-N1-P2 complex was the first tool for assessing the neural representation of sound in population with and without hearing loss. The P1-N1-P2 complex is an auditory evoked potential that is characterized by a positive peak (P1), followed by a negative peak with a latency of about 100 milliseconds after stimulus onset (N1), followed by a positive peak called P2. These peaks reflect neural activity generated by multiple sources in the thalamic-cortical segment of the central auditory system. Multiple overlapping P1-N1-P2 responses can be seen in response to naturally produced speech stimuli like syllables, words etc. If we consider multiple overlapping responses to a syllable, the first P1-N1-P2 complex reflects the onset of the consonant whereas the second P1-N1-P2 response reflects the consonant vowel (CV) transition. These complex waveform patterns were shown to reflect acoustic changes, from silence to sound (onset of consonant) and the CV transition (from consonant to vowel) (Ostroff, Martin & Boothroyd, 1998). Martin and Boothroydin (1999) termed this cortical evoked response as 'Acoustic Change Complex' (ACC). ACC and other cortical potentials like mismatch negativity (MMN), P300 give information on the auditory discrimination ability of individual. But, to elicit MMN and P300, individual's cooperation is required whereas for ACC, the same is not mandatory. Moreover, the average amplitude of ACC is 2.5 times larger compared to MMN in normal hearing individuals (Martin & Boothroyd, 1999). These advantages of ACC over other potentials in normal hearing individuals gives more interest to probe into study of effect of hearing impairment and amplification on cortical representation of acoustic changes within speech sounds. It is still more imperative to study effect of sloping sensorineural hearing loss (SNHL) on ACC, reason behind is that individual with sloping SNHL has more problem with perception of speech because the higher frequency speech sounds contributes primarily

to the speech intelligibility. Hence, the high frequency speech sounds like fricatives within a syllable can be used to elicit ACC. Very few researchers gave more interest to probe more into it (Tremblay, Kalstein, Billings & Souza, 2006, Tremblay, Friesen, Martin & Wright, 2003).

Tremblay et al. (2006) found that /shee/ and /see/ each elicit distinct ACC responses. The first negative peak, signaling the onset of the consonant, was not significantly different for the /shee/ and /see/ stimuli. However, the second P1-N1-P2 complex (N345 and P413), presumably reflecting the CV transition, occurred significantly earlier when evoked by the /shee/ stimulus than when evoked by /see/. Onset of the vowel in /shee/ was 30 milliseconds earlier than the onset of the vowel portion in /see/. This 30-millisecond difference appears to correspond to the 30-millisecond latency difference between the negative peak N345 elicited by the /shee/ stimulus and the negative peak N375 elicited by the /see/ stimulus.

Tremblay et al. (2003), examined ACC patterns in normal-hearing young adults, evoked by two different speech stimuli, /shee/ and /si/. These particular stimuli were chosen because they share similar acoustic features and are frequently confused by listeners with hearing loss. /shee/ and /si/ are similar in that they are fricatives and different in that (1) /shee/ and /si/ differ by place of articulation, (2) the fricative portion of /shee/ contains lower spectral energy than the fricative portion of /si/, and (3) the fricative portion of /shee/ is shorter in duration than the fricative portion of /si/. Karthik and Vanaja (2005) demonstrated that ACC is an electrophysiological index of speech discrimination in adult and children. The study showed that ACC could be recorded in all adult subjects and there was a significant difference between N1P2 amplitudes between two stimuli indicative presence of ACC response.

All these research evidences suggest that ACC can be recorded successfully in adult normal hearing individuals. So, there is a need to know how successfully the aided ACC can be recorded in person with cochlear hearing loss and to correlate the findings to various degree and duration of hearing loss. In a study by Tremblay, Kalstein, Billings and Souza (2006) recorded ACC in adult hearing aid users with mild to severe degree of sloping sensorineural hearing loss for two consonant-vowel (CV) syllables (/shee/ and /see/). The result of the study showed that /shee/ and /see/ elicited different waveforms in terms of latency and amplitude. This finding indicated different neural detection of CV transitions (indicated by the presence of a P1-N1-P2 response) for /shee/ and /see/.The latency of the second N1 in the evoked cortical neural response coincided in time with the onset of the vowel in the /shee/ and /see/ syllable. This finding is in accordance with the study done by Tremblay, Billings, Friesen, and Souza in 2006.

To critically evaluate, the study demonstrated the coding of acoustic changes in the subjects with mild to severe sloping sensorineural hearing loss in aided condition but did not studied the effect of mild to severe degree of SNHL on ACC. Moreover, duration of sloping SNHL along with the degree of hearing loss could also have impact on unaided and aided ACC.

Interestingly, the further studies in the literature also failed to make an attempt to study effect of degree and duration of sloping SNHL on unaided and aided ACC. This leads to the initiation of the current study.

Firstly, the persons with sloping SNHL have problems in perceiving acoustic changes within speech sounds (mainly the syllables having high frequency consonant and low frequency vowel combination). The ability to perceive these acoustic changes is very important for normal perception of speech. How well the acoustic changes within the speech stimuli are coded in the cortical level can be studied electro physiologically using ACC. So, there is a need to study the ACC in individual with varying degree of sloping hearing loss to see cortical representation of acoustic changes within speech sounds.

Secondly, the amount of benefit the hearing aid provides varies greatly among individual with sloping sensorineural hearing loss. The factors contributing could be that the hearing aid is incapable to process spectral and temporal information properly or could be the inability of the peripheral and central auditory system in processing acoustic changes within speech sounds provided through hearing aid. Hence, there is also a need to study the neural representation of (cortical representation) acoustic changes within speech sounds through a hearing aid in individual with sloping SNHL across the various durations of losses.

Thirdly, the degree and duration of hearing loss could be the factors that affect the cortical representation of acoustical changes within speech sounds in individual with sloping SNHL. Hence, there is a need to compare the effect of different degrees across various duration of hearing loss with and without the use of amplification, and study the difference in cortical representation of speech. Therefore the aim of the study was to investigate the effect of degree and duration of sloping sensorineural hearing loss and digitally amplified speech on Acoustic Change Complex.

