Speech - Evoked Auditory Brainstem Responses (ABR) in Hearing Aid Selection

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Abstract

This study aimed to evaluate the usefulness of aided speech evoked ABR in prescription of hearing aid. As a preliminary study, adults with different degrees of sensorineural hearing loss were chosen as subjects. Results of both functional gain measurements (SIS) and Speech evoked ABR were compared in unaided, aided 1 and aided 2 conditions. Results revealed that there was no difference between the unaided and the aided conditions for speech evoked ABR measures. Extent of agreement between the functional gain measurements and the speech evoked ABR was just at chance level. Therefore it was concluded that speech evoked ABR may not be successfully used for fitting hearing aids.

***Key words**: Speech evoked ABR, functional gain measurements, sensorineural hearing loss, aided, unaided measures.*

In the field of clinical Audiology, hearing aid selection process has been the most widely discussed and researched topic. With the belief that early identification without early intervention is meaningless, it is very important to shed some light on this area, especially with the difficult to test population. The first step in habilitation of children with hearing impairment is early and appropriate selection of amplification. This is an ongoing process that involves several distinct steps with great contribution from parents, caregivers and other habilitation professionals. Various other factors that complicate the selection process in infants are, availability of less reliable and less complete assessment tools, inaccuracies in estimating the AC and BC thresholds through behavioral procedures, lack of frequency specificity with use of objective measures, presence of middle ear infections and other associated deficits.[1]

Literature states various procedures being considered for the selection of hearing aids. The earliest of the approaches considered to evaluate hearing aid benefit was the comparison method, where in patient performance with two or three hearing aids is evaluated using traditional word recognition tests and the aid that gives the best word recognition score is chosen (Carhart, 1946). But, these measures of hearing aid benefit were not sensitive enough to provide information about a specific hearing aid. Thus, various other approaches such as the real ear measurements were introduced in the early 1980's. Later, the focus shifted to explore the use of other objective measures such as aided ART's in the late 1970's and early 1980's. Similar to real ear measurements aided ART's do not provide any information about the speech perception abilities.

ABR as an objective hearing aid selection procedure was introduced by Hecox et.al in 1975. From then several researchers have focused their attention on considering ABR as a potential tool in the selection of hearing aids. Brown (1995) opined that comparison of unaided and the aided responses of ABR gives information about the detect abilities and no information about speech reception. Thus, use of ABR for hearing aid selection was restricted.

Greenberg (1980) was the first to adopt complex stimuli such as the vowel formants in recording ABR. His views were in accordance with Sachs (1979) where they believed that the speech patterns were preserved in the discharge patterns of the auditory nerve and these encoded patterns in the auditory nerve were further transmitted to the brainstem and the higher auditory structures. His findings suggests that the auditory brainstem response to speech mimics the acoustic characteristics of the signal with remarkable fidelity, thereby helping one to understand and derive theoretical and clinical applications relevant to the auditory processing.

Brainstem responses to complex stimulus are well researched upon in the recent years because; it provides a good insight about the central auditory processes involved in normal communication. It is also reported that the brainstem responses encode the spectral and the temporal characteristics of speech with good accuracy. Research by Banai (2007), Johnson (2005); Kraus and Nicol, (2005) suggest that separate neural mechanisms are responsible in processing different aspects of the speech sound. As known, a speech sound consists of three fundamental components. The

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fundamental frequency which provides information about the source, the formants which are the filter characteristics conveyed by the selective enhancement or attenuation of the harmonics and the timing information of the major acoustic landmarks. Although the source and the filter characteristics are simultaneously represented in the speech signal and in the response, there exist specific sections in the brainstem response that speaks about the acoustic characteristics of the pitch, formants and the segment level timing information.

To assess the accuracy of ABR for coding the complex stimulus, a large number of stimuli have been considered, one among them is the synthesized syllable /da/(Cunningham, 2001; Plyler and Ananthanarayan, 2001; Russo & Kraus , 2004). ABR to the syllable /da/ is widely studied under different conditions such as monaural and binaural, auditory alone and auditory visual modality, right ear versus the left ear and in presence of background noise. In addition, ABR was also studied in terms of the stimulus characteristics such as, modifications of its formant duration, formant frequency and duration of the stimulus. ABR using /da/ has been recorded to see the effect of training on both the trained and the untrained musicians and also has been extensively studied in individuals with learning disability, autistics and specific language impairment.

Since the past decade, Kraus and her colleagues have attempted to understand the neural correlates of specific neural events within the syllable /da/. The synthesized speech stimuli /da/ (King, Warrier, Hayes & Kraus ,2002) includes the onset burst frication at F3,F4,F5 for the first 10 msec followed immediately by a 30 msec F1, F2 transition ceasing immediately before the vowel steady state(Johnson, 2005).

