The Cortical Neural Processing for Spectrally Different Speech Sounds in Individuals with Cochlear Hearing Loss

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Abstract

The Auditory Late Responses (ALLRS) is reported to test the integrity of the auditory system and it also provides a tool to investigate the neurophysiological processes that underlie our ability to perceive speech (Purdy, Katsch and Sharma, & Dillon, 2001). The development of such electrophysiological measures such as ALLRS is important because they can be used to evaluate the benefits of hearing aids and cochlear implants in infants, young children, and adults those who do not cooperate for behavioral speech discrimination testing. In the current study ALLRSs were recorded using three different speech sounds, which together covered a range of frequencies across the speech spectrum. It was determined whether it could be differentiated from each other based on response latency and amplitude measures. ALLRSs were recorded from 32 ears of 16 subjects with normal hearing adults and 23 ears of 12 adult subjects with cochlear hearing loss for three different speech sounds at 40dB SL and 70 dBnHL. ALLRS waveforms were reliably elicited by each of the speech sounds in all participants in both normal hearing and cochlear hearing loss individuals. Each of the speech sound elicited different ALLRS waveforms. The results suggest that neurophysiological processes are different for different speech sounds. Longer latency for /da/ suggests that the processing at the cortical center is different depending on the frequency composition of the signal. A significant difference between the groups for latency and amplitude of ALLRSs for all the three speech sounds at each presentation level suggests that speech processing is altered in individuals with cochlear hearing loss.

Introduction

The cortical auditory evoked potentials are scalp recorded evoked potentials that occur in response to variety of stimuli (Näätänen and Picton, 1987). Cortical auditory evoked potentials can be classified into 'obligatory' and 'discriminative' potentials. Discriminative potentials are evoked by a change from frequent 'standard' stimulus to an infrequent 'deviant' stimulus. The discriminative potentials consist of mismatch negativity (MMN) and P_{300}. The 'obligatory' Auditory Late Latency Responses (ALLRS) are classified in terms of their latencies or the time of occurrence after presentation of a stimulus (Hall, 1992). These responses are reported to test the integrity of the auditory system (Hall, 2007).

The auditory late latency responses have four major components. The first voltage component, P1 occurs in the 50 to 80 ms region. It is followed by, N_1 between 100 and 150 ms, P_2 between 150 – 200 ms and N_2 between 180 to 250 ms. Early positive component in the region of 40 to 50 ms (P_1) occurs less consistently than N_1 and P_2. The amplitude of long latency auditory evoked potentials is around 2–7 micro volts (Hall, 2007).

The ALLRSs can be used as an electrophysiological method for estimation of hearing sensitivity in infants and young children. It has been used in the evaluation of auditory processing disorders in learning disabilities and auditory neuropathy (Hall, 2007). ALLRSs have been recently used to determine the effect of phonologic and acoustic features (Crottaz-Herbette and Ragot, 2000) and to identify the cortical areas

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activated by these features (Makela, Alku and Tiitinen, 2003). This objective measure provides a tool to investigate the neurophysiological processes that underlie our ability to perceive speech (Purdy, Katsch and Sharma and Dillon, 2001; Trembley, Friesen, Martin and Wright, 2003). Furthermore, it has been used to index changes in neural processing with hearing loss and aural rehabilitation (Martin, Trembley and Stapells, 2007). The auditory late responses elicited by speech stimuli can be applied in the electrophysiological assessment to assess the representation of speech in the central auditory nervous system. Furthermore, it can be used to understand the neural encoding of speech in individuals with impaired auditory pathways (Eggermont and Ponton, 2003).

Agung, Purdy, McMahon and Newall (2006) recorded ALLRS for, /a, u, i, s, sh, m and כ / which covered a broad range of frequencies across the speech spectrum. They observed that P_1 and P_2 elicited by longer duration vowels /u/, /a/ , /כ / /i / decreased in latency in the order as written above. Hence, it was concluded that ALLRS wave components may provide an objective indication about the neurophysiological process of speech processing. Spectrally different speech sounds might be encoded differently at the cortical level. However, the ALLRS recording using different speech sounds may not be sufficient to measure the discrimination ability of an individual.

