Effect of Sensorineural Hearing loss and Digital Hearing Aids on Speech Evoked Auditory Late Latency Response

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Abstract

The aim of present study was to compare the auditory late latency response (ALLR) obtained for naturally produced speech tokens, /ba/, /da/, and /ga/ in unaided and aided conditions for different degrees of sensorineural hearing loss and also to evaluate the usefulness of ALLR in selection of amplification device using naturally produced speech tokens. Two groups of participants including 12 individuals (12 ears) with normal hearing in the age range of 20 to 50 years and 25 individuals (35 ears) with hearing impairment in the age range of 20 to 50 years participated in the study. Individuals with sensorineural hearing loss were further sub-divided into 3 groups based on degree of hearing loss (moderate, moderately-severe and severe). Functional gain measurement as well as speech evoked ALLR were done both in unaided and aided conditions with two pre-selected digital hearing aids with first fit. For all the four groups, there was difference in response elicited by three speech stimuli. Individuals with normal hearing had longer latencies than those in the aided condition. Syllable /ga/ elicited longer latency and /ba/ elicited the least, response from /da/ lied in between. For clinical group, latency for /ga/ was shortest and /da/ was longest out of the three stimuli. Most of the subjects with hearing loss showed increased amplitude, decreased latency and improved waveform morphology in the aided condition but the response change was variable across individuals. From the results it can be concluded that, *aided ALLR can help in selection of hearing aids as it mimics the hearing aid processing. It also helps to assess the speech perception ability of the cortical structures objectively.*

Key words: *Auditory late latency response, functional gain measurement, digital hearing aids, speech stimuli.*

Hearing is the most important channel of human attributes for language and communication. Language enables humans to communicate at a distance and across time and has played a decisive role in the development of society and its culture (Rapin, 1993). Individuals having sensorineural hearing loss will have problem because of decreased audibility, decreased frequency and temporal resolution, reduced dynamic range and abnormal loudness growth (Fabry & Van Tasell, 1986).

It is very important to assess the speech perception ability of an individual with hearing impairment using hearing aids as it gives us an idea about individual's perception ability in everyday situation. The hearing ability of an individual with hearing impairment can be improved by using amplification devices, such as hearing aids, cochlear implants, assistive listening devices etc. Hearing aid is a device that can help in perceiving these acoustic cues in individuals with hearing impairment. Therefore, the goal of the hearing aid selection process is to define the appropriate physical and electroacoustic characteristics of the desired hearing aids for a particular individual using methods that will facilitate ordering, verification, and validation of the devices.

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There are many procedures which helps us to select hearing aids. They are mainly classified as subjective and objective measures. Subjective measures include functional gain measurement. Whereas objective measures includes insertion gain measurement, electrophysiological tests like auditory brainstem response, middle latency response, late latency response, auditory steady state response, mismatch negativity etc. These measures are used to investigate the neurophysiological processes that underlie our ability to perceive speech (Purdy, Katsch, Sharma, Dillon, Storey, & Ching, 2001) and may allow us to better understand the neural encoding of speech in individuals with impaired auditory pathways (Eggermont & Ponton, 2003).

CAEP is one of the ideal objective tools for aided hearing instrument evaluation because it is reliably present in young infants and adults and it correlates well with perception. It can be evoked by speech stimuli and seems to be sensitive to differences between speech stimuli like voice onset time and place of articulation (Tremblay, Friesen, Martin, & Wright, 2003).

The auditory long latency evoked potentials are characterized by components comprising time domain of 50 to 500 ms (McPherson & Starr, 1993) and are labeled according to their latency and polarity at the vertex (Picton, Wood, & Proulx, 1978). The major component of Auditory Late Latency Response (ALLR) are characterized by an initial positive peak between 60-80 msec (P60/P1), having an amplitude of about 7 μV and a width of about 15 ms. The second peak occurs between 90-100 msec (N100/N1) and is a negative peak with amplitude of 10 μv and width of 40-50 ms. The third peak is a positive occurring at about 100-160 ms (P160/P2) and has amplitude of 6 μv and a width of 40-50 ms. The forth peak occur at 180-200 msec (N200/N2) is a negative peak and has amplitude of 6 μV and width of 70 ms.