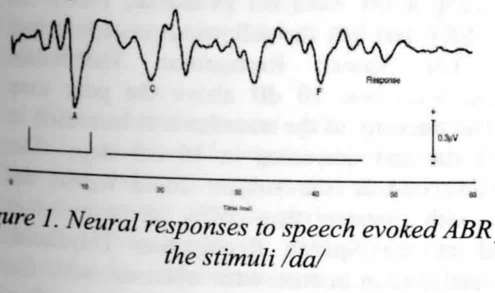

Figure 1. Neural responses to speech evoked ABR for the stimuli /da/

To date, the major clinical application of ABR has been to evaluate the difficult to test population with clicks and tone bursts because it elicits a passive neurophysiologic response to the auditory stimuli and does not require any active participation from the subject. Recently a few studies have been conducted where speech ABR is considered to evaluate the speech perception difficulties in individuals with different degrees of sensorineural hearing loss. Sumesh (2007) evaluated the effect of cochlear hearing loss on brainstem processing to speech in individuals with different degree of hearing loss. Since cochlear hearing loss results in degeneration of the higher auditory structures (Moore, 1987), it was hypothesized that hearing loss can have a deleterious effect on the brainstem processing to speech. Results of his study suggest that, higher degree of hearing loss eliminates the neural responses to the speech stimuli.

On similar lines, the present study makes an attempt to experiment the other potential applications of speech evoked ABR, one such being, the use of Speech ABR in assessing the amplification benefit. In the past, various other electrophysiological measures have been used to assess effect of amplification. P1-N1-P2 measures, ASSR and MMN measures have been considered in older individuals and in infants with different degrees of sensorineural hearing loss. The common consensus obtained from the research findings for the above electrophysiological tests was that the amplitude measures showed a significant difference in the aided condition when compared to the unaided condition. But, a word of caution was also put across regarding the factors affecting the electrophysiological recordings. A few such factors were, modification of the neural response by the hearing aid, interaction between the output of the hearing aid and the listener's ear, extent of coding for the acoustic cues by the listeners auditory system and the correct identification of the speech sounds by the listener.

Considering the above criticisms, the present study makes an attempt to evaluate the unaided and the aided responses solely obtained through the electrophysiological measures such as Speech ABR. In addition, the present study makes an attempt to draw a relationship between the objective measures (Speech evoked ABR) and the subjective measures (functional gain measurements) used to assess the speech perception abilities.

The present study was aimed to compare the unaided and aided measures of speech evoked ABR in adults with different degrees of sensorineural hearing loss and the aided functional gain measurements with the aided Speech evoked measures in adults with different degrees of sensorineural hearing loss.

Since the electrophysiological tests are time consuming and as these results could be affected with the slightest movement or activity of the participant, adults were chosen to be the target group of interest in the present study.

Method

The present study was conducted to investigate the usefulness of Speech evoked ABR in validation of hearing aids and the same was used to correlate with the obtained behavioral measures.

Participants: The present study included 28 subjects with sensorineural hearing loss. They were further classified into three groups based on their degree of hearing impairment. Experimental group 1 comprised of 8 adults with hearing impairment in the age range of 18-60yrs (mean age = 44.12 SD = 11.7) diagnosed with mild sensorineural hearing loss (mean PTA = 44.24, SD=7.98). Experimental group 2 comprised of 10 adults with hearing impairment in the age range 18-60 years (mean age = 52.75, SD = 5.94) diagnosed with moderate sensorineural hearing loss (mean PTA=48.27, SD=11.7). Experimental group 3 comprised of 10 adults with hearing impairment in the age range of 18-60 years (mean age= 48.16, SD= 11.19) diagnosed with moderately severe sensorineural hearing loss (mean PTA = 52.7, SD = 2.46).

Material: The speech stimuli considered in this study was a CV syllable /da/, synthesized by King, Warrier, Hayes & Kraus (2002), she used a Klatt cascade/parallel formant synthesizer to synthesize a 40 msec speech like syllable /da/ at a sampling rate of 10 KHz. The stimulus was constructed to include an onset burst frication at F3, F4 and F5 during the first 10 msec, followed by 30 msec F1 and F2 transitions ceasing immediately before the steady state portion of the vowel.

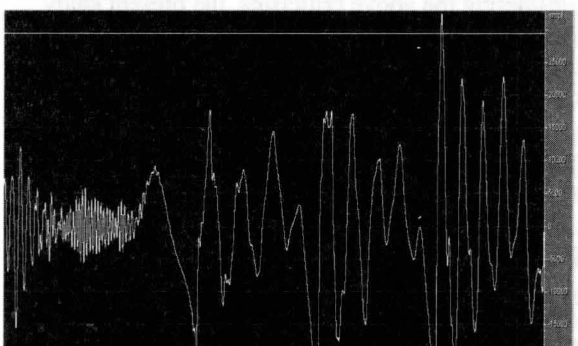

Figure 2. Time domain waveform of the synthesized stimuli /da/

For the syllable /da/ the formants F0, F1, F2, F3 changes linearly over the duration of the stimulus. The fundamental frequency F0 changes from 103-120 Hz, similarly the first formant changes from 200-720 Hz, the second formant F2 changes from 1240-1700 Hz, the third formant F3 changes from 2500-2580 Hz, the fourth and the fifth formants remained constant at 3600 and 4500 Hz respectively.

