ISSN 2470-4059

http://dx.doi.org/10.17140/OTLOJ-2-118

Research

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Volume 2 : Issue 3
Article Ref. #: 1000OTLOJ2118

Article History
Received: March 8th, 2016
Accepted: May 23rd, 2016
Published: May 24th, 2016

Citation
Vanaja CS, Nimisha K. Cortical auditory evoked potentials in persons using hearing aids. *Otolaryngol Open J*. 2016; 2(3): 80-86. doi: 10.17140/OTLOJ-2-118

Cortical Auditory Evoked Potentials in Persons Using Hearing Aids

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ABSTRACT

Introduction: A review of literature on usefulness of Cortical Auditory Evoked Potentials (CAEPS) in verifying the usefulness of hearing aid shows equivocal results and a majority of the studies are carried out in a research laboratory.
Objective: The aim of the present investigation was to investigate the usefulness of recording CAEPs for verification of hearing aids in a clinical set up.
Material And Methods: CAEPs to stimulus /ma/, /ga/ and /ta/ were recorded from 14 persons with normal hearing and nine persons with mild to moderately severe sensorineural hearing loss. For persons with hearing impairment, the testing was carried out without a hearing aid (unaided) and with a hearing aid (aided) programmed based on NAL NL 1 prescriptive formula.
Results: The results revealed that in aided condition, the detectability of CAEP responses was more when compared to unaided condition in persons with hearing impairment. There was a significant difference between the unaided CAEP responses of persons with hearing impairment and CAEP responses of persons with normal hearing. However, no such difference was observed between aided CAEPS responses of persons with hearing impairment and those of normal hearing.
Conclusions: CAEPs can be reliably recorded in a clinical set up from individuals using hearing aids. The detectability of responses increases when a person is wearing hearing aid. CAEPs will be helpful in verification of hearing aids especially in persons with moderately severe to severe hearing loss.

KEYWORDS: Long latency response; Aural rehabilitation; Hearing aid fitting.

INTRODUCTION

The advancement in the field of pediatric audiology has resulted in early, efficient and objective measures of hearing threshold estimation for infants. This has provided with the ability to fit appropriate hearing aid at a very young age. Verification of the selected hearing aid in infants and small children is a challenging task as it is difficult to obtain reliable behavioral measures from them. There is a need to use electrophysiological measures for such population.

A review of literature shows that investigators have studied the usefulness of various auditory evoked potentials such as auditory brainstem response (ABR), auditory steady state responses (ASSR) and cortical auditory evoked potentials (CAEPs) as a tool for verification of selected hearing aid. ABR and ASSR are best elicited by click and tonal stimuli and these stimuli gives very limited information regarding speech perception thus their use is limited. CAEPs can be elicited using speech stimuli and hence can be more useful in verification of hearing aids. CAEPs recorded in persons using hearing aids will also verify if the sounds are sufficiently amplified and processed in the auditory pathway till cortex.

Rapin, Graziani[1] were the first to study the effect of sensorineural hearing loss and personal hearing aids on CAEPs. They found that a majority of their participants (5 out of 8) had aided cortical responses better than the unaided cortical responses to clicks and pure tones,

ISSN 2470-4059 Open Journal http://dx.doi.org/10.17140/OTLOJ-2-118

however, two of the infants did not show any changes in cortical responses for aided *versus* unaided condition. Though attempts to record CAEPs in persons wearing hearing aid started 50 years back, it is still not a proven measure of validating hearing aid use in the clinical set up. Some of the investigators have reported that CAEPs demonstrate benefit of hearing aids. It has been reported that use of personal hearing aid substantially improve the detectability of CAEPs and a majority of individuals with hearing impairment showed reduced latency, increased amplitude and improved morphology when tested in with their hearing aids, The improvement in detectability was especially observed in individuals with higher degree of hearing impairment.[2]

Recent research has also focused on investigating the usefulness of CAEPs in assessing the benefit from hearing aid in different frequency regions. It has been suggested the recording CAEPs for /m/,/g/ and /t/ stimuli will check the hearing across the speech spectrum, as each of the stimuli represent low, mid and high frequency region respectively.[3]

Contrary to the studies which support use of CAEPs in hearing aid validation, some researchers reported that CAEPs do not reflect the change in hearing aid gain. Tremblay, Kalstein, Billings, Souza[4] observed very subtle enhancement in amplitude of CAEPs when the hearing aid provides mild high frequency gain. Similarly, Billings, Tremblay, Souza, Binns[5] reported no significant difference in latency and amplitude of CAEPs when the hearing aid gain was changed by 20 dB.

