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Original Article

Cortical Evoked Potentials and Hearing Aids in Individuals with Auditory Dys-Synchrony

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OBJECTIVE: The purpose of the present study was to investigate the relationship between cortical processing of speech and benefit from hearing aids in individuals with auditory dys-synchrony.

MATERIALS and METHODS: Data were collected from 38 individuals with auditory dys-synchrony. Participants were selected based on hearing thresholds, middle ear reflexes, otoacoustic emissions, and auditory brain stem responses. Cortical-evoked potentials were recorded for click and speech. Participants with auditory dys-synchrony were fitted with bilateral multichannel wide dynamic range compression hearing aids. Aided and unaided speech identification scores for 40 words were obtained for each participant.

RESULTS: Hierarchical cluster analysis using Ward's method clearly showed four subgroups of participants with auditory dys-synchrony based on the hearing aid benefit score (aided minus unaided speech identification score). The difference in the mean aided and unaided speech identification scores was significantly different in participants with auditory dys-synchrony. However, the mean unaided speech identification scores were not significantly different between the four subgroups. The N2 amplitude and P1 latency of the speech-evoked cortical potentials were significantly different between the four subgroups formed based on hearing aid benefit scores.

CONCLUSION: The results indicated that subgroups of individuals with auditory dys-synchrony who benefit from hearing aids exist. Individuals who benefitted from hearing aids showed decreased N2 amplitudes compared with those who did not. N2 amplitude is associated with greater suppression of background noise while processing speech.

KEYWORDS: Auditory dys-synchrony, cortical-evoked potentials, wide dynamic range compressions, hearing aid benefit score, speech identification score

INTRODUCTION

Auditory dys-synchrony is a hearing disorder that has unique physiological and perceptual consequences for affected individuals. This perplexing disorder primarily affects perception of conversational speech. Auditory dys-synchrony was considered to be a rare disorder until recently, with estimates suggesting that 10%–15% of individuals with congenital hearing loss are affected by auditory dys-synchrony [1]. This disorder is variously known as auditory dys-synchrony [2], auditory neuropathy [3], orauditory neuropathy spectrum disorder, which is a more recent term [4].

Auditory dys-synchrony is characterized by the absence of auditory brainstem responses (ABRs) in the presence of normal otoacoustic emissions (OAEs) and cochlear microphonics [3]. ABRs, if present, are likely to be severely abnormal. In general, subjects with auditory dys-synchrony present evidence of normally functioning outer hair cells (OHC) in the presence of abnormal auditory nerve conduction [5].

The management of individuals with auditory dys-synchrony remains controversial. It is generally believed that individuals with auditory dys-synchrony, particularly adults, do not benefit from hearing aids even though they have varying degrees of hearing loss. The presence of OAEs in individuals with auditory dys-synchrony suggests normal functioning of OHCs. Hearing aids are designed to compensate for missing OHC [6]; therefore, as individuals with auditory dys-synchrony have normally functioning OHCs, hearing aids may not be of much benefit to them [3, 7]. However, there is evidence that some individuals with auditory dys-synchrony may benefit from conventional amplification through hearing aids.

The results of several studies can be interpreted to suggest that subgroups of subjects with auditory dys-synchrony who benefit from hearing aids exist and that their speech identification scores are better than those who do not benefit from hearing aids or who may variably benefit from hearing aids [8-10]. There is some evidence, albeit indirect, relating benefit from hearing aids and cortical auditory-evoked potentials.