This CV syllable was chosen in the present study, for the reason that, it minimizes the test time and also retains the key phonetic information necessary for the perception of speech. An advantage of using synthesized speech syllables is the possibility to create a speech stimulus that differs only in terms of its VOT and this feature serves to be a very important issue in conducting parametric studies. On similar lines, some researchers are of the opinion that both natural and synthetic speech syllables result in similar VOT categorization (Michael, Torsten & Ulrich, 2009).

Test environment: All measurements were carried out in an acoustically treated double room condition. The ambient noise levels were maintained within the permissible levels according to ANSI standards (1996, S3.22).

Procedure

For each of the participant, pure tone thresholds were obtained using MADSEN OB-922 audiometer for the air conduction stimuli between the octave frequencies 250Hz to 8 kHz under the headphone condition and BC thresholds were obtained for frequencies between 250- 4 kHz with bone vibrator Radio ear B71 using the modified Hughson and Westlake procedure (Carhart & Jerger, 1959).

Speech audiometry was carried out to obtain Speech Recognition Thresholds (SRT) using a standardized spondee word list (Rajashekar, 1978). Similarly, Speech Identification Scores (SIS) was obtained using a PB word list (Vandana, 1998). To obtain the SRT and SIS the following procedure was followed. For Speech Recognition Thresholds, presentation level was 20 dB above the pure tone average. The intensity of the stimulus was increased in steps of 5 dB and decreased in 10 dB steps. The intensity level where the subject could repeat the spondees with greater than 50% accuracy was considered as the Speech Recognition Threshold. Speech identification scores were obtained with the presentation level 40 dB above the speech recognition thresholds. At this supra threshold level, the number of correct words uttered over the total words was calculated and converted in to percentages to obtain the speech identification scores. Uncomfortable loudness level (UCL) was established using the speech stimuli. Here the participants were asked to respond/ react when the loudness of the sound was too loud or uncomfortable. Tympanometry and reflex measurements was carried out to rule out any middle ear pathology using GSI-Tympstar immittance meter.

Click evoked ABR measurement was considered to rule out any indication of retro cochlear pathology in individuals with sensorineural hearing impairment.

Functional gain measurements

For the functional gain measurements, two digital hearing aids 'A' and 'B' which satisfy the fitting range for mild / moderate/ moderately severe degree of hearing impairment was selected . Hearing aids '1' and '2' which can process short duration stimuli was selected for the study by evaluating their group delay measures and their processing time measures.

Spectral characteristics of the hearing aids were measured using a Bruael and Kjaer Pulse analyzer. Initially, the input spectrum of the stimulus /da/ was routed to a computer with the help of a 2cc coupler, for a sample of 50 µsec at 9.1 repetition rate. A similar procedure was used to obtain the output spectrum of the hearing aids '1' and '2'. The modified output from the hearing aids was first received by a microphone and then was routed back to the computer for further analysis.

Electrocharacteristics of the hearing aids were analysed to make sure that the hearing aids were functioning as per the requirement. They were connected to the HIPRO with appropriate cables. The audiogram was fed into the NOAH software and the target gain was estimated based on the audiogram. The hearing aids were programmed based on the audiometric thresholds using NAL-NL1 fitting formula. It was ensured that the first fit program was maintained for all the subjects. Parameters of AGC (Automatic gain compression) and the volume control were set off.

The aided functional gain measurements were carried out by considering the preselected hearing aids. These hearing aids were ranked as rank '1' and rank '2' based on the subjects performance for aided FM tones (Average of 500Hz, 1kHz, 2kHz and 4kHz) and aided speech identification scores (SIS in %). The hearing aid 'A' or 'B' was ranked as '1' when the sound field threshold for the speech identification scores was greater when compared to the other hearing aid. Thus, the other hearing aid with poor SIS was ranked as '2'.

Initially the unaided pure tone thresholds were obtained for frequency modulated tones for octave frequencies between 500 to 4 kHz. For establishing the sound field thresholds the participants were asked to raise the finger whenever they heard the tone. The starting presentation level of the warble tones was kept around 70 dBHL and was gradually decreased in steps of 5 dB and increased in 10 dB steps to obtain accurate thresholds. The response criterion point of 75% was considered to calculate the thresholds. The order of presentation of the stimulus was varied to control the order effect. Similarly, speech identification scores were obtained in the unaided condition using a standardized speech material. Here the participants were instructed to repeat the words as heard. Presentation level was 40 dBHL (equivalent to 65 dBSPL), which corresponds to the normal conversation level.