Thus, though there is evidence in literature suggesting that CAEPs can be recorded reliably from persons using hearing aid, there is variability in the results observed in different studies. This variability may be due to the variations in the test protocol and the amplification devices used. It has been well established that both stimulus related and acquisition related factors have an effect on CAEPs. In addition the effect of hearing aid related variables on aided cortical potentials is yet to be completely explored. It has been reported that hearing aid processing alters the acoustic properties of the signal used for eliciting CAEPs and the aided CAEPs may not reflect accurately reflect the signal amplified from a hearing.[6,7] Also, CAEPs may not reliably reflect hearing aid gain as amplification alters the signal to noise ratio which in turn can affect the CAEPs.[8] The effect of amplification on hearing aid output is complicated as it depends on the amplification device or the hearing aids used. Easwar, Purcell, Scollie[9] compared the hearing aid processing of phonemes in running speech and phonemes used for recording CAEPs. There was a difference in processing of the two signals by hearing aids. In addition, they observed that the output from the hearing aid varied depending on the hearing aid used.

Thus, it can be inferred from these studies, that the latency and amplitude of aided CAEPs may not be good parameters to measure the benefit from hearing aid/s. However, the presence or absence of waveforms may be better indicator of hearing aid benefit in a clinical situation. Glista, Easwar, Purcell, Scollie[10] investigated the reliability of recording and interpreting CAEPs using a commercially available clinical instrument to assess the benefit from hearing aid technology. They observed that for some children frequency compression hearing aids increased audibility in certain frequency regions which in turn increased the detectability of tone burst CAEPs. An investigation by Billings, Papesh, Penman, Baltzell, Gallun[11] corroborate this. They reported that CAEPs are helpful clinically in determining whether audible signals are detected physiologically.

The aim of the present investigation was to probe the feasibility and usefulness of recording CAEPs from persons using hearing aids, in a clinical set up using a commercially available auditory evoked potential system. The present research also investigated if there is a difference in the CAEP responses recorded from persons with hearing loss and those of normal hearing. All the three measures, the latency and amplitude of peaks as well as the detectablity of waveforms were considered for analysis.

MATERIAL AND METHODS

Participants

Nine individuals with hearing impairment and 14 individuals with normal hearing in the age range of 60-70 years participated in the study. Pure tone average for 500 Hz, 1000 Hz and 2000 Hz was less than 25 dB HL and immittance evaluation indicated no middle ear pathology for participants with normal hearing. For participants with hearing loss, pure tone average ranged between 41 to 70 dB HL in the better ear with an air-bone gap of less than 10 dB and immittance evaluation revealed no middle ear pathology. Retro-cochlear pathology was ruled out based on the clinical history and the results of the audiological test battery including pure tone audiometry, speech audiometry, immittance evaluation and auditory brainstem responses. All the participants with hearing loss benefitted from the hearing aid used in the study. Sound field behavioral thresholds with the hearing aid programmed based on NAL NL formula was less than 55 dB HL. Participants were in good general health, with no report of any otologic or neurologic disorders. The study was approved by the Research and Ethics Committee of Bharati Vidyapeeth University, Pune and informed consent was taken from all the participants before collecting data.

Stimuli For Recording Caeps

Stimulus for CAEPs was natural speech sound /ma/, /ga/ and /ta/ recorded in a computer using adobe audition software, version 2.0. The sampling frequency was 48,000 Hz with 16 bit resolution. The sound was spoken by a native, male Marathi speaker into a unidirectional microphone connected to the computer. The duration of each stimulus was approximately 350 msec. The stimuli were loaded into Biologic auditory evoked potential system for CAEP recording.