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Though individuals with auditory dys-synchrony have abnormal (or absent) ABRs, it is possible to elicit late latency responses (LLRs) from these individuals for a variety of stimuli [11-13]. Starr et al. [3] were the first to relate LLRs and speech perception in individuals with auditory dys-synchrony. They recorded click-evoked LLRs (P1-N1-P2) in four adults with auditory dys-synchrony. The responses to supra-threshold click stimuli were recordable in three of these four subjects. Starr et al. [3] further observed that subjects for whom LLRs could not be recorded had poorer speech identification scores. Rance et al. [10] demonstrated significantly improved open set speech perception in 50% of children with auditory dys-synchrony who were fitted with hearing aids. Furthermore, Rance et al. [10] were able to link observed improvements in aided speech identification to the presence of recordable cortical event-related potentials in their subjects. Narne and Vanaja [12] classified their subjects with auditory dys-synchrony into two groups, namely good and poor performers, based on their speech identification scores. They recorded click-evoked LLRs for their subjects and found that the N1-P2 amplitudes were significantly greater in good performers than in poor performers. Speech identification scores were correlated with the amplitudes of N1-P2 but not with their latencies. Abdeltawwab [14] recorded N1-P2 complexes in 13 of 16 subjects and reported that latency was prolonged and the N1-P2 amplitudes were reduced in individuals with auditory neuropathy. Furthermore, he reported that poorer speech discrimination scores were associated with decreased amplitude and prolonged N1-P2 latencies in his subjects.

Cortical auditory-evoked potentials or LLRs represent the sum of the neural activity in the auditory pathways in response to sound. LLR is an objective recording of the brain's response to sound and, therefore, it is an ideal tool for investigating auditory function [15]. In addition, speech stimuli across the speech spectrum evoke a neural response at the level of the auditory cortex. A difference in the neural responses to different speech stimuli suggests that the stimuli are distinguished from each other. Obligatory LLRs (LLRs primarily determined by the physical properties of the stimulus) seem to be an ideal objective tool for the evaluation of aided hearing instruments because they (a) correlate well with perception, (b) can be evoked by a range of speech stimuli, and (c) seem to be sensitive to differences between speech stimuli [15].

Individuals with auditory dys-synchrony show severe speech perception problems in the presence of noise [16-19], indicating the importance of the signal to noise ratio. N2 of LLR reflects the ability of an individual to synthesize the acoustic features of a sound into a sensory representation [20], including temporal features of the speech signal. Therefore, N2 reflects high-level stimulus processing [15], and N2 amplitude reflects the inhibitory control of the cortical auditory mechanisms, a necessary function for suppressing unwanted background noise [21].

Recording of ABRs and OAEs and pure tone audiometry is a standard audiological battery for the clinical diagnosis of auditory dys-synchrony. Cortical-evoked potentials for obligatory responses have been previously studied; they only reflect the ability of the individual to detect sound. Studying higher processing abilities in individuals with auditory dys-synchrony, which are represented by their N2 results, may help explain why some individuals with auditory dys-synchrony who have recordable LLRs benefit from hearing aids and others do not. Therefore, the purpose of this study was to correlate benefits from hearing aids and the presence of LLRs in individuals with auditory dys-synchrony.

MATERIALS and METHODS

Participants with Auditory Dys-Synchrony

This study was conducted after obtaining approval from the Institute's Ethics Committee (Letter No. NIMH/65th IEC/2009, dated 19.3.2009: Item 11.01). The participants were explained the purpose of the study as well their role in it in their own language. Following this, each participant completed a consent form agreeing to participate in the study. Thirty-eight individuals who were aged from 16 to 30 years (mean age, 22.38 years), including both males (N=25) and females (N=13), participated in the study. The age of onset of their auditory problems ranged from 9 to 29 years (mean age of onset, 16.08 years). No information was available on the etiologies of the problems as there were no medical records. The criteria for the identification of auditory dys-synchrony were those recommended by Starr et al. [8] and are as follows: individuals with (a) preserved cochlear amplification (presenting OAEs), (b) no ABRs or abnormal ABRs, if present, and (c) who show no acoustic reflexes.

Testing for Participant Selection

Air conduction and bone conduction, pure tone thresholds for octave frequencies, and speech identification scores for monosyllables were obtained using a calibrated clinical audiometer (Grason Stadler; GSI 61, Eden Prairie, US). Monosyllables were presented at 40 dB SL monoaurally. All testing was conducted in a sound-treated room built as per American National Standard Institute (ANSI 1991) for noise levels. Pure tone thresholds varied from normal to moderate degree.