Speech ABR recording

Speech ABR was recorded using /da/ stimuli without the hearing aid i.e. in the unaided condition and later was recorded with the two preselected hearing aids chosen for the functional gain measurements(Hearing aids ranked as '1' & '2') one after the other using an appropriate ear tip. The instrument BIOMARK navigator pro with the 580 Sinser 12 earphones was considered for this speech ABR recording. Participants were comfortably seated to ensure a relaxed posture and a minimum rejection rate. Loudspeaker delivering the stimulus was kept at a distance of 1 meter at an azimuth of 45 degree calibrated for free field condition which delivered the stimulus at 65dBSPL Silver chloride cup electrodes were placed after cleaning the electrode site with the preparation gel. Conducting gel was used to ensure proper conductivity; electrodes were placed on the respective site and secured with the help of a plaster. Conventional electrode montage was used with noninverting electrode on the vertex (Fz),inverting electrode on the test ear mastoid(Tm) and the common ground ohms and inter electrode impedance was maintained around 3 kΩ or < 3 kΩ. At each electrode the impedance was maintained to be less the 5 K ohms. The protocol for speech ABR recording is as depicted in the Table 1.

Analysis

The neural response to speech syllable /da/ is described morphologically in terms of an onset response and a FFR as shown in the Figure 3.

Table 1. Protocol for Speech evoked ABR

S.N	Protocol	
1.	Stimuli	/da/
2.	Stimulus level	65 dB SPL at the ear level
3.	Transducer	Loudspeaker
4.	Polarity	Alternating
5.	Filter	100-2 kHz
6.	Notch filter	ON
7.	Electrode placement	Cz: non inverting electrode Forehead : ground electrode Test ear: inverting electrode
8..	No of channels	Single channel
9.	Recording time window	- 15 to + 60 ms
10.	Sweeps	3000 sweeps for one recording. Calculated response – 6000 sweeps.
11	Repetition rate	9.1 /s
12	Amplification	1,00,000 times
13	Modeof presentation	Ipsilateral (monoaural)

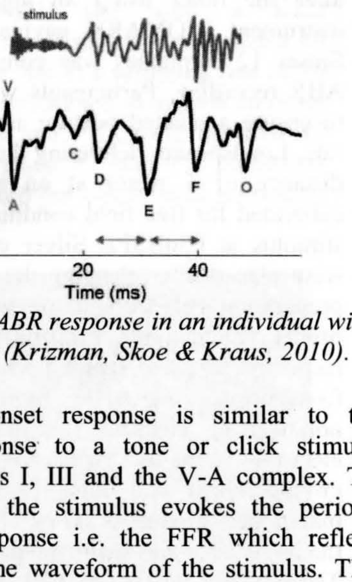

Figure 3. Speech ABR response in an individual with normal hearing (Krizman, Skoe & Kraus, 2010).

The robust onset response is similar to that observed in response to a tone or click stimulus consisting of waves I, III and the V-A complex. The voiced portion of the stimulus evokes the periodic portion of the response i.e. the FFR which reflects phase locking to the waveform of the stimulus. Thus period between the peaks D, E, F of the FFR corresponds to the F0(100-120Hz). Peaks between D, E, F represents the phase locking at the frequency of the first formant. For the acceptability of the speech ABR waveforms, it was ensured that speech ABR was replicated at least twice with a minimum of 3000 sweeps for each of the recording.

In the current study the following parameters were analyzed:

Onset response: The following wave 'V' parameters were measured from each of the ABR recording: Peak latency of wave 'V', Peak amplitude of wave 'V'.

Sustained response: In the brainstem response for speech the later peaks constitute the FFR or the sustained response with the wave marked as 'D', 'E' and' 'F. Frequency following responses for frequency encoding was analyzed using a Fourier analysis for 21.4 to 40.6 ms time window. To increase the number of sampling points in the frequency domain, the time window was zero padded to 4096 points before performing a discrete Fourier transform. The average spectral amplitude was calculated for three frequency ranges: Fundamental frequency (F0): 103-120 Hz, first formant (F1): 455-720 msec and high frequency (HF): 721-1154 Hz. Here the high frequency range corresponds to the 7^{th} through 11^{th} harmonics of the F0 of the stimulus i.e. the frequency range between the first and the second formants (Russo et.al, 2004).

For the offline analysis of FFR, a software known as "Brainstem Tool Box" (open source software, eeskoe@northwestern.edu) was used. This software is a MATLAB based program, which gives information about F0, F1 and the other formants of the FFR with its respective amplitudes. It also provides information about the latency and amplitude parameters of the onset and sustained responses along with SNR values. It is a comprehensive program which depicts the correlation between the stimulus and the response. Prior to this analysis, the FFR waveform was converted to ASCII format using the software "AEP to ASCII". This ASCII formatted data was fed into the "Brainstem Tool Box" software and was analyzed. The below picture 1.6, depicts the analysis window of the "Brainstem toolbox software".

The analysed data was available in two conditions: (1) Unaided condition. (2) Aided condition with Hearing aid ranked as '1', Hearing aid ranked as '2'.