Method

Participants

Total of 19 individuals with unilateral or bilateral sloping sensorineural hearing loss who are the naive hearing aid users were selected as participants of the study. The participants were in the age range of 19 to 55 years

(17 males and two females with a mean age range of 41.31 years) and the hearing loss was post lingual in onset. A total of 21 ears with sloping sensorineural hearing loss were selected for the recording of aided and the unaided ACC who has less than or greater than two years of duration hearing loss. The slope of the audiogram was defined based on the occurrence of the thresholds at equal or successively higher levels from 250 to 8000 Hz and the difference between thresholds at 250 and 8000 Hz was always >20 dB (Pittman & Stelmachowicz, 2003). The degree of the slope of audiogram was calculated based on PTA_1 (average of the pure tone thresholds at 500Hz, 1 kHz, 2 kHz) and PTA_2 (average of the pure tone thresholds at 1kHz, 2 kHz, 4 kHz). All 27 ears were divided into two groups, group one had 10 ears with minimal to moderate sloping cochlear hearing loss and group two had 11 ears with moderate to severe sloping sensorineural hearing loss. The number of ears in the group I and group II were categorized into four subgroups based on duration of hearing loss; minimal to moderate sloping sensorineural hearing loss (SNHL) with duration of hearing loss less than two years (subgroup A), minimal to moderate sloping SNHL with duration of hearing loss greater than two years (subgroup B), moderate to severe sloping SNHL with duration of hearing loss less than two years (subgroup C), moderate to severe sloping SNHL with duration of hearing loss greater than two years (subgroup D) as shown in the Table 1.

Table 1: Number of ears selected in each subgroup based on duration of hearing loss

Degree of Sloping cochlear hearing loss	Duration of hearing loss(Number of ears)	
	<2 years	*>2 years*
Minimal to Moderate	6	4
Moderate to Severe	4	7

Test Procedure

Procedure involved four phases: 1) Selection of participants, 2) Selection of hearing aid, 3) Hearing aid fitting, 4) Acquiring aided and unaided Acoustic change complex

Phase 1: Selection of Participants

The following audiological tests were carried out for participant selection in to group I and group II. To begin with, a detailed case history was taken for each participant to make sure that the participants have no symptoms of retro-cochlear pathology.Modified Hughston and Westlake method by Carhart and Jerger (1959), was used to measure the air conduction thresholds at octave frequencies from 250 Hz to 8 kHz and bone conduction thresholds for octave frequencies from 250 Hz 8 kHz. PTA_1(average of the pure tone thresholds at 500Hz, 1 kHz, 2 kHz) and PTA_2(average of the pure tone thresholds at 1 kHz, 2 kHz, 4 kHz) werecalculated to define the degree and configuration of hearing loss for group I and group II.

Speech identification score was obtained using the speech identification test material given by Yathiraj and Vijayalakshmi (2005), at a level of 40 dB SL (Re: SRT). Twenty five words were presented in the live mode (male speaker) at a level of 40 dBHL above PTA1. Scoring was done in such a way that each correct responses (repeating back correctly) got a score of 4%.Tympanometry was done using probe frequency of 226 Hz (Brooks, 1968; Holte, Margolis & Cavanaugh, 1991) at 85 dB SPL. Ipsilateral and contralateral reflexes were obtained

from test ear at 500 Hz, 1 kHz, and 2 kHz and for broad band noise. Mean threshold for group at each frequency is given in the Table 2.

Table 2: Mean thresholds at each audiometric frequency for each group

Degree of hearing loss	Duration of hearing loss (years)	Mean threshold (dBHL) across frequencies				
Minimal to moderate		*250 Hz*	*500Hz*	*1 kHz*	*2 kHz*	*4 kHz*
	< 2	18.33	22.55	37.55	48.33	60.00
	> 2	18.00	22.00	35.00	45.00	68.00
Moderate to severe	< 2	25.00	42.55	52.55	70.00	75.00
	> 2	42.88	50.77	60.00	70.00	80.71

Phase 2 - Selection of Hearing Aid

Four channel digital behind the ear hearing aid was selected to record aided ACC. The fitting range of the hearing aid covered severe to profound hearing loss. According to the manufacturer's specification, in 2cc coupler the frequency response of the hearing aid extended from 100 Hz to 6200Hz. Peak full on gain was 70dB and high frequency average full on gain was 62dB. Attack time was 10 ms and release time was 51 ms. The total harmonic distortion was less than 3% at 500 Hz, 2% at 800 Hz and 1% at 1600 Hz, whereas, the equivalent input noise was 18 dBSPL. The measured electroacoustic characteristics of the hearing aid were according to manufacturer's specification.

Phase 3 - Hearing Aid Fitting

After the selection of the hearing aid hearing aid fitting was done to the participants test ear. Regular ear mold that is attached to the BTE adapter was used to ensure that the squealing was absent and that is snugly fit into the participants test ear without creating discomfort. The following two approaches were made prior recording of ACC - i) programming of hearing aid ii) Real ear measurement of hearing aids.

Programming of Hearing Aid: The selected hearing aid was connected to the personal computer and Noah fitting software by using HiPro. The Bass Boost facility of the hearing aid was turned off, and the hearing thresholds were fed on to Noah fitting software and fitting

module. The hearing aid was set in omni-directional mode with enabled compression circuits, where compression ratio in the NAL-NL1 default setting was used and volume control was disabled. NAL-NL1 fitting formula was used to prescribe the gain for hearing aid and hearing aid was programmed to match the target gain at acclimatization level two.

Real Ear Measurements: The participants were seated in front of the free field speaker of phoenix FP 7000 equipment. The speaker of equipment was placed at 45 degree azimuth and 1 meter distance from the participant. Then the sound field was equalized.