Need for the study

The P_1-N_1-P_2 complex signals the arrival of stimulus information to the auditory cortex and the initiation of cortical sound processing (Hillyard and Kutas, 1983). As reported by Novak, et al. (1989), Trembley, et al. (2003) cortical potentials reflect the functional integrity of the auditory pathways involved in processing of complex speech stimuli. In general, majority of the studies have focused on recording of ALLRSs to click stimulus or more frequency specific tone bursts. But using tone burst doesn't give much information about the processing or perception of the speech. Based on the cortical potentials recorded using speech sounds it can be possible to predict the communication abilities of an individual, and also can be used as a tool to evaluate the improvement due to treatment. ALLRS changes have been shown to occur prior to improvement seen in behavioral perception of speech sounds; physiological recordings may be helpful to predict the prognosis (Trembley, Kraus and McGee, 1998). Hence, use of speech signal has been taken in the current study.

Recording of ALLRSs using speech sounds can probe how the brain processes that underlie auditory detection and discrimination is altered in the individuals with cochlear hearing loss. To date, there is dearth of information regarding the effects of cochlear hearing loss on the ALLRSs to the speech stimuli. Hence, there was a need to study the speech processing abilities in individuals with cochlear hearing loss. As there are no normative to compare, in the Indian population, the study was also considered to include the individuals with normal hearing as a control group.

It is not sufficient to study only the processing of single frequency stimuli. Hence, there was a need to study the ALLRSs which are evoked by speech stimuli with a different spectral energy. Hence, the three different speech stimuli /ba/, /ga/ and /da/ which have spectral energy concentration in low, mid and high frequency spectral energy respectively were taken up for the study.

Speech perception of individuals with cochlear hearing loss is poorer relative to normal hearing individuals in spite of presenting stimuli at most comfortable levels. This

is because spectral and temporal cues of speech get distorted at the peripheral level before reaching the higher structures. Hence, it was hypothesized that cortical processing may be abnormal in individuals with cochlear hearing loss as cortical structures receive abnormal inputs from the lower auditory structures. Because dynamic cues like speech burst and transition are more susceptible to show abnormality. Hence, two different presentation levels were considered to record the ALLRs.

Aims of the study

The aims of the present study were to determine:
(i) whether the auditory late latency responses recorded for spectrally different syllables differ significantly in normal hearing adults, (ii) whether the auditory late latency responses recorded from spectrally different syllables differ significantly in hearing impaired adults, (iii) whether the ALLRSs from two groups differ significantly, and (iv) to investigate the difference in speech evoked ALLRSs between the normal hearing and cochlear hearing loss individuals when the signal presented at the same sensation level or at the same intensity level.

Method

Control group

Thirty two ears from 16 subjects with normal hearing were evaluated. The subjects had pure tone threshold within 15 dB HL at octave frequencies between 250 to 8000 Hz for air conduction and between 250 to 4000 Hz for bone conduction. 'A' type tympanogram with normal acoustic reflex thresholds. Speech identification scores were >90%. No history of acute or any chronic ear infection, ear ache, tinnitus, vertigo or any other otological problems. No relevant history of any medical and neurological impairment.

Clinical Group

Twenty three ears from 12 subjects with cochlear hearing loss were evaluated. The subjects were diagnosed as having cochlear hearing loss by an experienced audiologist. Air bone gap was within 10 dB HL. Pure tone average (PTA) ranged from 26 dB HL to 55 dB HL. 'A' type tympanogram with elevated or absent acoustic reflexs. Speech identification scores were proportionate to their pure tone average. No history of acute or any chronic middle ear infection, ear ache, tinnitus, vertigo or any other otological problems.

Stimulus generation

Syllables /ba/ /da/ and /ga/ were spoken by a male speaker and digitally recorded into a computer with the PRAAT software version 4.2.01 with a sampling frequency of 44,000 Hz and a 16 bit resolution. The voice onset time, burst portion and a little portion of the vowel was retained to make the syllable duration approximately 150 ms. The stimuli durations were 147 ms-/ba/, 150 ms-/da/ and 146 ms-/ga/.

Test procedure

Pure tone audiometry

A Calibrated double channel diagnostic audiometer Orbitter 922 was used. Pure tone air conduction and bone conducted thresholds for each individual was established using Modified Hughson-Westlake method (Carhart and Jerger, 1959).

Immittance

A Calibrated immittance meter (GSI tymp star) was used to assess middle ear status. A 226 Hz probe was used to know the type of tympanogram and acoustic reflexes were measured at 500 Hz, 1000 Hz, 2000 Hz and 4000 Hz eliciting stimulus.