There are different types of stimuli used to evoke electrophysiological response. All stimuli differ in terms of their spectral and temporal parameters. The stimuli used for recording ALLR include tones, toneburst, clicks, and speech stimuli (natural and synthetic vowels, syllables and words)

Yetkin, Ronald, Christensen and Purdy (2004) suggested the physiological reasons for difference in the ALLR responses for the low and the high frequency stimuli. They reported that the cortical area responding to low frequency auditory stimuli are located more superficially than the deep layer of the cortical regions for high frequency. Hence low frequency stimuli produce large amplitude of ALLR than high frequency speech sounds.

An investigation by Hinduja, Kusari and Vanaja (2005) revealed that ALLR of individuals with a hearing aid showed larger amplitude and shorter latency when the aided thresholds were within speech spectrum than compared to the hearing aid in which aided thresholds were outside the speech spectrum. These pre-attentive cortical potentials have also been used to reflect on the auditory training induced changes.

Agung, Purdy, McMohan and Newall (2006) recorded ALLR for, /a/, /u/, /i/, /s/, /sh/, /m/ and /ɔ / for 10 normal hearing adults in the age range of 20 to 29 years. N1-P2 response amplitudes elicited by higher frequency speech stimuli /s/ and /sh/ produced significantly smaller amplitudes compared to stimuli that had dominant spectral energies in low frequencies /m/, /a/, /u/ and /i/. Latency of N1 decreased systematically when elicited by /u/, /ɔ/, /a/ and /i/. Similarly, P1 and P2 elicited by longer duration vowels /u/, /a/,/ ɔ / and /i/, decreased in latency in the respective order. Hence, it was concluded that ALLR latencies and amplitudes may provide an objective indication that spectrally different speech sounds are encoded differently at the cortical level.

Tremblay, Billings, Friesen and Souza (2006) recorded ALLRs for amplified speech sounds /si/ and /ʃi/ in 7 adults with mild to severe sensorineural hearing loss and in 7 normal hearing individuals. The results revealed that the speech evoked ALLR can be used reliably both in aided and unaided conditions. They also noticed that even though most of them showed increased amplitude, decreased latency and improved waveform morphology in the aided conditions, the amount of responses change was quite variable across individuals. This variability may be related to the fact that the hearing aid alters the acoustics of a signal, which in turn affect the evoked response pattern. It could also be related to how the central auditory system detects acoustic cues contained in the speech (Tremblay et al, 2006). Individual with severe to profound hearing loss tested by Korczak, Kurtzberg and Stapells (2005) showed longer peak latencies and reduced amplitudes than the normal hearing group.

ALLR was recorded in both aided and unaided condition using /i/, /m/ and /s/ in 10 hearing impaired children in the age range of 5-7 years (Shruthi & Vanaja, 2007). The response obtained from the three stimuli resulted in distinct responses indicating that the stimuli are coded differently in the auditory system. Stimuli /i/ resulted in better morphology, shorter latency, and higher amplitude than /m/ and /s/ stimuli, indicating that vowels are better coded than the consonants.

ALLR was recorded using three speech stimuli, /ba/, /da/ and /ga/ from individuals with cochlear hearing loss (Sumitha & Barman, 2008). It was observed that the P1-N1-P2 latency was shorter for /ga/ stimuli, and longer for /da/ stimuli. Amplitude did not show significant difference across the three sounds in both normal hearing individuals as well as individual with hearing loss.

Functional gain is defined as the improvement in hearing sensitivity (unaided threshold minus aided threshold) consequent to the wear of the hearing aid in the same listening environment. Mueller (2001) encouraged audiologists to perform unaided and aided speech recognition testing as part of the hearing aid evaluation. Unaided speech recognition testing can help to determine hearing aid candidacy and provide patients with realistic expectations about speech understanding. Conducting aided speech recognition testing can also help to demonstrate when aided performance is better than unaided, the advantages of special features of the hearing aids, and help obtain information for counseling.

Speech does not consist of a single frequency component; the speech sounds cover a wide frequency region. It is important for any listener to listen to all the speech sounds, which encompasses the speech spectrum. It is not sufficient to study only the processing of single frequency stimuli. There is a need to study the ALLRs, which is evoked by speech stimuli which largely encompasses the speech spectrum. Hence, the three different speech stimuli /ba/ which has spectral energy concentration in low frequency, /ga/ syllable dominated by mid frequency spectral energy and /da/ syllable dominated by high frequency spectral energy was taken up in the present study.