The audiogram of the test ear was plotted and fitting formula of NAL NL1, stimulus of digi-speech at 65 dB-SPL was selected in the phoenix FP 7000 software. The probe tube of the microphone was inserted by means of premeasured length, 25 to 30 mm past tragal notch of the test ear. Then, the hearing aid was fitted to the test ear using regular ear mold attached with a BTE adapter. The real gain was verified to match the NAL-NL1 target. The gain of the hearing aid was increased to match the target whenever the real ear SPL was not matching the target gain curve.

Phase 4 - Acquisition of Aided and Unaided Acoustic Change Complex

Once the gain of the hearing aid in the ear canal is verified through real ear measurement, ACC was acquired in aided and unaided condition in each participant. The participants were seated comfortably in an armed chair and the fitted hearing aid was switched to 'on' position. The electrode site was cleaned with skin preparation gel. Disc type gold coated electrodes was placed with the help of conduction gel at the test ear mastoid (M1/M2), upper forehead (Fpz), and vertex (Cz). The impedance was less than 5 kΩ and inter-electrode impedance within 2 kΩ. Caution was taken about the chance of closer proximity or contact of electrode and hearing aid microphone. The hearing aid was positioned to the periphery of the pinna and made sure that the hearing aid is not in closer proximity or contact of electrode and hearing aid microphone. For recording the ACC in aided conditions, the stimulus /si/ was presented through free field speaker, positioned at one meter distance at 45 ^{o} azimuth. The stimulus was presented at level of 65dBSPL and ACC was recorded for checking replicability of waveform. The non-test ear was blocked with ear mold impression material to avoid its participation (whenever required). The subjects were asked ignore the stimulus and watch a close captioned video while recording ACC.

After the acquisition of aided ACC the hearing aid was removed from participant's ear and unaided ACC was recorded. The non-test ear remained blocked with ear mold impression material to avoid its participation (whenever required).

Table 3: Stimulus and Acquisition parameters for recording ACC

Stimulus parameters	
Stimuli	/Si/
Duration of stimuli	250.8
Intensity	65dBSPL
Polarity	Alternating
Transducer	Loudspeaker
Mode of presentation	Free Field
Acquisition parameters	
Mode of stimulation	Ipsi
Electrode montage	Cz(+ve), M1/M2(-ve) of test ear and ground at Fz
Filter setting	0.1-30 Hz.
Analysis window	535 msec.
No. of channels	Single
Amplification	25,000
Repetition rate	1.1 per sec
Number of sweeps	150
No. of repetitions	2

Analysis of Waveforms

Analyses of unaided and aided ACC waveforms were done for all participants. The peak identification and morphology rating were done by two experienced audiologist in waveform analysis. The peaks which are marked by both audiologists were considered for analysis. When an audiologist marked a peak, but, not the other, the peak was not considered for analysis. The peaks of ACC were marked as P1, N1, P2, N2, P1', N1', P2', and N2'. Amplitude, latency, and morphology were the three measures considered for waveform analysis. The amplitude of the each peak was defined as the largest positive or negative deflection depending on whether it's a negative or positive peak in the response window. The latencies of the peaks were calculated by taking the center or midpoint when wave form contained double peak of equal amplitude. Latency was measure at the center of larger peak when peaks were not equal in amplitude (Ostroff, Martin &Boothroyd, 1998). The data point values representing N1, P2, N1' and P2' were tabulated for statistical analysis.

Results and Discussion

Three independent variables; subgroup, unaided, and aided condition were taken and their influence on the dependent variables; parameters of ACC (latency and amplitude) was studied. N1, P2, N1', P2' were the target parameters considered for statistical analysis.

Descriptive statistics (mean and standard deviation) were calculated for each subgroup; minimal to moder-

ate sloping sensorineural hearing loss (SNHL) with duration of hearing loss less than two years (subgroup A), minimal to moderate sloping SNHL with duration of hearing loss greater than two years (subgroup B), moderate to severe sloping SNHL with duration of hearing loss less than two years (subgroup C), moderate to severe sloping SNHL with duration of hearing loss greater than two years (subgroup D).Mann Whitney test was administered to compare the unaided & aided ACC separately, between minimal to moderate & moderate to severe degrees of sloping sensorineural hearing loss, with duration of hearing loss less than and greater than two years.Mann Whitney test was administered to compare between less than or greater than two years of duration of hearing loss in minimal to moderate & moderate to severe degree of sloping sensorineural hearing loss separately.Wilcoxon signed rank test was done for comparing unaided and aided ACC within each subgroup. Figure 1 shows the unaided and aided waveforms of each subgroup.

Effect of Different Degree of Sloping SNHL on Unaided and Aided ACC

Mann Whitney test was administered to study the differential effect of different degree of sloping SNHL with duration of hearing loss less than two years on unaided and aided ACC. Latency and amplitude of N1' , P2' were compared separately between subgroup 'A' and 'C' in the unaided condition. N1, P2 peaks were absent in subgroup C, whereas, in subgroup A, the N1and P2 peaks were present only for two and three ears out of six ears. Hence, these ACC peaks were not included for comparison in the unaided condition. In the aided condition, N1 peak was present in all ears except one ear in the same subgroup. However, in subgroup C, it was present for all four ears. P2 peak was obtained for all ears in subgroup A. But, in subgroup C it was absent for one ear out of four ears aided condition. The reason for absence of N1 and P2 in subgroup C and its presence in subgroup A is discussed below.