Transient otoacoustic emissions (TEOAE)

ILO 292 system was used to record transient evoked oto-acoustic emissions (TEOAE). The transient Otoacoustic emissions were recorded for nonlinear 256 clicks presented at 85 dBpeSPL. The absence of TEOAEs in the presence of hearing loss was considered as an indicator of cochlear hearing loss.

ABR and ALLR recording

Intelligent Hearing Systems (IHS smart EP windows USB version 3.91) evoked potential system was used to record and analyze the ABR and ALLR. TDH 49-P headphone was used to deliver the stimulus. ABR testing was done to rule out retro cochlear pathology. The recording was done at 90 dBnHL at 11.1 and 90.1 repetition rates using standard protocol for ABR. The parameters used to record ALLRS are given in Table1.

Table 1: Parameters used to record ALLRS

Acquisition parameters	
Amplification	50,000
Analysis window	-100 to500 ms
Filters	1– 30 Hz
Notch filter	On
Artifact rejection	100 µV
Stimulus parameters	
Transducer	TDH-49 head phone
Type of stimulus	/ba/ /ga/ /da/
Duration	/ba/- 147, /da/-150 ms, /ga/-146 ms
Intensity	70 dBnHL; 40 dB SL
Presentation ear	Monaural
Stimulus polarity	Alternating
No of averages	300
Rate	1.1/s

The recording was done twice at each presentation level, for each syllable to check for the replicability. The ALLRS peaks P_1, N_1 and P_2 were identified by 2 experienced judges other than the investigator. The latency of P_1, N_1 and P_2 and peak to

peak amplitude of P_1-N_1, N_1-P_2 were noted for /ba/, /ga/ and /da/ eliciting stimuli recorded at 70 dBnHL and at 40 dB SL.

Results

The latencies of P_1, N_1, P_2 and peak to peak amplitude of N_1-P_2 complex peaks were measured. The Mean and standard deviation (SD) were calculated for 2 groups for 3 syllables at each presentation level. Details are shown in Table 2.

It can be seen from the Table 2, that the mean latency values for the control group were shorter for all the speech sounds elicited at 70 dBnHL, compared to the clinical group. This trend was not seen at 40 dB SL level. The control group was having a mean latency values which were longer than the latency values obtained from the clinical group. The amplitude elicited was larger in the clinical group at 40 dB SL and 70 dBnHL.

Table 2: Mean, SD and t-values and significance levels for P_1, N, P_2 latencies and amplitude of N_1-P_2 elicited by /ba/, /da/ and /ga/ syllables at 40 dB SL and 70 dBnHL in control and clinical group

Para-meter	Level	Syllables	Control group		Clinical group		t values
			Mean	SD	Mean	SD	
P_1	40 dB SL	/ba/	100.00	19.65	75.95	15.44	4.87**
		/da/	110.81	16.88	78.21	19.58	6.60**
		/ga/	104.37	19.95	69.43	13.50	7.27**
	70 dBnHL	/ba/	74.25	21.31	87.52	12.92	2.65**
		/da/	83.72	17.53	97.17	18.27	2.75**
		/ga/	78.72	15.19	83.17	17.17	1.01
N_1	40 dB SL	/ba/	152.65	18.53	131.78	18.78	4.096 **
		/da/	162.25	20.76	142.21	18.64	3.680**
		/ga/	155.15	22.84	127.17	22.33	4.522**
	70 dBnHL	/ba/	124.87	27.15	144.52	16.37	3.085**
		/da/	137.65	21.69	160.65	18.72	4.100**
		/ga/	129.09	22.58	142.73	22.38	2.218*
P_2	40 dB SL	/ba/	213.93	25.59	197.391	24.45	2.409*
		/da/	222.56	43.90	205.13	24.73	1.716
		/ga/	225.90	16.81	202.30	35.11	3.318**
	70 dBnHL	/ba/	183.80	42.76	210.43	22.85	2.716**
		/da/	205.25	23.30	227.6	16.14	3.979**
		/ga/	191.78	28.53	219.1	24.62	3.714**
N_1-P_2	40 dB SL	/ba/	3.91	2.04	5.33	4.40	1.609
		/da/	3.61	2.14	4.67	2.00	1.849
		/ga/	3.28	1.34	4.75	2.48	2.826**
	70 dBnHL	/ba/	3.88	2.10	5.23	2.75	2.068*
		/da/	3.83	2.66	5.45	3.13	2.062*
		/ga/	3.20	1.83	4.48	2.29	2.397*