Both the onset and the sustained responses , i.e. the latency and amplitude of the peaks V, A, D, E, F was considered for the above two conditions. Information about both the fundamental frequency and the formants was available from the FFT analysis. Additionally, the data obtained from the the objective measures of speech evoked ABR was compared with the functional gain measuremetns for the hearing aids ranked as '1' and '2'.

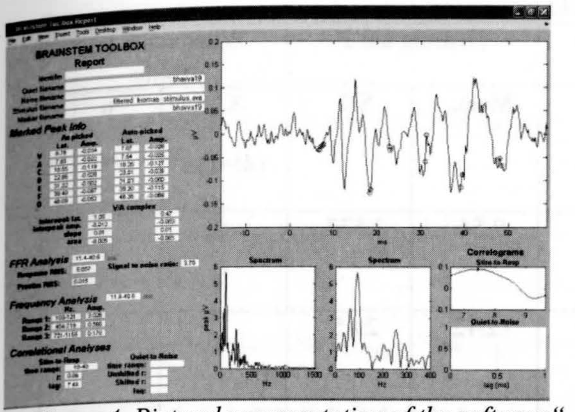

Figure 4. Pictoral representation of the software " Brainstem Toolbox" used for FFT analysis.

Results and Discussion

The primary objectives of the study was to compare the unaided and the aided measures of speech evoked ABR in adults with different degrees of hearing loss to evaluate speech ABR as a useful tool for selection of hearing aids. This study also aimed to investigate the usefulness of speech evoked ABR with the aided functional gain measurements (subjective measures).

Statistical analysis was carried out using "Statistical Package for Social Sciences", Version – 16. The data of 28 subjects was considered for the analysis. A total of eight, ten and ten samples were considered in the mild, moderate and the moderately severe group respectively. Non parametric tests were used for the analysis as unequal number of data was available in each group for each of the conditions. The mean and the standard deviation values were calculated for the measures of latency and amplitude. Overall, the latency and amplitude of the onset and the sustained responses with the FFT measures were subjected to both between group comparison and within group comparison.

Analysis was carried out in two phases:

Phase 1: Comparison of speech evoked measures for the unaided and the aided conditions for all three groups.

Within group comparison: Within group comparison was made to rule out the effect of hearing aids on measures of speech evoked ABR. Here the unaided condition was compared across the two aided conditions (hearing aid '1' and hearing aid '2'). The two aided conditions were further compared to see whether there was any difference between the two hearing aids for the same given input signal.

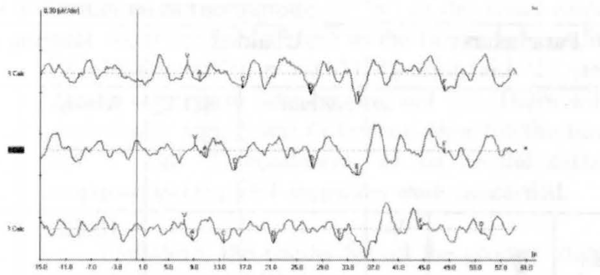

Figure 5. Speech ABR waveforms recorded for the synthesized stimuli /da/, for the unaided condition (bottom), hearing aid '1' (middle) and hearing aid '2' (extreme top), for an individual with mild hearing loss.

Mild group: It can be seen in the table 2, that there is a decrease in the latency for the onset responses 'V' and 'A' and the sustained responses 'D','E' and 'F', for the hearing aid '2' when compared to the unaided condition. This trend was not observed for the hearing aid '1'for both the onset and the sustained responses. There was no pattern of change seen between the unaided and the aided conditions, for the amplitude measures of both the onset and the sustained responses. Similarly, for the amplitude measures of FFR, there was no difference seen between the unaided and the aided responses.

With the perspective that the latency measures are more prone to be affected by the processing time of the hearing aids, amplitude of speech ABR alone was considered for the analysis. Further, there have been various studies reported in the literature, who claim that the amplitude measures provides a good correlation with the behavioral measures when compared to latency (Kiesling, 1982; Sumesh, 2007). Since the present study attempted to correlate the speech ABR measures with functional gain measurements, the decision to analyze the amplitude parameter was justified.

For the mild group, to statistically determine the difference in the amplitude for the unaided and the aided conditions, the onset, sustained response and the FFT measures were compared applying the Friedman's test. There was no difference observed for the amplitude measures of the onset and sustained responses except for the HF of the FFT at 5% level of significance ($p < 0.05$), for both the unaided and the aided conditions.