The N1 of ACC represents the onset of consonant portion in the stimulus (syllable) (Ostroff, Martin & Boothroyd, 1998). The consonant portion (fricative portion) in the stimulus (/si/) has a spectral energy of 2 k Hz and above, more energy around 4 to 8 k Hz (shown in Figure 2). The audibility at the higher frequency is important for the perception of fricatives (Annabelle, Sher & Owens, 1972), and it is also evident from studies that if proper audibility is present there is indemnity of generation of far field recordable cortical potentials. In the present study, the two ears in the subgroup A had mean threshold at high frequency (from 1 k Hz to 4 k Hz) as 41.6 and 43.3 dBHL. Hence, the presence of N1 is accounted to the intensity level of the presentation of stimulus, which was at 65 dBSPL. But, in group C N1 was absent for all subjects. This suggests, audibility at

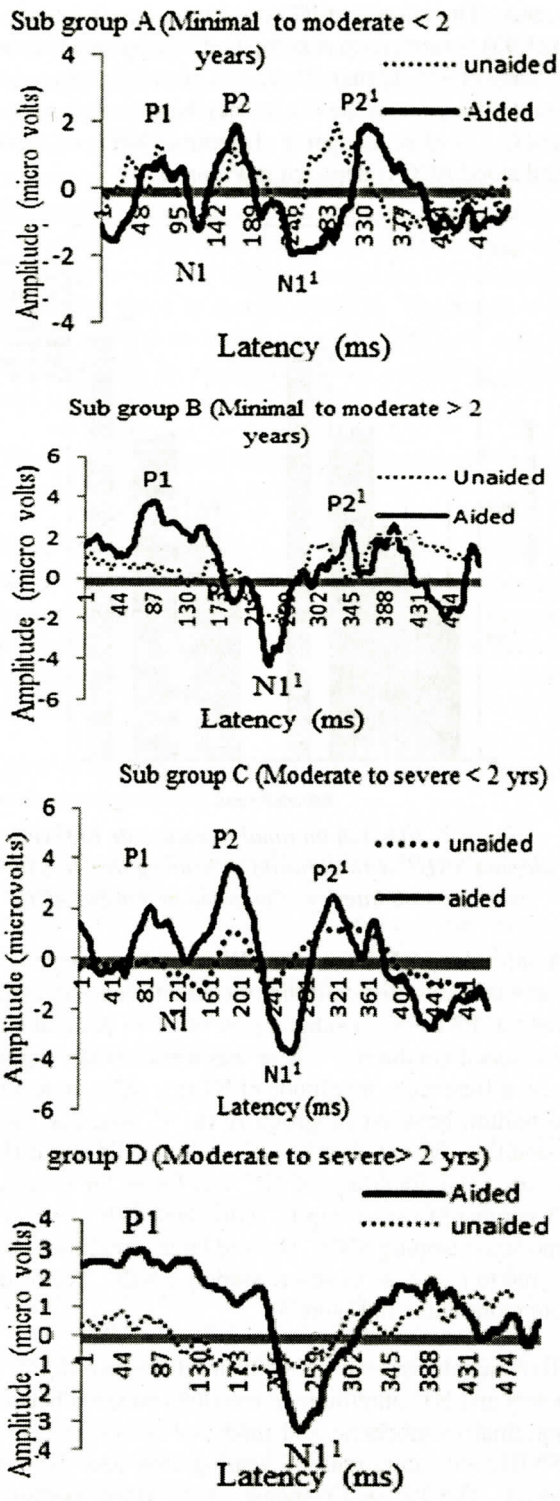

Figure 1: Unaided and aided waveforms for each subgroup.

the higher frequencies (1 k Hz and above) is important for the generation of N1.

Latency of N1', P2': The results of the Mann Whitney test for latency of N1' , P2' revealed that there is a significant difference in latency of P2' (Z = -2.07 p = .038) in unaided condition between subgroup A vs. C. But, aided condition did not show any statistical signif-

icance. The latency of P2'was shorter (mean latency of 321.93) for subgroup A compared to subgroup C (mean latency of 346.92 ms). There was no statistically significant difference in the N1'latency between subgroup A and C. The effect of degree of sloping SNHL on unaided and aided ACC is depicted in Figure 2 .

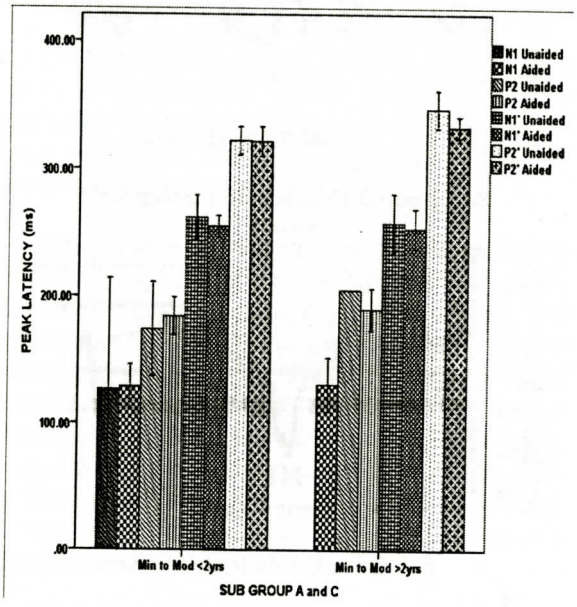

Figure 2: Effect of minimal to moderate to severe sloping SNHL with duration of hearing loss less than two years on latency of unaided and aided ACC.

Amplitude of N1', P2': Mann Whitney test revealed that there was no statistically significant difference in amplitude of P2 between subgroup A vs. C in both unaided and aided conditions. There was a statistically significant difference in amplitude of N1 ($p = .020$) in unaided condition between subgroup A vs. C, whereas, aided condition did not shown statistically significant differences. The amplitude of N1' was larger for subgroup A compare to subgroup C, individual with minimal to moderate sloping SNHL showed larger amplitude compared to moderate to severe sloping SNHL. The results are represented in Figure 3.