** $p < 0.05$, ** $p < 0.01$*

Comparison between the groups

Independent t-test was done to compare the latency of ALLR parameters between the groups elicited by the three spectrally different speech syllables at two different presentation levels. The t-values with significance level for P_1, N_1 and P_2 are given in table 2. There was statistically significant difference in P_1 latency between the control group and the clinical group for all the speech sounds at 40 dB SL. At 70 dBnHL a statistically significant difference between the two groups for syllable /ba/ and /da/ was obtained but no difference was noticed for the syllable /ga/. The latency values of N1 for control group were longer than the clinical group at 40 dB SL. The latency for N1 wave was prolonged for /ba/, /da/ and /ga/ in the clinical group compared to control group elicited at 70 dB nHL. There was a statistically significant difference in P2 latency between the control and clinical group for /ba/ and /ga/ speech sounds at 40 dB SL. The latency was significantly different for /ba/ /da/ and /ga/ at 70 dBnHL.

There was a statistically significant difference in N_1-P_2 amplitude between the control group and the clinical group for all speech stimuli at 70 dBnHL. Whereas, at 40 dB SL significant difference was obtained for /ga/ and no difference for /ba/ and /da/ at 40 dB SL.

Within group comparison

A Two-way repeated measure (3 speech sounds×2 levels) ANOVA were used to check for the effect of the speech stimuli and the level on the latency and the amplitude of ALLR parameters within the group. This was done separately for the control group and for the clinical group. Bonferroni post hoc test was administered to see the pair wise comparison for effect of syllable, when there was significant difference observed.

Control group

The results indicated a significant effect of presentation level for latency of three ALLR waves at 0.01 levels. The amplitude of N_1-P_2 did not show any significant effect due to the presentation level, whereas, ALLR eliciting syllable had significant effect only for latency of P_1 and N_1 component. Levels and syllables did not have significant interaction affect for any of the ALLR component. The results are displayed in Table 3 and 4

Table 3: F-values with significance level for P1, N1 and P2 latency and N1-P2 amplitude for /ba/, /da/ and /ga/ in control group

Parameters	Presentation level	Syllable	Level and syllable
P_1	(1,31)=256.56**	(2,62)=3.87*	(2,62)=0.07
N_1	(1,31)=218.97**	(2,62)=3.57*	(2,62)=0.11
P_2	(1,31)=62.72**	(2,62)=2.38	(2,62)=2.13
N_1-P_2	(1,31)=0.015	(2,62)=2.355	(2,62)=0.160

** $p < 0.05$, ** $p < 0.01$*

Table 4: Result of Bonferroni post hoc test for effect of syllable for P_1 and N_1 latency in control group

(a)

Peak	Syllable	/da/	/ga/
P_1	/ba/	10.14**	4.42
	/da/		5.71

(b)

Peak	Syllable	/da/	/ga/
N_1	/ba/	11.18*	3.35
	/da/		7.82

** p < 0.05, ** p < 0.01*

Clinical group

Results indicated a significant effect of presentation level for latency of three ALLR waves. The amplitude of N_1-P_2 did not show any significant effect due to the presentation level, whereas, ALLR eliciting syllable had significant effect only for latency of P_1 and N_1 component but not for the P_2 latency and for amplitude parameters. Levels and syllables had a significant interaction effect only for P_1 latency, but did not have significant affect for any other ALLR component. These results are shown in the Table 5 and 6.

Table 5: F-values with significance level for P_1, N_1, P_2 latency and N_1-P_2 amplitude for /ba/, /da/ and /ga/ in the clinical group

Parameters	Presentation level	Syllable	Level and syllable
P_1	(1,22)=44.70**	(2,44)=5.72**	(2,44)=3.22*
N_1	(1,22)=54.69**	(2,44)=10.02**	(2,44)=1.65
P_2	(1,22)=33.76**	(2,44)=2.74	(2,44)=2.09
N_1-P_2	(1,22)=.23	(2,44)=.87	(2,44)=.91

*p < 0.05, ** p < 0.01*

Table 6: Result of Bonferroni post hoc test for effect of syllable on P_1 and N_1 latency in the clinical group

(a)

Peak	Syllable	/da/	/ga/
P_1	/ba/	5.95	5.43
	/da/		11.39**

(b)

Peak	Syllable	/da/	/ga/
N_1	/ba/	13.28**	3.19
	/da/		16.47**

** p < 0.05, ** p < 0.01*

Table 6(a), indicates that there was a significant difference between the /da/ and /ga/ for P_1 latency. The mean P_1 value for the /da/ is longer compared to the /ga/ syllable, which could have led to this result. There is statistically significant difference for N_1 latency between the /ba/ and /da/ syllable and also between /da and /ga/ syllable (Table 6(b)). The /da/ latency was prolonged when compared to the /ba/ and /ga/ syllable. The /ga/ syllable had the least N_1 latency values.