Immittance evaluation for a 226-Hz probe tone was conducted with a calibrated middle ear analyzer (Grason Stadler; GSI-Tympstar, Eden Prairie, USA). ABRs were recorded three times using a Brain Electro Scan System (Axxonet System Technologies; Axxonet-BESS, Bradford, UK) with a standard protocol. Proof of the presence of cochlear microphonics was the reversal of the waves for condensation clicks. Individuals who had no ABRs or only the 5th peak with poor morphology in the presence of cochlear microphonics were considered. Transient-evoked otoacoustic emissions (TEOAEs) were recorded using an Echosport ILO 292-II instrument (Otodynamics Ltd; Herts, UK) for clicks at 80 dB SPLpe (peak equivalent SPL). An emission was considered valid only if the waveform reproducibility was 75% or more and the overall signal to noise ratio was equal to or greater than 6 dB. Individuals who showed "A-type" tympanograms with absent acoustic reflexes and normal otoacoustic emissions were included in the study.

Speech Material for Hearing Aid Fitting

Aided and unaided speech identification scores (binaural presentation) were obtained for words from a list of the 500 most familiar words in written Kannada (Jayaram, unpublished). Each of these "most familiar words" occurred 50 to 55 times in 100,000 words of randomly selected printed text in Kannada published between the years 2000 and 2006. The longest words in these lists were four syllables long. Twenty-five lists, each with 20 randomly selected words, were prepared for convenience.

Stimuli for Recording LLRs

Cortical-evoked potentials were recorded for both clicks and speech (Axxonet System Technologies; Axxonet-BESS, Bradford, UK). The speech stimulus was a natural consonant-vowel (CV) syllable /ta/ (retroflex /t/) spoken by an adult female speaker and recorded at a sampling frequency of 16 kHz on an IC recorder (Sony, ICD-PX820; Bangalore, India). It has been reported that speech intelligibility for syllables uttered by female speakers is higher than that for syllables uttered by male speakers [22]. Natural speech was used as the stimulus because LLRs for natural speech show remarkable stability between recordings from the same individual. Given this stability, any significant alteration in morphology would likely reflect changes in neural activation to speech and not simply random variability [23]. Most auditory-evoked responses are onset responses triggered by the leading edge as well as the first few tens of milliseconds of the stimulus envelope, for which there is some integration of sound energy. The syllable /ta/ was used because it has a short onset time compared with that for other syllables [24].

The recorded stimulus (syllable /ta/) was edited to improve the signal-to-noise ratio using the noise reduction feature of Cool Edit Pro software (Version 2, Adobe; San Jose, US). The duration of the stimulus to be presented was limited to 100 milliseconds by deleting the final portion of the steady state vowel and windowing the offset of the vowel [25].

Recording Parameters of LLRs

All recordings were conducted in a sound treated room built as per ANSI standards. Recordings were conducted using a Brain Electro Scan System (Axxonet System Technologies; Axxonet BESS, Bradford, UK). The participants were awake and seated in a comfortable position (to minimize myogenic responses). The stimuli were presented at 40 dB SL (ref: pure tone average for 500 Hz, 1 kHz, and 2 kHz). After skin preparation at the electrode site, electrodes were placed at Cz (active), ipsi lateral mastoid (reference), and contralateral mastoid (ground). Eye movements were monitored using a bipolar electrode montage. Impedance was <5 KΩ. The recording window had a 50 millisecond pre-stimulus and 750 millisecond post-stimulus time; however, the analysis window was maintained at 350 milliseconds. Incoming signals were filtered from 1 to 30 Hz. Clicks of alternating polarity and speech syllables were presented at a rate of 1.1/second through insert headphones. All waveforms were corrected for baseline electroencephalogram activity by subtracting pre-stimulus electrical activity from the response waveforms.