ISSN 2470-4059 Open Journal http://dx.doi.org/10.17140/OTLOJ-2-118

Hearing Aid

A digitally programmable behind-the-ear hearing aid coupled to an open tube was used throughout the study for all the participants. According to the manufacture's published specifications the frequency range of the hearing aid extended from 100 to 6000 Hz. The hearing aid had a maximum output of 133 dB SPL with a gain of 0-100 dB. The hearing aid had 4 channels and 8 bands. Hearing aid used for the research was checked for the electroacoustic characteristics using Fonix 7000 hearing aid analyzer. The hearing aid was programmed using NOAH software and hearing aid programmer, HI-PRO.

Procedure

Biologic auditory evoked potential system (Navigator pro) with auditory evoked potential software version 7.0.0 was used to record CAEP. Participants were instructed to sit on a chair in relaxed and comfortable position. Silver coated disc electrodes were placed on testing sites after cleaning the site with skin preparing gel. Conduction paste was used to increase the conductivity of the signal. The electrodes were securely placed using a medical tape. The inverting electrode was placed on the mastoid of the test ear; non-inverting electrode was placed on vertex (Cz), with the common electrode on low forehead (Fpz). It was ensured that electrode impedance and inter-electrode impedance was less than 5 kΩ and 2 kΩ, respectively. CAEPs were recorded using the protocol given in Table 1. CAEPs were recorded twice to ensure replicability and the waveforms obtained in two recordings were then added to improve the morphology. P1, N1, P2 and N2 peaks were marked independently by two audiologists who were unaware of the test conditions.

Stimuli	/ma/, /ga/, /ta/
Stimulus intensity	60 dB SPL
Repetition rate	1.1/sec
Polarity	Rarefaction
Filter	0.1-30 Hz
No. of channels	Single channel
Amplification	30,000
No. of sweeps	300

Table 1: Protocol for CAEP recording.

For persons with hearing impairment, testing was carried out without a hearing aid (unaided) and with a hearing aid (aided). The hearing aid programmed based on NAL NL 1 prescriptive formula was fitted to the better ear and the poorer ear was blocked during testing. The obtained data from behavioral and electrophysiological measures were tabulated and statistical analyses were carried out using Statistical Package for Social Sciences (SPSS) version 16.

RESULTS

CAEPs could be reliably recorded for all the three stimuli, however all the peaks were not present in all the individuals. The most consistent peaks were P2 and N2. All the four peaks (P1, N1, P2, N2) could be recorded for /ma/ in 13 individuals. For /ga/ sound P2 and N2 were present in all 14 individuals. P1 could be identified in eight individuals and N1 could be identified in only 9 individuals. Responses for /ta/ sound showed P1 and N1 in all 14 individuals, P2 in 13 and N2 in 12 individuals. Figure 1 shows representative waveforms recorded from participants with normal hearing for the three stimuli.

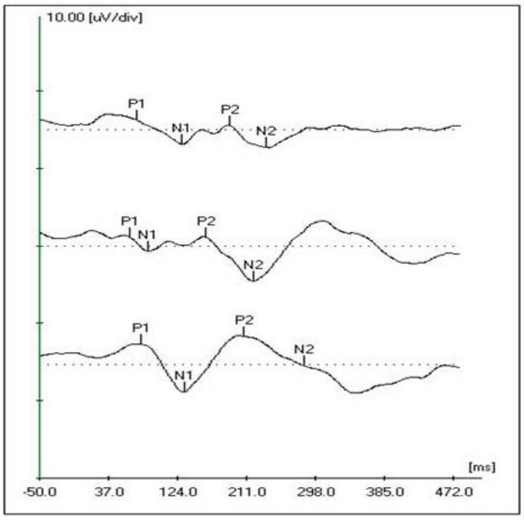

Figure 1: CAEPs for /ma/, /ga/ and /ta/ stimuli in normal hearing individuals.