To conclude, there is a significant difference in P2' latency and N1' amplitude in unaided condition between minimal to moderate and moderate to severe sloping SNHL with durations of hearing loss less than two years. The P2' is a response to the vowel portion of the stimulus i.e. syllables (Ostroff, Martin, Boothroyd, 1998) and thresholds at the 250Hz to 2 kHz is important for the generation of P2'. In present study stimulus had a vowel (/i/) with more spectral energy in this region. Subgroup A had better thresholds at this frequency region compare to C as a result of this, the P2' latency was shorter for Subgroup A compare to C. Hence, it is possible to electrophysiologicaly state that when the degrees of slope till 2 kHz increases, the vowel coding at the cortical level decreases. The onset portion of /i/ vowel has got low frequency content than its steady

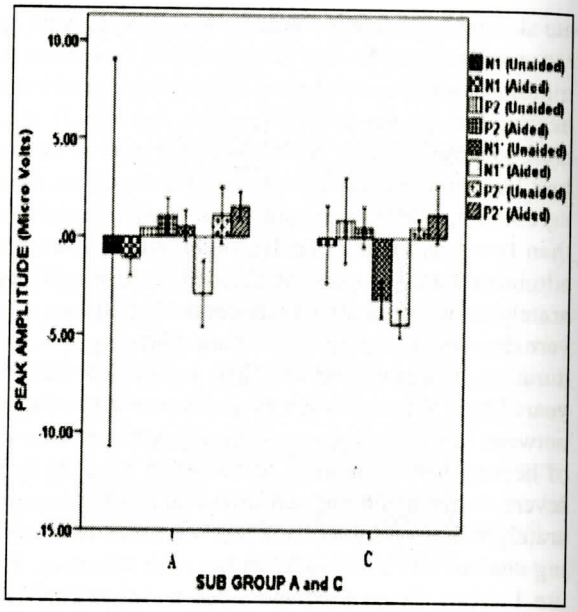

Figure 3: Effect of minimal to moderate and moderate to severe sloping SNHL with duration of hearing loss less than two years on the amplitude of unaided and aided ACC.

state portion and cortical response to this onset portion is represented by N1' peak of ACC. The low frequency thresholds (250 Hz and 500 kHz - mean of 20.44 dBHL) were better for subgroup A than C (mean threshold of 33.77). So, there is larger amplitude of N1' for minimal to moderate than moderate to severe sloping SNHL with duration of hearing loss less than two years. But, in aided condition, there was no significant difference between two groups. It says that the hearing aid in both degrees (higher and lower) works similarly.

Effect of Minimal to Moderate vs. Moderate to Severe Sloping SNHL with Duration of Hearing Loss Greater than Two Years on Unaided and Aided ACC.

Latency of N1, P2, N1', P2': In unaided condition, N1 was absent for subgroup B and D, whereas, P2 was present only for two ear in the subgroup B with a mean latency of 203ms. Mann Whitney test revealed that there was no statistically significant difference in latency of N1, P2, between subgroup B vs. D in aided conditions. Latency of N1' ($p = .059$) in aided condition and P2' in unaided condition ($p = 0.50$) between subgroup B vs. D is approaching statistical significance. The latency of N1' in aided condition was longer (mean latency of 262.07) for subgroup B compare to subgroup D (mean latency of 252.78), i.e., minimal to moderate sloping SNHL group showed longer latency compare to moderate to severe sloping SNHL. The effect of minimal to moderate and moderate to severe SNHL on latency of unaided and aided ACC is depicted in Figure 4.

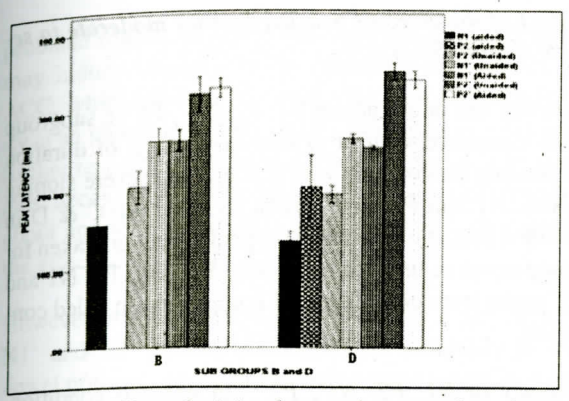

Figure 4: Effect of minimal to moderate and moderate to severe sloping SNHL with duration of hearing loss more than two years on latency of unaided and aided ACC.

Amplitude of N1, P2, N1', P2': Mann Whitney test revealed that there was no statistically significant difference in amplitude of N1, P2, between subgroup B vs. D in aided conditions. In unaided condition, N1 was absent for subgroup B and D, and P2 was present only for two ear in the subgroup B with a mean amplitude of 2.67uv. Amplitude of N1'(p=0.053) and P2' (p=0.050) in unaided condition between subgroup B vs. D is approaching statistical significance. The amplitude of N1' in unaided condition was larger (mean amplitude of -3.9uv) for subgroup B compared to subgroup D (mean amplitude of -2.05μV), i.e., in individual with minimal to moderate sloping SNHL showed larger amplitude compare to moderate to severe sloping SNHL Effect of minimal to moderate and moderate to severe sloping SNHL with duration of hearing loss more than two years on amplitude of unaided and aided ACC is represented in Figure 6.

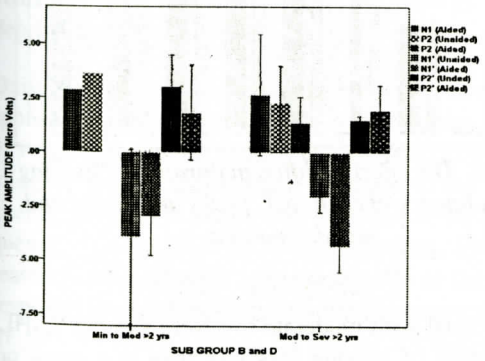

Figure 5: Effect of minimal to moderate and moderate to severe sloping SNHL with duration of hearing loss more than two years on amplitude of unaided and aided ACC.

The comparison of greater duration (greater than two years) with two different degree of sloping SNHL demonstrated statistically different amplitude of N1' and P2'latency and amplitude in unaided condition. When, effect of greater duration of hearing loss added to degree of slope, N1' showed significant difference between minimal to moderate and moderate to severe sloping SNHL in unaided and aided condition. The auditory deprivation effect could be the probable reason for this. It indicates that if the duration of hearing loss is more, even with effective amplification also there is difference in cortical representation of speech sounds. The concept of auditory deprivation in individuals with moderate to severe SNHL as a measure of cortical potential was given by Buckley (2003). The result of the present study is in agreement with Buckley's study in terms changes in amplitude of the cortical potentials with auditory deprivation.