Across syllable

One-way ANOVA was administered to find out the significance differences in the latencies of P_1, N_1 and P_2 peaks and the amplitude of N_1-P_2 across three different speech stimuli within group. A Bonferroni post hoc test was done to find out the effect of stimuli, when there was significant difference.

Control group

Table 7 shows that a significant difference was obtained for P_1 latency at 40 dB SL and significant difference for P_2 latency at 70 dBnHL. None of the other parameter showed significant effect across the stimuli. The results of the Bonferroni post hoc test for the effect of speech stimuli are shown in the Table 8.

Table 7: F- values with significance level for P_1, N_1, P_2 latency and N_1-P_2 amplitude at 40 dB SL and 70 dBnHL for the control group

Parameters	F values	
	40 dB SL	70 dBnHL
P_1	(2,62)=3.24*	(2,62)=2.58
N_1	(2,62)=2.19	(2,62)=2.96
P_2	(2,62)=1.15	(2,62)=3.44*
N_1-P_2	(2,62)=1.30	(2,62)=1.37

** p < 0.05*

Table 8: Result of Bonferroni post hoc test for effect of syllable on P_1 and P_2 latency in the control group

(a)

Peak	Syllable	/da/	/ga/
P_1 at 40 dB SL	/ba/	10.81*	6.43
	/da/		6.43

(b)

Peak	Syllable	/da/	/ga/
P_2 *at 70 dBnHL*	/ba/	21.44*	7.98
	/da/		13.46

** p < 0.05*

It can be observed from the Table 8(a) that there was a significant difference between the P_1 latency elicited by /ba/ and /da/ at 40 dB SL. The mean P_1 value for the /da/ stimulus was prolonged compared to the /ba/ syllable in normal hearing group. A statistically significant difference was obtained between /ba/ and /da/ syllable for the P_2 latency at 70 dBnHL which can be seen in Table 8(b), the mean P_2 latency values for the syllable /da/ were longer than /ba/.

Clinical group

There was a significant effect of syllables at 40 dB SL only for N_1 latency. No significant effect on P_1, P_2 and N_1-P_2 parameters observed at 40 dB SL. At 70 dBnHL, there was a significant effect of syllables on the P_1, N_1 and P_2 latencies at a 0.01 level, but there was no effect observed for N_1-P_2 amplitudes.

Table 9: F- values with significance level for P_1, N_1, P_2 latency and N_1-P_2 amplitude at 40 dB SL and 70 dBnHL for clinical group

Parameters	F values	
	40 dB SL	70 dBnHL
P_1	(2,44)=3.09	(2,44)=7.49**
N_1	(2,44)=9.02**	(2,44)=8.76**
P_2	(2,44)=.743	(2,44)=5.56**
N_1-P_2	(2,44)=.44	(2,44)=1.79

** p < 0.01

It is evident from the Table 10 that there was a significant difference between the N_1 elicited by ba/-/da/ and /da/-/ga/ syllable at 40 dB SL. The mean values for the /da/ syllable was prolonged compared to the /ba/ and /ga/ syllable, this resulted in the significant difference.

Table 10: Result of Bonferroni post hoc test for effect of syllable on N1 latency in the clinical group at 40 dB SL

Peak	Syllable	/da/	/ga/
N_1	/ba/	10.43*	4.60
	/da/		15.04**

* $p < 0.05$, ** $p < 0.01$

There was statistically significant difference between the /da/ and /ga/ syllable for P_1 latency at 70 dBnHL as shown in Table 11(a). The mean P_1 latency values for the syllable /da/ are longer than the /ga/ stimulus in the clinical group. In the Table 11(b), there is significant difference between /ba/-/da/ and /da/-/ga/ syllables for N_1 latency. The /da/ had longer latency when compared to /ga/ and /ba/ syllable. /ga/ had the least latency values. In Table 11(c), it is shown that there was a significant difference in the P_2 latencies across /ba/ and /da/. /da/ had prolonged P_2 latency when compared to /ba/ syllable.