The aims of present study were to investigate the following aspects: (1) To compare the ALLR waveform obtained for naturally produced speech tokens, such as /ba/, /da/, and /ga/ for individuals with hearing impairment in unaided and aided condition with that of normal hearing individuals. (2) To evaluate the effect of different degree of sensorineural hearing loss on aided and unaided ALLR. (3)To evaluate the usefulness of ALLR for naturally produced speech tokens, such as /ba/, /da/, and /ga/, in validation of appropriate hearing aid.

Method

Participants: Two groups of participants were included in the study. **Control Group I:** 12 individuals (12 ears) with normal hearing in the age range of 20 to 50 years. **Clinical Group II:** 25 individuals (35 ears) with hearing impairment in the age range of 20 to 50 years, which was further sub-divided into 3 groups based on degree of hearing loss (moderate, moderately-severe and severe).

Participant selection Criteria: Group I included individuals having hearing sensitivity less than 15 dB HL at octave frequencies between 250 Hz to 8000 Hz for air conduction and from 250 Hz to 4000 Hz for bone conduction. They had normal middle ear functioning as indicated by immittance evaluation. ABR and TEOAE were done to rule out auditory neuropathy. Participants having speech identification scores greater than 90% and having no history of any otologic, neurologic problems were included for this study.

Group II included individuals having pure tone thresholds greater than 41 dB HL and less than 90 dB HL with air bone gap of less than 10 dB. They had normal middle ear functioning as revealed by immittance evaluation. ABR and TEOAE were done to rule out auditory neuropathy. Participants having speech identification scores proportionate to their pure tone average and having no history of any otologic and neurologic problems were considered for this study.

Instrumentation: To carry out the pure tone audiometry and speech audiometry, a calibrated two channels Orbiter-922 diagnostic audiometer with TDH-39 headphone with MX-14 AR ear cushion, Radio ear B-71 bone vibrator, and loudspeaker were used. A calibrated immittance meter, GSI-Tympstar was used to assess middle ear functioning. ILO (version, VI) OAE Analyser was used to check for the hair cell functioning. Bio-logic system (version, 7.0) with matched loudspeaker was used to record and analyse the auditory late latency responses (ALLR) and auditory brainstem response. NOAH HI-PRO software (Version, 3.12) was used to program the hearing aids.

Materials: Stimuli for recording ALLR were /ba/, /da/, and /ga/. These syllables were spoken by an adult male speaker having clear articulation, into a unidirectional microphone connected to the computer. The recording was done using Adobe Audition software (version 2) with a sampling rate 48000 Hz and 16 bit resolution. The stimuli duration was kept less than 250 ms across all the speech sounds. The wave file was loaded into Biologic system for ALLR recording.

Test Environment: All the measurement was carried out in an acoustically treated double room situation. The ambient noise level was within the permissible level according to ANSI (1991).

Procedure

Group I: Pure tone thresholds were obtained in the sound field for octave frequencies between 250 Hz to 8000 Hz for air conduction and 250 Hz to 4000 Hz for bone conduction using modified Hughson-Westlake procedure (Carhart & Jerger, 1959). Speech audiometry was also done using "Phonemically balanced word lists" (Yathiraj & Vijayalakshmi, 2005). Speech recognition threshold and speech identification scores were obtained, to rule out any discrepancy with pure tone audiometry.

The tympanometry and acoustic reflex were carried to rule out any middle ear pathology. Auditory brainstem response and TEOAE were done to rule out retrocochlear pathology (auditory dys-synchrony). ALLR recording was done using the protocol as given below in Table 1 for the participants who meet the selection criteria.

Table 1. ALLR test protocol

Stimuli	/ba/, /da/ and /ga/
Stimulus Level	65 dB SPL
Transducer	Loudspeaker at 0^0 azimuth
Rate	1.1/sec
Polarity	Alternating
Filters	1-30 Hz
Notch Filters	On
Number of channels	Single channel
Recording time window	500 ms
Amplification	50,000
Sweeps	200
Number of Repetition	2

For ALLR recording, participants were made to sit comfortably in order to ensure a relaxed posture and minimum rejection rate. Loudspeaker was placed at a distance of one meter and at a 0^0 azimuth to the test ear.