CAEPs were obtained from individuals with hearing impairment without a hearing aid (unaided) and with a hearing aid (aided condition). The responses obtained were compared with those recorded from persons with normal hearing. P2 was the most consistent response and was present in a majority of individuals with hearing impairment. Two individuals showed no response to all the sounds. For /ma/ sound, CAEPs could be recorded from 7 individuals whereas for /ga/ and /ta/ sound, responses could be obtained only from 6 individuals. Figure 2 shows samples of waveforms obtained from persons with hearing impairment. Detectability of responses increased in aided condition. However, CAEPs could not be recorded from all the individuals with hearing impairment even in aided condition. A lot of individual variability was observed. Some persons showed improvement in morphology with a hearing aid while a few did not show any improvement. Figure 3 shows CAEP responses for the three stimuli in an individual with hearing impairment who showed improvement with hearing aid while Figure 4 shows responses for a person who did not show any improvement in CAEPs with a hearing aid.

Table 2 shows the mean and standard deviation of the latencies (P1, N1, P2, and N2) for individuals with normal hearing and for those with hearing impairment. The table shows latencies in both unaided condition and aided conditions for those with hearing impairment. Overall, the mean latencies were longer for individuals with hearing impairment when compared to

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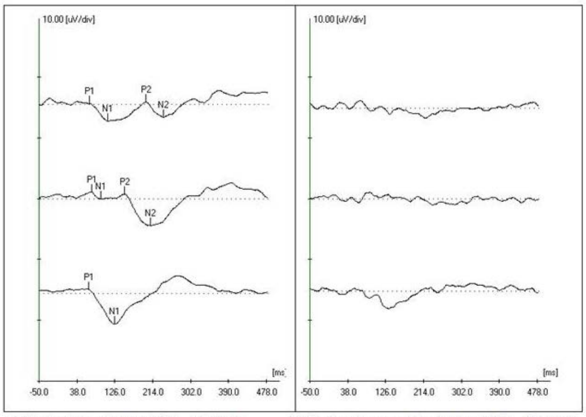
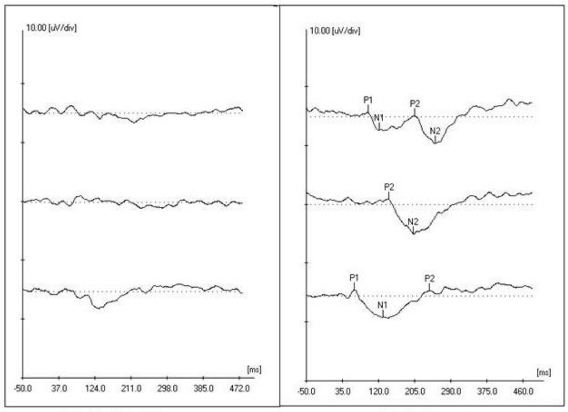


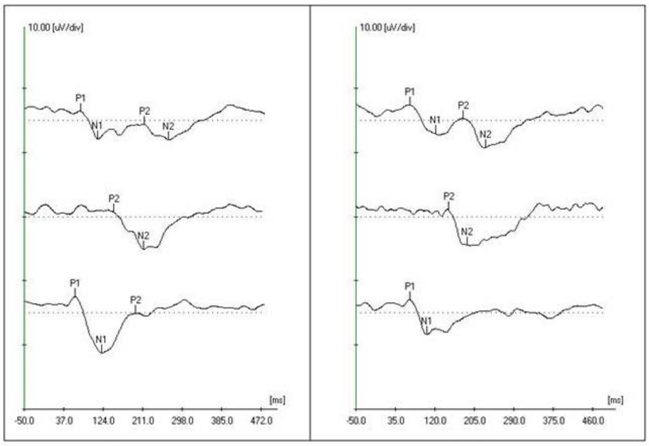
a) Moderate hearing loss PTA - 46 dBHL b) Moderately severe hearing loss PTA - 69 dBHL

Figure 2. Representation of CAEP responses in individuals with hearing impairment..



a) unaided responses b) aided responses

Figure 3. CAEP responses for /ma/, /ga/, and /ta/ stimuli in an individual with hearing impairment who showed improvement with hearing aid.



a) unaided responses b) aided responses

Figure 4. CAEP responses for /ma/, /ga/, and /ta/ stimuli in an individual with hearing impairment who did not show any improvement in CAEPs with a hearing aid.