Table 11: Result of Bonferroni post hoc test for effect of syllable on P1, N1 and P2 latency in the clinical group at 70 dBnHL

(a)

Peak	Syllable	/da/	/ga/
P_1	/ba/	9.65	4.34
	/da/		14.0**

(b)

Peak	Syllable	/da/	/ga/
N_1	/ba/	16.13**	1.78
	/da/		17.91**

(c)

Peak	Syllable	/da/	/ga/
P_2	/ba/	17.26**	8.73
	/da/		8.52

** $p < 0.01$

Effect of the presentation level

Paired t-test was carried out to the effect of the presentation level on each of the parameters of ALLR elicited by three different speech stimuli. Both the control group and the clinical group had a significant effect of the presentation level across the speech sounds on the P_1, N_1 and P_2 latencies. Whereas there was no significant effect observed for the amplitude of N_1-P_2 in both the groups. The mean latency values for P_1, N_1 and P_2 for the control group is shorter for all the speech stimuli at 70 dBnHL. However, the latency values were shorter in the clinical group when presented at 40 dB SL. These differences lead to the significant difference in the latencies of different ALLR waves between the two presentation levels for both the groups. The results obtained for each presentation level can be seen in Table 12.

Table 12: t-values along with significance level for control group and clinical group

Parameter	Syllable	Control group t	Clinical group t
P_1 Latency	/ba/	8.94**	4.95**
	/da/	9.37**	5.31**
	/ga/	8.47**	5.91**
N_1 Latency	/ba/	7.88**	5.83**
	/da/	6.73**	5.79**
	/ga/	7.41**	5.42**
P_2 Latency	/ba/	5.33**	4.92**
	/da/	2.17**	4.65**
	/ga/	9.61**	3.91**
N_1-P_2 Amplitude	/ba/	.070	.15
	/da/	.42	1.29
	/ga/	.22	.63

** $p < 0.01$

Discussion

Effect of speech stimuli

The speech stimulus in the present study selected in such a way that it had low, mid and high frequency spectrum. All the stimuli selected for the study was voiced CV syllable, the vowel /a/ was kept constant. The duration of the three stimuli was approximately 150 ms (/ba/-147 ms, /ga/- 146 ms and /da/-150ms).

It has been noticed that latency obtained for /da/ stimulus was longer in both normal and cochlear hearing loss group at both 40 dB SL and 70 dBnHL. However, significant difference was there for P_1 latency at 40 dB SL and P_2 at 70 dBnHL in control group. The speech stimuli /ba/ elicited a shorter latency in control group both at 40 dB SL and 70 dBnHL. There was significant difference for N1 latency at 40 dB SL in clinical group. The P_1, N_1 and P_2 latency was significantly longer for /da/ at 70 dBnHL in individuals with Sensory-Neural hearing loss. The speech stimuli /ga/ elicited a shorter latency in clinical group both at 40 dB SL and 70 dBnHL. Amplitude did not show significant difference across the three speech sounds in both groups at 40 dB SL and 70 dBnHL.

These findings are in agreement with the findings of Shruti (2007). She used /i/, /m/ and /s/, and found that the latency of the high frequency content speech stimuli had a prolonged latency than the other. This also supports the results of Agung et al., (2006). They used the speech stimuli /a/, /u/, /i/, /s/, /sh/, /m/ and / כ / which covered a broad range of frequencies across the speech spectrum. They found that the latencies of speech stimuli with high frequency content /s/ and /sh/ had significantly prolonged latencies than the other stimuli. This can be attributed to the fact that the high frequency has a less speech energy concentration when compared to the low or the mid frequency syllable. This would have resulted in longer latencies for /da/. Another reason could be the duration of the stimulus. The duration of /da/ (150 ms) stimulus was longer than the /ba/(147 ms) and /ga/ (146 ms), this difference in the latency for /da / can also be

attributed to the duration difference. However, the slight variability in stimulus duration may not cause significant difference in latency difference.