Silver chloride electrodes were placed after cleaning the electrode sites with skin preparing gel. Conduction paste was used to improve the conductivity of the signal. The electrodes were secured in place using plasters. Conventional electrode montage with non-inverting electrode on Fz, inverting electrode on the mastoid of the test ear and common electrode on the mastoid of the non-test ear. The electrode impedance value was kept less than 5 kΩ and the inter electrode difference was less than 3 kΩ.

Group II: Those participants also underwent the similar procedure as done for group I. Two digital hearing aids having similar features (2 channels, 3 programmable memories, suitable till severe degree of hearing loss) were selected and programmed based on the audiological findings through NOAH software and first fit option was selected. Aided ALLR was used to rate the hearing aids regarding their suitability.

ALLR was recorded separately for the three stimuli /ba/, /da/, and /ga/ without the hearing aid as well as with the two pre-selected hearing aids. The procedure selected for the ALLR was same as that used for group I.

Functional Gain Measurement: Unaided and aided speech recognition scores were obtained for all individuals with hearing impairment. The presentation level selected was 65 dB SPL through live voice in free field condition with the speaker kept at 1 meter distance and 0^0 azimuth. The stimuli used for this test was "Phonemically balanced word lists" (Yathiraj & Vijayalakshmi, 2005) developed for Kannada speaking individuals. Two pre-selected hearing aids which were used for ALLR measurement were also used for functional gain measurement. All the settings of the hearing aids were kept constant through out the testing.

Analysis

The waveform was analyzed for P1-N1-P2 peaks by two audiologists who were unaware of the test conditions identified the latency and amplitude of the identified peaks. Appropriate statistical analysis was done.

Latencies and amplitude of ALLR obtained were compared across all the four groups, i.e. individuals with normal hearing, moderate, moderately-severe and severe hearing loss. Latencies and amplitude were compared across hearing aid 1 and hearing aid 2. Comparison of latency and amplitude across three speech stimuli, i.e. /ba/, da/ and /ga/, elicited at 65 dB SPL.

Results and Discussion

The aim of the present study was to explore, how ALLR differs for spectrally different natural speech sounds in individuals with normal hearing and sensorineural hearing loss. The study also investigated the effect of different degree of sensorineural hearing loss on aided and unaided ALLR.

The latencies and amplitudes of P1, N1, P2 and peak-to-peak latency and amplitude difference of N1-P2 complex were measured. The Mean and standard deviation (SD) were calculated for control and clinical groups for three different speech stimuli with two different hearing aids having similar feature rated as (HA1 & HA2). Comparison of latency and amplitude of the ALLR to speech, between the groups and within the groups were also carried out.

The above parameters were analyzed using descriptive statistics, as well as non-parametric test such as Mann Whitney U test, Kruskal-Wallis test and Wilcoxon signed rank test for comparing between the different groups.

Latency and amplitude for different speech stimuli in individuals with normal hearing: The mean and SD for latencies and amplitudes of P1, N1, P2 and N1-P2 complex of control group (individuals with normal hearing) was determined for different speech stimuli, /ba/, /da/ and /ga/ (Table 2).

Table 2. Mean and SD for P1, N1, P2, and N1-P2 complex latencies and amplitudes elicited by different speech stimuli /ba/, /da/, and /ga/ in control group

Peaks	Syllables	Control Group			
		Latencies (ms)		Amplitude (μV)	
		Mean	SD	Mean	SD
P1	/ba/	75.04	12.02	2.72	1.40
	/da/	77.51	10.71	2.77	0.95
	/ga/	79.47	17.11	2.65	1.06
N1	/ba/	105.70	11.29	1.15	0.78
	/da/	111.91	8.65	0.82	0.79
	/ga/	124.27	32.56	1.74	0.90
P2	/ba/	143.17	16.66	1.64	0.96
	/da/	143.80	15.51	1.70	0.79
	/ga/	179.80	27.52	0.80	0.54
N1-P2	/ba/	37.47	12.72	1.55	0.96
	/da/	31.88	13.56	1.32	0.84
	/ga/	46.41	19.45	2.14	1.19

From Table 2, it was observed that in individual with normal hearing, /ga/ sound elicited longer latency and /ba/ elicited the least, response from /da/ lied in between the two stimuli. It means in individuals with normal hearing low frequency speech stimuli represents better responses than mid or high frequency speech stimuli. The present findings are in agreement with the finding of other studies (Agung et al., 2006; Shruthi & Vanaja, 2007; Sumitha & Barman, 2008).