To further establish the extent of difference between the unaided and the aided conditions for the amplitude of HF, Wilcoxon's signed rank test was considered. Here the HF was compared in three

Table 2.The Mean and the SD for speech ABR measures, for the unaided, hearing aid '1' and hearing aid '2' conditions in an individual with mild hearing loss

Parameters			Unaided		Hearing aid 1		Hearing aid 2		Wilcoxon's test results	
			Mean	SD	Mean	SD	Mean	SD	X^2 (df=1)	p
Onset responses	(ms) Latency	V	-	-	10.22	2.07	9.54	2.577		
		A	-	-	11.98	2.50	12.12	2.85		
	(µV) Amplitude	V	-	-	0.06	0.028	0.046	0.031	0.909	0.364
		A	-	-	0.056	0.038	0.086	0.037	2.234	0.026*
Sustained responses	(ms) Latency	D	-	-	21.75	1.47	21.66	1.95		
		E	-	-	32.75	3.74	32.03	3.69		
		F	-	-	45.78	5.80	43.36	4.37		
	(µV) Amplitude	D	-	-	0.107	0.068	0.88	0.63	1.051	0.293
		E	-	-	0.088	0.056	0.172	0.27	1.559	0.119
		F	-	-	0.140	0.095	0.096	0.069	0.829	0.407
FFT	(µV) Amplitude	F0	-	-	1.10	0.495	2.06	0.615	0.943	0.346
		F1	-	-	0.33	0.11	0.435	7.9	1.772	0.076
		HF	-	-	0.173	3.8	0.179	1.7	0.761	0.447

(* significant at 0.05 level)

permutations i.e. unaided v/s hearing aid 1 unaided v/s hearing aid 2, hearing aid 1 v/s hearing aid 2.

It was noted that for the amplitude of HF, there was no difference obtained for the unaided and the hearing aid '1' condition [X^2(df=2) =1.693, p>0.05] and the hearing aid '1' and the hearing aid '2' condition [X^2(df=2)=0.734, P>0.05]. But, there was a difference seen for the unaided and the hearing aid '2' condition [X^2(df=2) =0.0205, P<0.05].

Moderate group: Similarly when Mean and SD was calculated for the moderate group there was no difference seen for the amplitude measures of speech ABR across the unaided and the aided conditions. But, when the mean and the SD were scrutinized visually, a positive trend was seen for the amplitude of the onset responses 'V' and 'A' in the unaided and the aided conditions with the hearing aids '1' and '2'. On the contrary, no such trend was observed for the amplitude measures of the sustained responses and the FFT measures.

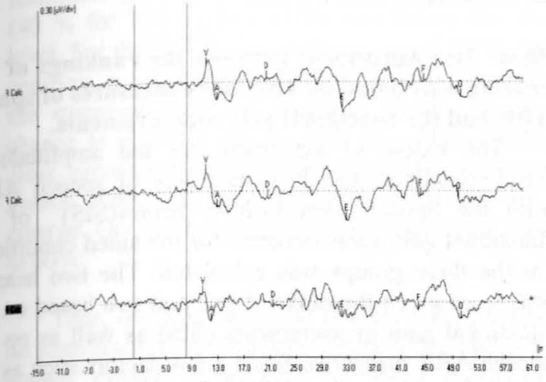

Figure 5. Speech ABR waveforms recorded for the synthesized stimuli /da/, for the unaided condition (bottom), hearing aid '1' (middle) and hearing aid '2' (extreme top), for an individual with moderate hearing loss

Moderately severe group: In none of the subjects in this group, the unaided speech ABR could be recorded and hence, only the aided condition of hearing aid '1' and hearing aid '2' was considered for the analysis. Here, presence of aided responses implies that the amplified signal was successfully encoded in the brainstem structures.

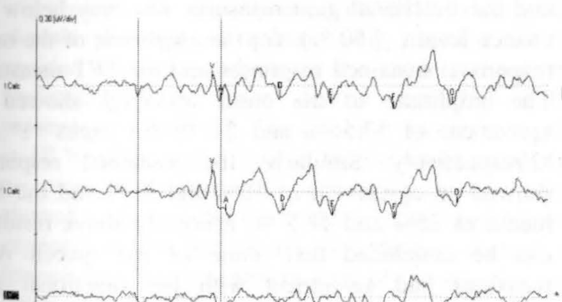

Figure 6. Speech ABR waveforms recorded for the synthesized stimuli /da/, for the unaided condition (bottom), hearing aid '1' (middle) and hearing aid '2' (extreme top), for an individual with moderately severe hearing loss.

For this group it was it was observed that the amplitude of the onset responses 'V' and 'A' was differently coded by the two hearing aids '1' and '2'. For the sustained responses D', 'E', 'F', a similar trend was seen where in the hearing aid '1' showed better amplitude than the hearing aid '2'. Inversely, the amplitude of F0, F1 and HF was better represented by the hearing aid '2' than the hearing aid '1'.

Wilcoxon's signed rank test was administered. It was seen the amplitude of 'A' in the onset response was significantly different in the two aided conditions [X^2(df=1)= 0.026, $p < 0.05$]. Hearing aid '2' yielded greater amplitude than hearing aid '1'. There was no statistically significant difference seen for the hearing aid '1' and '2' conditions, as far as the sustained response and the FFT measures were concerned.

Therefore, the results for all the groups' suggests that the speech ABR measures are not sensitive in illustrating the effects of changed/ amplified input speech. In spite of a few variables being controlled, such as the compression characteristics and the processing time measures, the expected results of changes in the speech ABR response could not be recorded consistently across the different parameters.