Effect of duration of hearing loss along with degree on unaided and aided ACC

Mann Whitney test was administered to study the effect of duration of hearing loss on a particular degree of sloping hearing loss. The results of effect of duration of hearing loss on degree of sloping SNHL in unaided and aided ACC conditions are discussed in the following section

Effect of duration of hearing loss on minimal to moderate sloping SNHL

Mann-Whitney test was administered to study the two different duration of hearing loss; less than two years and greater than two years on minimal to moderate sloping SNHL. Latency and amplitude of N1, P2, *N1', P2'* in subgroup A is compared with the same of subgroup B to study the effect of duration of hearing loss on ears with minimal to moderate sloping SNHL.

Latency of N1, P2, N1', P2': Mann - Whitney test revealed that there was no statistically significant difference in latencies of N1, P2, N1', P2' between subgroup A vs. B in unaided condition. The N1 is present only for two ears in subgroup A (mean latency of 126.61ms) out of six ears, whereas, it was absent for all ears in subgroup B. P2, is present in three out six ears (mean latency of 174.01)in subgroup A and two ears out of four ears (mean latency of 203ms) in the subgroup B. But, latency of P2in aided condition is approaching statistical significance (p = 0.052) between subgroup A vs. B. The latency of P2was shorter (mean latency of 184.30ms) for subgroup A compared to subgroup B (mean latency of 203.26ms).

Amplitude of N1, P2, N1', P2': Mann Whitney test revealed that there was no statistically significant difference in amplitude of N1, P2, between subgroup A vs. B in aided conditions, but these peaks were not considered in the unaided condition as N1 was absent for all ears in subgroup B and P2 was only present for three (mean amplitude of 0.44μV) and two ears (mean amplitude of 2.67μV) in subgroup A & B respectively. Amplitude of N1' in unaided condition between subgroup A vs.

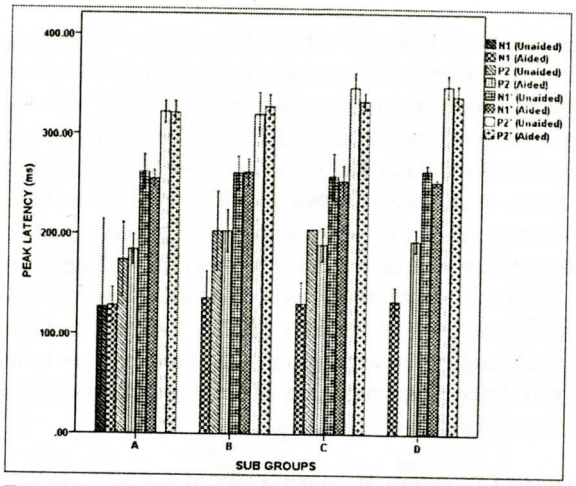

Figure 6: Effect of duration of hearing loss (less than two years and more than two years) of minimal to moderate and moderate to severe sloping SNHL on latency of unaided and aided ACC.

B is statistical significant (p = 0.020). The amplitude of N1'in unaided condition was larger for subgroup A compare to subgroup B.

To conclude, minimal to moderate sloping SNHL with different durations are not affecting the latency of unaided ACC, but, the amplitude of N1'. This effect was more seen in minimal to moderate sloping SNHL with duration of hearing loss greater than two years. The probable reason is auditory deprivation. In aided condition, P2 showed a difference, this tells us that with amplification there is difference in consonant coding at cortical level in individual with more than two years of duration of minimal to moderate sloping SNHL. So, it could be that the auditory deprivation within minimal to moderate sloping SNHL has an effect on cortical neural coding of acoustical changes within speech sounds with amplification.

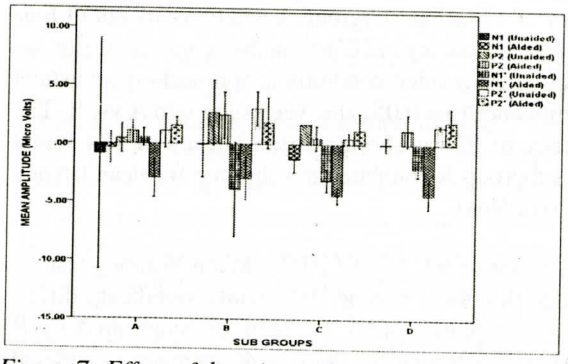

Figure 7: Effect of duration of hearing loss (less than two years and more than two years) of minimal to moderate and moderate to severe sloping SNHL on amplitude of unaided and aided ACC.

Effect of duration of hearing loss on moderate to severe sloping SNHL

Latency and amplitude of N1, P2, N1', P2' in subgroup C is compared with D to study the effect of duration of hearing loss on ears with moderate to severe sloping SNHL.N1 and P2 were absent in subgroup C & D in unaided condition, hence these peaks were not taken for comparison in unaided condition. But, N1, P2, N1'and P2'peaks were considered for comparison in aided condition.

Latency of N1, P2, N1', P2': In unaided condition, Mann Whitney test revealed that there was no statistically significant difference in latencies of N1' and P2' between subgroup C and D, whereas, in aided condition latencies of N1, P2, N1',P2' also does not shown any statistically significant differences. Effect of duration of hearing loss on latency of unaided and aided ACC is represented in figure7.

Amplitude of N1, P2, N1', P2': Mann Whitney test revealed that there is a statistically significant difference in amplitudes of P2' (p = 0.034), between subgroup C vs. D. Whereas, N1' is approaching statistical significance (0.059) in unaided condition. In aided condition, only the amplitude of showed statistically significant difference (p = 0.019) between subgroup C &D. Effect of duration of hearing loss on amplitude of unaided and aided ACC is represented in Figure 8.

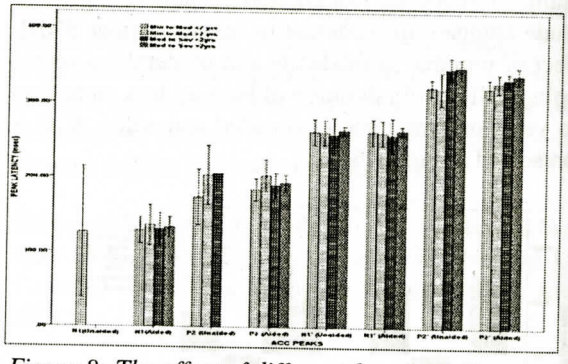

Figure 8: The effect of different duration of hearing loss on latency of each ACC peaks in unaided and aided condition.