Agung et al. (2006) used the speech stimuli /a/, /u/, /i/, /s/, /sh/, /m/ and /ɔ/ which covered a broad range of frequencies across the speech spectrum. They found that latencies of speech stimuli with high frequency content had significantly prolonged latencies than the other stimuli. Shruthi and Vanaja (2007) used /i/, /m/ and /s/ sounds as stimuli and found that the latency of the high frequency content of speech stimuli had a prolonged latency than others. Sumitha and Barman (2008) used similar stimuli, as used in present study and found similar results in normal hearing individuals.

In clinical group, different degree of hearing loss such as moderate, moderately-severe, and severe sensorineural hearing loss were included in present study, which is been described separately.

Latency and amplitude for different speech stimuli in individuals with moderate hearing loss: The mean and SD of latencies and amplitude were calculated for under both unaided and aided condition with two hearing aids.

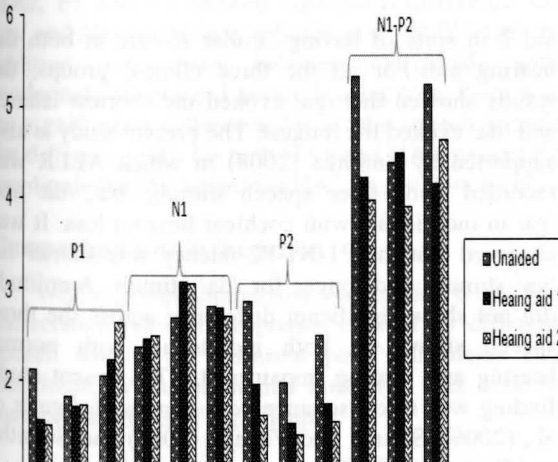

Figure1. Latency values (ms) of P1, N1, P2 and N1-P2 complex for all the three speech stimuli (/ba/, /da/ and /ga/) for individuals with moderate hearing loss.

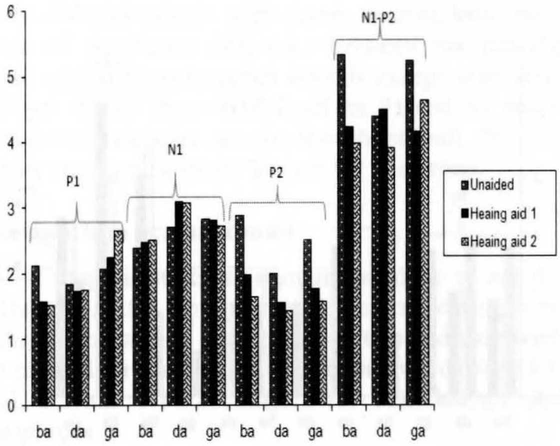

Figure 2. Amplitude values (μV) of P1, N1, P2 and N1-P2 complex for all the three speech stimuli (/ba/, /da/ and /ga/) for individuals with moderate hearing loss.

From Figure 1 and 2, it is clear that in clinical group /ga/ stimuli elicited response having the shortest latency followed by /ba/ and longest for /da/. However, there was no specific pattern for amplitude. Sumitha (2008) also observed similar trends of latency changes in individuals with cochlear hearing loss.

Latency and amplitude for different speech stimuli in individuals with moderately-severe hearing loss: The unaided responses were absent for all the individuals at 65 dB SPL because of the degree of the hearing loss and thus not depicted in Figure 3 and 4.