In the mild group, the amplitude of the HF for the hearing aid'2' was better than that of the unaided and the hearing aid '1' condition; for the moderate group, there was no difference obtained for the unaided and the two aided conditions for the amplitude of the onset, sustained and the FFT measures. Further, In the moderately severe group it is important to note the observation that aided responses were recorded in the absence of unaided response and the hearing aid'1' and hearing aid '2' did not show any significant difference for the speech ABR measures except for the amplitude of onset response 'A'.

Thus, the hypothesis made for this section of the results that there is a difference between the unaided and the aided conditions for the measures of Speech evoked ABR was rejected. This is in consensus with the previous research where the researchers claim that ABR is not an effective tool to assess the amplification benefit (Beauchaine, 1986, Kileny 1982).

Between group comparison

Mild group v/s Moderate group: Comparison of performance for the mild and moderate groups, in unaided, hearing aid '1' condition and the hearing aid '2' condition. Only the amplitude measures were considered for the comparison across the groups , as mentioned in the previous section.

The amplitude of the onset, sustained and the FFT measures were compared in the mild and moderate groups. The results showed that for the unaided condition, there was no difference seen between the groups for the onset and the sustained responses except for the F0, F1 and HF parameters of the FFT. In individuals with mild hearing loss, as the audibility is preserved and as less number of OHC could be damaged, more number of auditory filters would be available to process the spectral peaks of the speech signals (Van Tasell, 1997). Also, the F0 and the lower formants might have been perceived better than the higher formants because of the greater energy restored in the lower formants Pickett, 1972).

For the hearing aid '1', there was a significant difference seen only for the amplitude of 'A' and 'D' and for the F0 of the FFT. The mild group showed a better (enhanced) response than the moderate group. For the FFT measures, the hearing aid '1'was effective only in processing the F0 compared to its formats in the mild group and not in the moderate group.

For the hearing aid 2, there was a significant difference seen for the amplitude of 'V' and F0. The amplitude of 'V' was better in the moderate group as compared to the mild group. And, the amplitude of F0 was better in the mild group than the moderate group.

Mild v/s moderately severe group: Comparison across the mild and the moderately severe group reveals the following findings for the unaided condition, the results were not tabulated and compared between the groups because of the absence of responses in individuals with moderately severe hearing loss. This finding is in consensus with the results obtained by Sumesh (2007), where he concluded that speech ABR was not efficiently coded in individuals with higher degree of hearing loss.

There was a significant difference seen between the two groups for the hearing aid '1', where the amplitude of 'D' and the amplitude of F0 & F1 differed across the two groups. For the amplitude of the sustained 'D' and the FFT measures F0 & F1, performance of the mild group was better than the moderately severe group.

For the hearing aid '2', there was a significant difference seen only for the amplitude of F1 for the two groups. The mild group showed enhanced amplitude than the moderately severe group.

Moderate v/s moderately severe group: The data for the unaided condition could not be tabulated and compared due to absence of response in the moderately severe group. For the hearing aid '1' there was a significant difference seen between the groups for the amplitude of 'A', where the moderate group had better amplitude than the moderately severe group.

For the hearing aid '2' condition there was significant difference seen between the groups for the amplitude of 'V' , where in the moderate group had an enhanced amplitude for the onset response 'V' than the moderately severe group.

Phase II: Agreement between the rankings of the hearing aids based on amplitude measures of speech ABR and the functional gain measurements.

The extent of agreement for the amplitude of onset, sustained and FFT measures of speech ABR, with the Speech Identification Scores(SIS) of the functional gain measurements for the aided conditions, for the three groups was calculated. The two hearing aids were given the ranks of one and two based on the functional gain measurements (SIS) as well as on the speech ABR measures. Since a few factors such as the processing delay of the hearing aids can contaminate the latency measures to a larger extent, the ranking for speech ABR was based on the amplitude measures only. The hearing aid which gave higher amplitude for the various speech ABR parameters was given the first rank. The hearing aid with the higher SIS was given the first rank on the functional gain measurements. A matrix which had the ratings as rank '1' and rank '2' on the columns and rows for the speech ABR measures and the functional gain measurements respectively was used to check the extent of agreement.

Mild group: For individuals with mild hearing loss the agreement between the ranks for the speech ABR and the functional gain measures was way below the chance level (≤ 50 %) for the amplitude of the onset responses, sustained responses and the FFT measures. The amplitude of the onset measures showed an agreement of 37.5 % and 25 % for ranks '1' and '2'respectively. Similarly, the sustained responses showed an agreement of 50% and 25% and the FFT measures 25% and 12.5 %. From the above results it can be concluded that, none of the speech ABR measures had agreement with the functional gain measurements in ranking the hearing aids, in terms of their benefit.

Moderate group: Similarly, for individuals with moderate hearing loss, an agreement of 50% and above was seen for all the measures of speech ABR (The amplitude of onset responses, sustained responses and the FFT responses) with the functional gain measures.