The another physiological reasons for difference in ALLRS responses for low and high frequency stimuli was investigated using fMRI studies by Yeltin, Ronald, Chriestensen and Purdy (2004). It was reported that the cortical areas that respond to the low frequency auditory information are located more superficially (ie. closer to the surface of the scalp) and for high frequency deep layer of the cortical regions respond. Hence, the low frequency stimuli may activate more superficial cortical areas and produce smaller latency of ALLRS component than the high frequency speech sounds, when surface scalp electrodes are used.

Effect of presentation level

At same dB SL

All the speech sounds elicited a shorter latency in the clinical group at 40 dB SL. All most all the peak latencies differed between the groups was statistically significant at 40 dB SL. Amplitude obtained in clinical group was significantly more only for /ga/ stimuli. When the presentation level of the stimulus was 40 dB SL, the intensity level was much higher for clinical group when compared to the control group. Higher the intensity reaching the ear, broader will be the excitation of the basilar membrane which would have lead to excitation of more number of auditory nerve. Hence, this could have resulted in faster transmission and shorter latency and more amplitude of ALLRS components in clinical group.

Another reason for decrease in the latency with an increase in the stimulus intensity could be due to the progressively faster rising generator potential within the cochlea and similarly faster development of excitatory post synaptic potential (Moller, 1981). Picton and Hillyard (1974) reported that the latency of the compound action potential directly depends on how quickly the generator potential and the excitatory post synaptic potential reach the threshold for firing. Hence, this would lead to shorter latency in cochlear hearing loss group when presented at 40 dB SL as the intensity level was much higher in this group than the control group.

Increase in the amplitude parameters with the increase in the stimulus intensity may be because of the increase in the audibility of the stimulus. This is supported by Hall (1992). He said that the AEPs amplitude increases with the increase in the intensity. The amplitude of an AER is decided by the number of neurons firing for particular stimulus intensity. At higher intensities, the number of neuron beginning to fire will be more and amplitude of the compound action potential thus generated will be high. This would have resulted in higher ALLR amplitude elicited responses in cochlear hearing loss group.

In control group the presentation level would have been approximately 40 to 55 dBnHL, which was much lesser than clinical group. In normal hearing individuals the active mechanism was dominated at this intensity level, leading to sharp tuning of the basilar membrane. Thus, resulted in excitation of less number of auditory nerve, and less volume conduction, which leads to slow transmission. This might have lead to the longer latency and reduced ALLR amplitude in the control group.

At same dBnHL

At 70 dBnHL latency of all the ALLRS waves was shorter for control group. All most all the peak latencies differed between the groups was statistically significant at 70 dBnHL. Amplitude obtained in the clinical group for all speech sounds were more for all speech sounds at 70 dBnHL.

The latencies were shorter in the control group and prolonged in the clinical group. This can be supported by the fact that at 70 dBnHL both the passive as well as the active mechanism would have played an role in excitation of basilar membrane in normal hearing individuals, which leads to faster transmission and shorter latency. In the clinical group the energy reaching to the cochlea was less as they had hearing loss. The level would have reduced with the increase in severity of hearing loss. Hence, less compound action potential would have generated which would have lead to slower transmission and thus led to longer latency.

To conclude, the speech stimuli dominated by high frequency energy elicited a latency which was longer than the other sounds; this was true for both control as well as clinical group. These findings are in agreement with the findings of Agung et al. (2006) and Shruthi (2007). ALLRSs recorded for three stimuli at each presentation level differ significantly in control and clinical group. This suggests that the speech processing is altered in clinical group which leads to reduced speech perception abilities in clinical group.

The comparison between the groups at equal hearing level were done in order to see the difficulties that the hearing impaired individuals will face in day to day situation. As we know that in day to day situation both normal and hearing impaired individuals would be exposed to sounds at equal hearing levels. At equal presentation level the transmission of signal could be slower due to reduced energy at the cochlea. This suggests that in individual with cochlear hearing loss temporal processing may be affected if the signal is low.

At 40 dB SL the transmission of information is faster in clinical group, but still the processing is affected in clinical group. This can be due to the degraded frequency resolution due to broadening of the basilar membrane excitation. In sensorineural hearing loss group, speech perception ability is correlated with the pure tone threshold. The cochlear distortion effects, increases with the increase in the degree of hearing loss, which results in loss of cochlear amplifier leading to poor speech perception abilities (Moore, Poston, Eggermont and Huang, 1996).