The individual with moderate to severe sloping SNHL with duration of hearing loss less than two years or greater than two years had no N1 and P2 peaks of ACC. This indicates that consonant (fricative /s/) is not coded at their auditory cortical structures which are responsible for the generation of ACC potential at usual conversational speech level (65 dBSPL). The reason for this is poor thresholds at the higher frequencies (frequencies above 2 KHz) leading to lack of 'audibility' of high frequency, low intensity speech sounds like fricatives. Lack of audibility at high frequencies could not be the only reason even though it is the major one. The other

probable reason could be that the auditory deprivation may induce changes in the amplitude and latency of ACC, which may act together with decreased audibility at an input level of 65 dBHL. Hence, to support this, further research with various input levels to the hearing aids, needs to be conducted which will give information about auditory deprivation of ACC, as at higher levels the effect of audibility is compensated.

However, in these individuals there was a presence of N1' and P2' peaks, which indicate audibility to the vowel portion, can be preserved to some extent in these individuals with sloping SNHL. But, there is a question which need to be answered is, why the vowel coding was not significantly different (no significant difference in latency and amplitude N1' and P2') between duration of hearing loss of less than two years and more than two years. The probable reason for this is the heterogenic cortical auditory response characteristics in individual with moderate to severe sloping SNHL, and also the variability in the participant selection (number of ears selected in subgroup C had only four, which, D had only seven). However, a proper amplification is given to these participants; there was a presence of N1, P2 peaks and statistically significant difference in N1' amplitude of aided ACC between moderate to severe sloping SNHL with duration of hearing loss less than two years (more amplitude)and more than two years (less amplitude). The reason for presence of N1, P2 indicates that with proper amplification the consonant (/s/) is coded in the cortical level of individual with moderate to severe sloping SNHL irrespective of duration of hearing loss. But, the reason for significant difference in N1' amplitude (indicates vowel onset portion (/i/) in the stimulus coded differently in moderate to severe sloping SNHL with duration of hearing loss less than two years and greater than two years is probably auditory deprivation.

Only N1'showed significant difference because this response is mainly elicited by the low frequency portions of vowel (/i/) and it is already evident from electrophysiological studies that cortical response to the low frequency stimulus is better than response to the high frequency stimulus (Picton, Woods &Proulex, 1978). The reason is that, inherent lower amplitude of the cortical response when elicited from stimulus containing high frequency content such as /ʃ/ and /s/ compared to /m/, /a/, /u/ and /i/ which had predominant low frequency content as documented by Agung, Purdy, McMahon &Newall (2006). One of the stimulus related reason is that /i/ portion of /si/ stimulus used in the present study had larger amplitude compared to /s/ portion. Hence, the better amplitude of N1'.

To explain further, physiologically, individuals with cochlear pathology have wider auditory filter, is a reason they are more prone to the effects of upward spread of masking (Moore, 1998). The preceding high frequency signals (fricative /s/) in the stimulus of this study could have been masked to an extent by low frequency vowel portion. It is evident from studies that low frequency portions of speech like vowels may mask higher frequency components like frication noise as reported by Dillon (2001). Hence, the N1' amplitude was higher compare to other peaks.

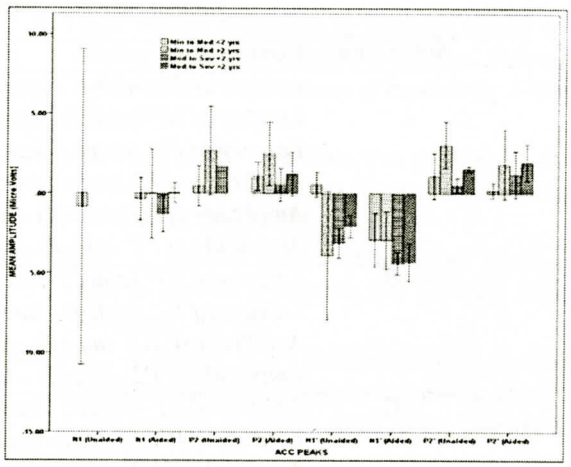

Figure 9: Effect of duration of hearing loss on amplitude of unaided and aided ACC.

Comparison of Aided and Unaided ACC within Each Subgroup

Latencies and amplitude of P2, N1', $P2^1$ (compared only within subgroup A) and N1', P2' (compared within subgroup B, C, D) were compared using Wilcoxon Signed Ranks test between unaided and aided condition within each subgroup. Latency and amplitude comparison of unaided and aided peaks of ACC were done, in order to study the effect of amplification along with degree and different duration of hearing loss on cortical neural representation of acoustical changes within speech sounds (syllable).

Comparison of aided and unaided ACC within subgroup A

The latency and amplitude of P2, N1', and P2'peaks were compared separately between unaided and aided condition within subgroup A using Wilcoxon Signed Ranks test. The results of wilcoxon Signed Rank test for each subgroup is shown in Table 3.

Latency of P2, N1', P2': The results of the test revealed that there are no statistically significant difference latencies of P2, N1', and $P2^1$ between unaided and aided condition within minimal to moderate sloping SNHL with duration of hearing loss less than two years.