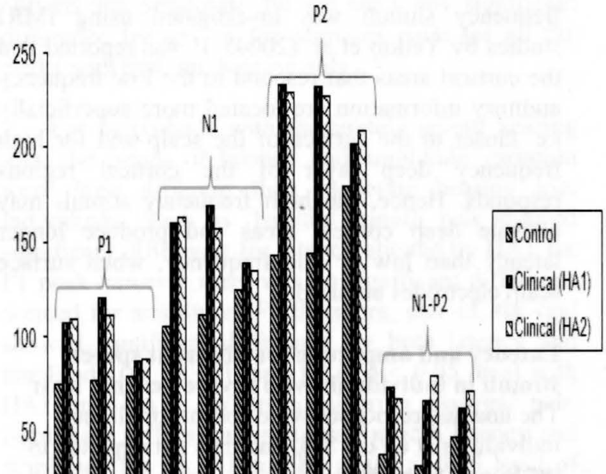

Figure 3. Latency values (ms) of P1, N1, P2 and N1-P2 complex for all the three speech stimuli (/ba/, /da/ and /ga/) for individuals with moderately-severe hearing loss.

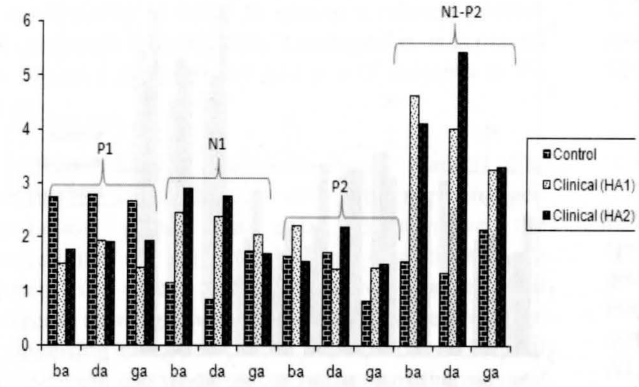

Figure 4. Amplitude values (µV) of P1, N1, P2 and N1-P2 complex for all the three speech stimuli (/ba/, /da/ and /ga/) for individuals with moderately-severe hearing loss.

It revealed that the results are similar, as seen in moderate hearing loss group, i.e. /ga/ showed shortest latency and /da/ the longest with /ba/ response intermediate. From figure 3 and 4, it can be seen that control group is having better latency than clinical group irrespective of speech stimuli. In clinical group, high frequency stimuli showed prolonged latency responses than low and mid frequency stimuli. However, there were no specific trends noticed for amplitude responses. The present finding is in consonance with other studies (Agung et al., 2006; Shruthi, 2007; Sumitha, 2008).

The another physiological reasons for differences in ALLRs responses for low and high frequency stimuli was investigated using fMRI studies by Yetkin et al. (2004). It was reported that the cortical areas that respond to the low frequency auditory information are located more superficially i.e. closer to the surface of the scalp and for high frequency deep layer of the cortical regions responds. Hence, the high frequency stimuli may activate deep cortical areas and produce longer latency than low or mid frequency, when surface scalp electrodes are used.

Latency and amplitude for different speech stimuli in individuals with severe hearing loss: The unaided responses were absent for all the individuals at 65 dB SPL and thus not depicted in the Figure 5 and 6.

From Figure 5 and 6, it can be seen that /ga/ elicited shortest latency and /da/ the longest however /ba/ stimuli latency was intermediate. Apart from that, it also reveals that overall responses with hearing aid 1 showed better responses than hearing

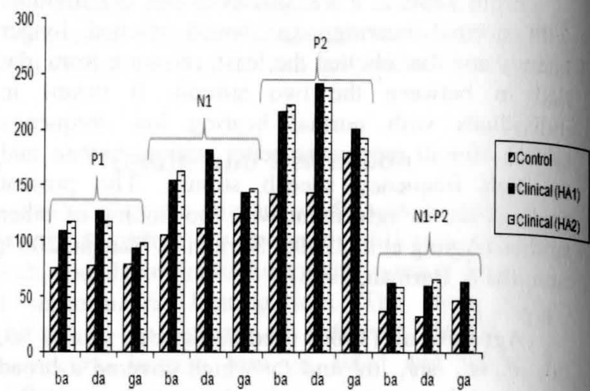

Figure 5. Latency values (ms) of P1, N1, P2 and N1-P2 complex for all the three speech stimuli (/ba/, /da/ and /ga/) for individuals with severe hearing loss.