The onset responses showed an agreement of 50% for the both rank '1' and '2'; the sustained responses showed an agreement of 50 % for the ranks '1' and 60% for the rank '2'.For the amplitude measures of the FFT, a better agreement was seen when compared to the onset and the sustained responses i.e. An agreement of 60 % was observed for the amplitude of speech ABR measures and SIS of the functional gain measurements for both ranks '1' and '2'.

Moderately severe group: Similarly, for individuals with moderately severe hearing loss there was a poor agreement seen between the speech ABR and the functional gain measurements for the onset responses (40 % for both ranks) which was below the chance level. For the FFT measures it was just at 50%. On the contrary, a better agreement (60 %) was obtained for the sustained response which is slightly above the chance level. As it can be seen from these results, a clear agreement between the amplitude measures of speech ABR and functional gain measures did not emerge. On isolated parameters the agreement was up to 60%.

Thus, the hypothesis for this section that there is no significant difference between the aided measures of speech evoked ABR and the aided measures of functional gain measurements for the hearing aids ranked as '1' and '2' was rejected.

From the above findings it can be concluded that, aided speech ABR may not be useful in prescribing hearing aids in individuals with different degrees of sensorineural hearing loss. They do not provide any scope for comparison with the well established measures such as the functional gain measurements. Therefore, it can be concluded that the ABR measures such as the click or speech ABR do not effectively represent the amplified effects of the signal in the auditory system.

Overall, the participants with mild hearing loss showed presence of speech ABR response in the unaided condition, where as the moderate and the moderately severe group showed variability in the presence of a response. The response was present only in 50 % of the individuals in the moderate group and no participants form the moderately severe group showed a response for the unaided condition. This was expected as for individuals with higher degrees of hearing loss the presentation level of the stimulus was either at threshold or just below the threshold resulting in no response for the unaided condition. However, in the aided condition responses were replicable for the all the participants in all the three groups with both the hearing aids.

Conclusions

With the invention of new technologies, the process of hearing aid selection has been the most widely discussed topic in the field of clinical Audiology. It is known that hearing aids help compensate for the disorders of the ear by amplifying the sound. However its effectiveness greatly depends on the central auditory systems ability to represent and integrate the spectral and temporal information delivered by the hearing aid. A few factors that determine the amount of benefit obtained from the hearing aids are the age of the client, degree and configuration of hearing loss, middle ear status of the client and prior experience with the hearing aids. Other non subjective factors such as the selection procedures (a choice for objective/ subjective / a combination of both), prescriptive strategies, frequency response and the gain characteristics of the hearing aid also determine the success of a fitting procedure.

To date, only a few studies have examined the effects of amplification on the objective measures such as the auditory evoked potentials (AEP/s). Among the AEP/s, Auditory Steady State Response (ASSR) has been the most widely researched AEP considered to assess the amplification benefit, but it is not been universally accepted due its limitations like, presence of artifacts at higher presentation level and use of tonal stimulus to assess the amplification benefit. Since the aim of fitting a most appropriate hearing aid is to enhance speech perception in individuals with hearing loss, it emphasizes the need to use speech stimulus for the validation of hearing aids. With the same purpose, Stapells, (2002); Souza and Tremblay, (2006) ; Billings, (2007) examined the effects of amplification on the obligatory potentials (P1-N1-P2) and ACC measures and concluded that application of CAEP in assessing the amplification benefit was limited because they failed to rule out the contribution/interaction of the hearing aids over the processing mechanism of the auditory cortex. Overall, they considered their findings to be premature to opine about the efficacy of CAEP in selection of hearing aids.

On similar lines, the present study made an attempt to examine the other potential applications of speech evoked ABR such as, use of Speech ABR in assessing the amplification benefit.

The results revealed the following, speech ABR measures could not be reliably recorded for all the subject groups in the unaided and the two aided conditions. It was seen that for the mild group, the amplitude of the HF for the hearing aid'2' was better than that of the unaided and the hearing aid '1' condition. For the moderate group, there was no difference obtained for the unaided and the two aided conditions. For the moderately severe group, hearing aid '1' and hearing aid '2' condition did not show any difference for amplitude measures of speech ABR. There is a very poor agreement between the amplitude measures of speech ABR and the SIS of the functional gain measurements, for the rank '1' and the rank '2' hearing aids. This suggested that speech ABR measures are not sensitive in assessing the benefit of amplification in individuals with different degrees of hearing loss.

Limitations of the study

The results of the present study cannot be generalized because of the limited sample size. Synthetic speech stimulus of very short duration was used in the present study, thus restricting the generalization of the results to a natural situation. The characteristics and the functioning mechanism of the hearing aids chosen could have affected the results to a larger extent.

Future directions

FFR measures can be recorded to assess the effect of experience (years) of hearing aid usage, to explore the issue of plasticity in the sub cortical structures, if any. The effect of different characteristics of the hearing aid on speech ABR may be explored. A larger scale study using natural speech stimuli may be undertaken to strengthen the results of the present study.

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