			/ma/			/ga/			/ta/	
		N	Mean	SD	N	Mean	SD	N	Mean	SD
P1	NL	13	69.28	10.99	8	76.35	13.4	14	74.18	11.30
	HI	5	81.58	9.43	0	-	-	6	69.86	11.33
		6	70.06	9.06	0	-	-	6	77.00	9.66
NI	NL	13	114.74	11.79	9	103.53	20.26	14	127.05	12.80
	HI	5	132.83	14.50	1	122.82	-	6	133.33	11.59
		6	120.38	17.70	1	129.05	-	7	135.45	16.39
P2	NL	13	189.43	9.90	14	163.56	16.82	13	211.09	26.10
	HI	7	214.12	37.90	6	158.54	11.28	6	225.35	26.94
		8	198.41	10.90	7	154.03	8.08	6	233.50	20.60
N2	NL	13	232.45	15.77	14	223.92	21.68	12	251.20	36.90
	HI	5	247.09	12.48	6	219.62	18.29	2	263.35	17.67
		7	245.05	10.79	7	225.87	21.77	3	282.43	5.91

Note: ‘NL’ refers to normal hearing individual ‘HI’ refers to individual with hearing impairment.

Table 2: Mean and SD of latency (in msec) of CAEP peaks in individuals with hearing impairment in unaided condition and those with normal hearing.

ISSN 2470-4059 Open Journal http://dx.doi.org/10.17140/OTLOJ-2-118

those with normal hearing. The latency of peaks in persons with hearing impairment was lesser in aided condition when compared with the unaided condition. Table 3 shows the amplitude (P1N1 & P2N2) for the two groups. The amplitude was larger for /ma/ and /ta/ sound and smaller for /ga/ in individuals with hearing impairment when compared to those with normal hearing except for P2N2 amplitude for /ta/. With a hearing aid, there was an increase in amplitude of P2N2 of /ta/ and /ga/ sound.

Mann Whitney U test was carried out to check if the latency and amplitude observed in persons with hearing impairment was significantly different from those observed in persons with normal hearing. Comparison between unaided responses of individuals with hearing impairment and those of normal hearing showed that for /ma/ sound, the latency of all the peaks was significantly different from those of participants with normal hearing but there was no significant difference in the amplitude of the response. For /ga/ sound the latencies of P1 and N1 as well as amplitudes of P1-N1 and P2-N2 differ significantly from those of persons with normal hearing. There was no significant difference between the two groups for latencies and amplitude of all the peaks of /ta/. It can be observed from the table that the latencies and amplitudes of responses obtained in aided were not significantly different from those obtained for individuals with normal hearing except for latency of N2 and amplitude of P2-N2 for /ma/ sound (Table 4).

To summaraise, the result revealed that in aided condition, the detectability of CAEP responses was more when compared to unaided condition in persons with hearing impairment. There was a significant difference between the unaided CAEP responses of persons with hearing impairment and CAEP responses of persons with normal hearing. However, no such difference was observed between aided CAEPS responses of persons with hearing impairment and those of normal hearing.

DISCUSSION

The aim of the present study was to investigate the usefulness of CAEPs in verification of hearing aid. The speech stimuli used in the present study were consonant vowel (CV) syllables with consonants representing low, mid and high frequency region. The duration of all the three stimuli was 350 m sec with a SD of 12 msec. Two of the consonants were voiced (/m/ and /g/) and one was voiceless (/t/), the vowel /a/ was kept constant.

Statistically significant difference observed between CAEP responses of individuals with hearing impairment in unaided condition and those of normal hearing can be attributed to the loss of audibility in persons with hearing impairment.