Amplitude of P2, $P2^1$ also does not shown any statistically significant differences, whereas, N1' has shown a statistically significant difference ($p = 0.028$). The amplitude of (mean amplitude of 0.54, shown in table 4.1)

Table 4: Results of Wilcoxon Signed Ranks Test

Subgroups	Comparisons	Z value	p
A	*Latency of P2 (aided) - latency of P2 (unaided)*	-0.535	*0.590*
	Latency of N1' (aided) - latency of N1' (unaided)	-1.15	0.249
	Latency of P2' (aided) - latency of P2' (unaided)	*-0.420*	0.674
	Amplitude of P2 (aided) -amplitude of P2 (unaided)	-0.535	0.593
	Amplitude of N1' (aided) - Amplitude of N1' (unaided)	-2.20	0.028*
	Amplitude of P2' (aided) - Amplitude of P2' (unaided)	-1.15	0.25
B	*Latency of N1' (aided) - latency of N1' (unaided)*	0.000	1.00
	Latency of P2' (aided) - latency of P2' (unaided)	-1.06	0.28
	Amplitude of N1' (aided) - Amplitude of N1' (unaided)	-1.06	0.10
	Amplitude of P2' (aided) - Amplitude of P2' (unaided)	-0.535	0.59
C	*Latency of N1' (aided) - latency of N1' (unaided)*	-0.730	0.46
	Latency of P2' (aided) - latency of P2' (unaided)	-1.82	0.06
	Amplitude of N1' (aided) - Amplitude of N1' (unaided)	-1.82	0.06
	Amplitude of P2' (aided) - Amplitude P2' (unaided)	-1.46	0.14
D	*Latency of N1'(aided) - latency of N1' (unaided)*	-2.19	0.028*
	Latency of P2' (aided) - latency of P2' (unaided)	-1.60	0.10
	Amplitude of N1' (aided) - Amplitude of N1' (unaided)	-2.36	0.01*
	Amplitude of P2' (aided) - Amplitude of P2' (unaided)	-1.60	0.10

*Indicates statistically significant. *Amplitude of P2, N1', P2'*

N1' in aided condition is larger than in unaided (mean amplitude of -2.91, shown in table 4) within subgroup A.

Comparison of aided and unaided ACC within subgroup B and C

The latency and amplitude of N1', P2[1] peaks were compared separately between unaided and aided condition within subgroup B and C using Wilcoxon Signed Ranks test.

Latency of N1', P2': The results of the test revealed that there are no statistically significant difference in the latencies of N1', P2[1] between unaided and aided condition within minimal to moderate and moderate to severe sloping SNHL with duration of hearing loss greater than and less than two years.

Amplitude of N1', P2': Amplitude of N1' and P2[1] did not show any statistically significant differences between unaided and aided condition within minimal to moderate and moderate to severe sloping SNHL with duration of hearing loss greater than & less than two years respectively.

Comparison of aided and unaided ACC within subgroup D

The latency and amplitude of N1', P2[1] peaks were compared separately between unaided and aided condition within subgroup D using Wilcoxon Signed Ranks test.

Latency of N1', P2': The results of the test revealed that there are no statistically significant difference in the latencies of P2[1] but, there is a statistically significant difference in N1' latency (p = 0.028) between unaided and aided condition within moderate to severe sloping SNHL with duration of hearing loss greater than two years .

Amplitude of N1', P2': Amplitude of N1' is also shown statistically significant differences (p = 0.018) between unaided and aided condition within moderate to severe sloping SNHL with duration of hearing loss greater than two years. But, there is no statistically significant difference in amplitude of P2'.

Justification for the results under within subgroup comparisons

The results of the within group comparison of unaided and aided ACC in subgroup A, clearly throws light on to the effectiveness of amplification in sloping hearing loss with duration of hearing loss less than two years. There was appearance of N1 in aided condition; which indicates that the audibility of (Korczak, Kurtzberg&Stapells, 2005; Oates, Kurtzberg&Stapells, 2000;Polen, 1984), the fricative portion was enhanced by amplification. The reason for absence of N1 in subjects minimal to moderate sloping hearing loss can be the upward spread of masking (Moore, 1998). In the present study low frequency - high amplitude vowel could have been masked the onset portion of fricative /s/. So, even minimal to moderate sloping SNHL with duration of hearing loss less than two years needs to be provided with hearing aids, even if they have minimal speech perception problems. The above statement has to be supported by further behavioral and electrophysiological studies.

The results of the within group comparison of unaided and aided ACC in subgroup B, throws light on to the effectiveness of amplification in sloping hearing loss with duration of hearing loss more than two years. It is indicated that latency and amplitudes of unaided and aided

condition did not show any significant differences, even though there is a difference in the mean value. The probable reason for this is auditory deprivation.

The results of the within group comparison of unaided and aided ACC in subgroup C, gives information on the effectiveness of amplification in moderate to severe sloping hearing loss with duration of hearing loss less than two years. There was appearance of N1, P2 in aided condition because of audibility at the higher frequency provided by the hearing aid. It is indicated that latency and amplitudes of unaided and aided ACC did not show any significant differences, though there is a difference in the mean value. The probable reason could be the abnormal growth of loudness phenomenon that occurred at the threshold level (Florentine, Fastle&Buus, 1998) in these participants in the unaided condition but not in aided condition with probably may be contributed to the amplification factors by the hearing aid.

The results of the within group comparison of unaided and aided ACC in subgroup D, clearly throws light on to the effectiveness of amplification in moderate to severe sloping hearing loss with a duration of hearing loss more than two years. There was appearance of N1, P2 peak in aided condition even in individual with more than two years of deprivation because of audibility at the higher frequency provided by the hearing aid. It is indicated that latency and amplitudes of unaided ACC peaks (N1', P2') did not show any significant differences but there was a difference in latency and amplitude of N1 ' of aided ACC compare to unaided ACC. The reason for this finding is presently unclear.

Conclusions

From the study we can conclude that since most of the peaks of ACC are present in aided condition compared to unaided condition in individual with varying degrees of sloping sensorineural hearing loss, ACC can be used as an objective measure to quantify the benefit from amplification.Vowel portion of the speech stimulus is better coded in the cortical level compared to consonant portion as evidenced from larger amplitude of N1' and P2' compared to N1 and P2 in individuals with varying degrees of sloping hearing loss.It is evident from the results of this study that the hearing aids are not able to give adequate amplification at higher frequencies as the fricatives are not being coded well at the cortical level compared to vowels. Hence, measures should be taken to improve the spectral content of the higher frequency sounds by the amplification device for individuals with sloping sensorineural hearing loss.

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