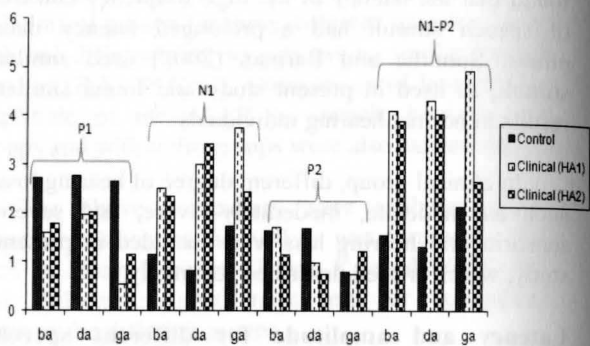

Figure 6. Amplitude values (µV) of P1, N1, P2 and N1-P2 complex for all the three speech stimuli (/ba/, /da/ and /ga/) for individuals with severe hearing loss.

aid 2 in spite of having similar feature in both the hearing aids.For all the three clinical groups, the results showed that /ga/ evoked the shortest latency and /da/ evoked the longest. The present study is also supported by Sumitha (2008) in which ALLR was recorded using three speech stimuli, /ba/, /da/ and /ga/ in individuals with cochlear hearing loss. It was observed that the P1-N1-P2 latency was shorter for /ga/ stimuli, and longer for /da/ stimuli. Amplitude did not show significant difference across the three speech stimuli in both individuals with normal hearing and hearing impairment. The present study finding was in consonance with results of Agung et al., (2006); Shruthi and Vanaja, (2007) and Sumitha and Barman, (2008).

Comparison across groups

When the unaided and the aided responses were compared among all the four (normal, moderate, moderately-severe & severe) groups, using Kruskal-Wallis test, it was observed that there was significant difference between all the 4 groups. Further, Mann-Whitney U Test was done to find the significant pairs that were differing on specified parameters. Comparison was made across the groups (Normal vs. Moderate, Normal vs. Moderately-severe, and Normal vs. Severe).

It was observed that there was significant difference between three speech stimuli for P1, N1, P2 and N1-P2 complex. The difference was highly significant for /ba/ and /da/ speech stimuli than for /ga/ stimuli. It can be concluded that in spite of individuals wearing hearing aids appropriate to their hearing loss, the response obtained is very different from that obtained from individuals having normal hearing. The hearing aids helps to compensate for disorder of the ear by amplifying sound, however its effectiveness depends on the central auditory system's ability to represent and integrate spectral and temporal information delivered by the hearing aid (Tremblay et al. 2006).

Comparison across different degree of hearing loss

While comparing individuals with moderate and moderately-severe hearing loss, Mann-Whitney U test showed no significant difference for any stimuli except for HA2 for /da/ sound in N1-P2 complex latency difference and amplitude of P2 peak at $p < 0.05$ level. When comparison was made between individuals with moderate and severe hearing loss, for both HA1 and HA2, there were no significant difference between any stimuli with different peaks except for /da/ sound in HA1 where latency of P1 and N1 and amplitude of /ga/ sound showed significant difference at $p < 0.05$ level. Further, for HA2, P1 and P2 showed significant difference for /ga/ and /da/ sound in amplitude at $p < 0.05$ level. In addition, comparison between individuals with moderately-severe and severe hearing loss, there was no significance difference for all the speech stimuli for different peaks for both HA1 and HA2, except P2 amplitude for /da/ sound for HA2, at $p < 0.05$ level.

Comparison within the group

Within group comparison was carried out to see the relation between responses elicited by different speech sounds for different peak's latencies and amplitude. Wilcoxon signed ranks test was done to measure the level of significance.

For individuals with moderate hearing loss, there was no significant difference across hearing aid 1 and 2 except for N1 peak in /da/ stimuli at $p < 0.05$ level. For individuals with moderately-severe hearing loss, there was no significant difference between two hearing aids performance except latency of /da/ stimuli for P1 and N1 peaks at $p < 0.01$ level, while amplitude of /da/ stimuli for P2 and N1-P2 complex at 0.05 level. There was no significant difference observed for /ba/ and /ga/ stimuli across two hearing aids. For individuals with severe hearing loss, there was no significant difference between two hearing aids with different speech stimuli except amplitude of /ga/ stimuli at $p < 0.05$ level for P1 and N1 peaks however, latencies across speech stimuli did not show any significant difference for this group.