			/ma/			/ga/			/ta/	
		N	Mean	SD	N	Mean	SD	N	Mean	SD
P1N1	NL	13	3.77	1.16	8	1.71	1.17	14	6.33	1.80
	HI	5	4.40	1.58	0	-	-	6	6.76	4.66
		6	4.40	3.02	0	-	-	6	5.88	3.90
P2N2	NL	13	2.32	0.69	14	5.33	1.76	12	1.75	1.20
	HI	5	3.97	1.92	6	4.69	2.46	2	1.11	0.45
		7	3.25	1.00	7	4.92	2.13	3	2.27	1.92

Note: 'NL' refers to normal hearing individual 'HI' refers to individual with hearing impairment.

Table 3: Mean and SD of amplitude (in µV) of CAEP peaks in individuals with hearing impairment in unaided condition and those with normal hearing.

	/ma/		/ga/		/ta/	
	Unaided	Aided	Uniaded	Aided	Unaided	Aided
P1	2.80**	-0.48	-2.66 **	-	-0.56	-0.54
N1	2.79**	-0.48	-2.43*	-1.22	-0.76	-1.68
P2	2.36*	-1.82	-0.76	-1.27	-1.23	-1.71
N2	2.77**	-2.58*	-0.82	-0.78	-0.37	-1.16
P1N1	1.54	-0.09	-2.00*	-	-0.30	-1.32
P2N2	0.51	2.02*	-1.96*	-1.04	-0.73	-0.72

Note: *=significant at 0.05 level; **=significant at 0.01 level.

Table 4: Results of Mann-Whitney U test (z values) comparing CAEPs of persons with hearing impairment with those of individuals with normal hearing.

ISSN 2470-4059 Open Journal http://dx.doi.org/10.17140/OTLOJ-2-118

Similar results have been reported by earlier investigators.[12,13] No significant difference was obtained between aided responses of individuals with hearing impairment and those of individuals with normal hearing indicates that the audibility has improved with hearing aid. However, the latencies in the aided condition were longer than those obtained for persons with normal hearing. Korczak, Kurtzberg, Stapells[13] also reported, prolonged latencies in aided conditions in comparison to the mean latencies obtained in the normal hearing individuals in persons who were benefitting from hearing aids. They concluded that despite of the benefits provided by the hearing aid, individuals with hearing impairment process speech in less effective manner than their normal hearing counterparts.

Inspection of individual data showed that for /ma/ sound, 8 participants showed improvement in aided condition. For /ga/ 6 participants showed improvement and for /ta/ only 4 individuals showed improvement with hearing aid. Individuals with severe hearing loss (pure tone average greater than 71.6 dB HL) showed marked improvement in CAEP responses when unaided and aided responses were compared. These findings suggesting detectability of CAEPs improve when the degree of hearing loss is high as compared to lesser degree of hearing loss, is similar to the finding's reported by earlier investigators.[13] These results suggest that CAEPs can be used to assess the usefulness of a hearing aid in those who cannot give a voluntary response. Recording aided CAEPs in infants and children can assure the clinician and the parents/caregivers that the child is hearing with the hearing aid.

Longer latency observed in aided condition when compared to unaided conditions for some responses could be attributed to fact that CAEP's are sensitive to the changes in temporal features within milliseconds[14] and hearing aids alter the acoustics of speech stimuli and thus CAEPs.[4,5] Billings, Tremblay, Miller[8] studied the effect of hearing aid gain settings on latency and amplitude of P1, N1 and P2 waves. They reported that hearing aid modifies stimulus characteristics such as SNR, which in turn affects CAEP in a way that does not reliably reflect hearing aid gain.

CONCLUSION

To conclude, the results of the present study reveal that the CAEPs can be reliably recorded in a clinical set up from individuals using hearing aids. The detectability of responses increases when a person is wearing hearing aid. CAEPs can be used for verification of hearing aids in difficult-to-test population who are not able to give reliable behavioral responses. CAEPs may be helpful in verifying the usefulness of hearing aids in persons with severe hearing loss.

ACKNOWLEDGEMENT

Authors wish to acknowledge the authorities of Bharati Vidyapeeth Deemed University School of Audiology and Speech Language Pathology for granting permission to carry out the study.

CONFLICTS OF INTEREST: None.

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ISSN 2470-4059

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