Conclusion

It can be concluded that the ALLRS recorded by spectrally different speech sounds are different in both normal hearing and cochlear hearing loss individuals. This suggests that neurophysiological processes are different for different speech sounds. Longer latency for /da/ suggests that latency of the processing at the cortical center is also different depending on the frequency composition of the signal. A significant difference between the groups for all the parameters for all the speech sounds at each presentation level suggests that speech processing is altered in individuals with cochlear hearing loss.

References

Agung, K., Purdy, S., Mc Mahon, C. & Newall, P. (2006). The use of cortical evoked potentials to evaluate neural encoding of speech sounds in adults. *Journal of American Academy of Audiology*, 17, 559-572.

Carhart, R. & Jerger, J. (1959). Preferred methods for clinical determination of pure-tone thresholds. *Journal of Speech and Hearing Disorder*, 16, 340-345.

Crottoz-Herbette, S. & Ragot, R. (2000). Perception of complex sounds: N1 latency codes pitch and topography codes spectra. *Clinical Neurophysiology*, 111, 1759-1766.

Eggermont, J.J. & Ponton, C.W. (2003). Auditory-evoked Potential Studies of Cortical Maturation in Normal Hearing and Implanted Children: Correlations with Changes in Structure and Speech Perception. *Acta Oto-Laryngologica*, 123, 249-252.

Hall, J.W. (1992). Handbook of auditory evoked responses. Massachusetts: Allyn and Bacon.

Hall, J.W. (2007). Auditory late responses (ALLRSs). In New Handbook for Auditory Evoked Responses (pp. 488-517). Florida: Allyn & Bacon.

Hillyard, S.A. & Kutas, M. (1983). Electrophysiology of cognitive processing. *Annual review of psychology*, 34, 33-61.

Makela, A., Alku, P. & Tiitinen, H. (2003). The auditory N1m reveals the left hemisphere representation of vowel identity in humans. *Neuroscience Letters*, 352 (2), 111-114.

Martin, B.A., Tremblay, K.L. & Stapells, D.R. (2007). Principles and applications of cortical auditory evoked potentials. In R.F. Burkard, M. Don, & J.J. Eggermont (Eds.), *Auditory Evoked Potentials: Basic Principles and Clinical Application* (pp. 482-509). Philadelphia: Lippincott Williams & Wilkins.

Moller, A.R. (1981). Latency in the ascending auditory pathway determined using continuous sounds: comparison between transient and envelope latency. *Brain Research*, 207, 184-188.

Moore, J.K., Poston, C.P., Eggermont, J.J., & Huang, J.G. (1996). Perinatal maturation of ABR changes in path length and conduction velocity. *Ear and Hearing*, 17, 411-418.

Naatanen, R. & Picton, T. (1987). The N_1 wave of the human electric and magnetic response to sound: a review and an analysis of the component structure. *Psychophysiology*, 24(4), 375-425.

Novak, G.P., Kurtzberg, D., Kreuzer, J.A. & Vaughan, H.G. Jr. (1989). Cortical responses to speech sounds and their formants in normal infants: maturational sequence and spatiotemporal analysis. *Electroencephalography and Clinical Neurophysiology*, 73, 295-305.

Picton, T. & Hillyard, S.A. (1974). Human auditory evoked potentials II: effects of attention. *Electroencephalography and Clinical Neurophysiology*, 36, 191-199.

Purdy, S.C., Katsch, R., Sharma, M., Dillon H. & Ching, T.Y. (2001). Hearing aid evaluation in infants and young children using cortical auditory evoked potentials. *Australia New Zealand Journal of Audiology*, 23, 138.

Shruti, K. (2007). Speech Evoked Auditory Late Latency Response (ALLRS) in hearing aid selection. Unpublished Master's dissertation in part fulfillment of M.Sc. (Audiology), University of Mysore.

Tremblay, K.C., Kraus, N. & Mc Gee, T. (1998). The time course of auditory perceptual learning: neurophysiological changes during speech sound training. *Neuroreport*, 9, 3557-3560.

Tremblay, K.L., Friensen, L., Martin, B.A. & Wright, R. (2003). Test-retest reliability of cortical evoked potentials using naturally produced speech sounds. *Ear and Hearing*, 24(3), 225-232.

Yetkin, F.Z., Roland, P.S., Christensen, W.F. & Purdy, P.D. (2004). Silent functional magnetic resonance imaging (FMRI) of tonotopically and stimulus intensity coding in human primary auditory cortex. *Laryngoscope*, 114, 512-518.