Comparison across stimuli

Comparison across stimuli was done to see the effect of ALLR on different degree of hearing loss. The speech stimuli were paired in two and then were compared for four ALLR parameters, which were P1, N1, P2 and N1-P2 complex for both latency and amplitude.

For individuals with normal hearing, the response was not statistically significant for /ba/-/da/ stimuli pair in terms of latency and amplitude. However, for /da/-/ga/ stimuli pair there were significant difference for latency and amplitude of N1 and P2 peaks at $p < 0.05$ level. Further, /ba/-/ga/ stimuli pair showed significant difference in terms of latency for P2 at $p < 0.01$ level and amplitude of N1 and P2 at $p < 0.05$ level.

For individuals with moderate hearing loss, there was no statistically significant difference observed for /ba/-/da/ stimuli pair for latency and amplitude across all the peaks. However, there were significant difference for /da/-/ga/ stimuli pairs in terms of latency for P1, N1, and P2 peaks at $p < 0.01$ level for both the hearing aids (HA1 and HA2). When considering /ba/-/ga/ stimuli pairs, there was significant difference in terms of latency for P1, N1 and P2 peaks at $p < 0.05$ level. Furthermore, it was noticed that amplitude did not show any significant difference for any of the stimulus pairs for all the peaks with both the hearing aids.

For individuals with moderately-severe hearing loss, the trends of latency and amplitude variation were little different than moderate hearing loss individuals. Such as /ba/-/da/ stimuli pair showed significant difference for latency elicited by HA1 for P1 peak however there was no significant difference noticed for amplitude. Furthermore, pair of /da/-/ga/ showed significant difference for both latency and amplitude for P1, N1, and P2 at $p < 0.05$ level with HA1 and HA2. When considering /ba/-/ga/ pair, significant difference was there for both latency and amplitude for P1, N1 and P2 peaks at 0.05 level of significance.

For individuals with severe hearing loss, it was seen that there was no significant difference in terms of latency and amplitude for /da/-/ga/ stimuli pair. However, /ba/-/da/ stimuli pair showed significant difference at $p < 0.05$ level for P1 and N1 peaks with HA1 and HA2. Furthermore, /ga/-/ba/ stimuli pair showed significant difference for P2 peak in terms of amplitude for HA2.

Functional gain measurement

Speech identification scores in the two aided conditions for the three groups of hearing loss is given in the Table 3.

Table 3. Mean and SD of the speech recognition scores obtained for the three groups of hearing loss

Groups	Hearing aids	Mean	SD
Moderate	HA1	22.23	2.27
	HA2	21.46	2.50
Moderately-severe	HA1	19.90	3.38
	HA2	18.30	3.19
Severe	HA1	19.00	4.47
	HA2	19.25	5.52

Unaided and aided speech recognition scores were obtained with the two hearing aids for all the three hearing loss groups. From the mean values, it can be inferred that the hearing aid 1 was giving better performance than hearing aid 2 in individuals with moderate and moderately severe hearing loss. For severe hearing loss group, hearing aid 2 performed better than hearing aid 1.

Comparison of Functional Gain measurement and ALLR measurement

For individuals with moderate hearing loss, overall performance on ALLR showed better response for HA1 than HA2. There were inter-subject variability which probably because of pathology. However, such overall conclusion was difficult to be made for individuals with moderately-severe and severe hearing loss as there were so many variables and heterogeneity in the individuals and their responses obtained.

Conclusions

The findings from this study showed that there was difference in response elicited by three speech stimuli for unaided and with both the hearing aids in aided conditions. The unaided responses showed longer latencies than the aided condition. There was significant difference between performances of individuals with different degree of hearing loss with the two hearing aids in aided ALLR. However, the difference was not noticed for all the individuals in clinical group. It may be because of individual variation. It was also noticed that even though most of the subjects with hearing loss showed increased amplitude, decreased latency and improved waveform morphology in the aided conditions the amount of responses change was quite variable across individuals. This variability may be related to the fact that the hearing aid alters the acoustics of a signal, which in turn affect the evoked response pattern.

Implications

The present study helps us to decide both behaviorally and objectively the most appropriate hearing aid for a client. Also, to assess the speech perception ability of the cortical structures objectively, ALLR are useful. Further, it can be useful in selecting hearing aids for difficult to test clients and to monitor progress in rehabilitation.

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