Analysis of Waveforms

The LLRs were checked for replicability by recording responses for a second time using the same protocol. Only replicable waveforms (similar morphology and latency in two recordings on visual inspection) were considered for analysis. Prior to analysis of the individual waveforms, grand averages of the LLR waves were generated separately for speech and clicks as well as for the right and left ears. The grand average waveforms were obtained by averaging individual recordings of 36 individuals with auditory dys-synchrony (LLRs were absent in two participants). Absolute latencies for individual waveforms (P1, N1, P2, and N2) were measured with reference to the grand averaged waveforms. Peak latency is the time interval between the onset of the stimulus and the target peak. The investigator and another experienced audiologist took all the measurements. The identified waves and obtained measurements had 100% agreement between the two judges. Figure 1 shows an example of the cortical-evoked waveforms.

Hearing Aid Fitting

Siemens (Siemens India Pvt. Ltd; Siron-'S', Connexx programming platform; Bangalore, India), Phonak (Phonak India Pvt. Ltd; Versta, iPFG programming platform; Bangalore, India), and ReSound (Resound India Pvt. Ltd., Vea-370, Aventa programming platform; Bangalore, India) hearing aids were used. The hearing aids were selected based on individual comfort and results. The hearing aids were programmed individually for each participant depending upon the configuration of their pure tone audiograms, and no particular prescriptive formula was employed for fitting. The hearing aids were programmed using a hearing aid programmer (HI-PRO, GN Otometrics AS; Taastrup, Denmark) and were fitted binaurally.

Aided and unaided speech identification scores were obtained in a sound-treated room. The stimulus was presented at a comfortable level through loudspeakers (Grason Stadler; Eden Prairie, US) maintained at a distance of 1 meter and 0° azimuth. Each participant was

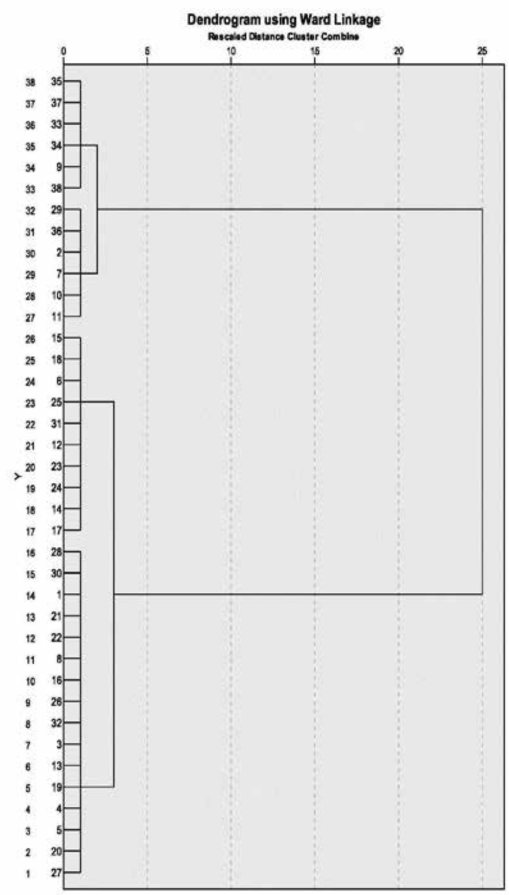

Figure 1. A recording of the cortical-evoked potentials from three active sites (Cz, Fz, and Pz). Note that only responses from Cz were considered in all analysis. The trace also shows the electroculographs (both vertical and horizontal), which were used to monitor eye blink artifacts

tested based on four lists of 20 words each (two lists in the aided and two lists in the unaided condition). The word lists were selected randomly for each participant. There was a minimum interval of 3 hours between aided and unaided testing. The difference between the aided and unaided speech identification scores was considered to be the hearing aid benefit score.

Statistical Analysis

All statistical analyses for both descriptive and non-parametric tests were conducted using Statistical Package for Social Sciences software (IBM SPSS statistics, Version 19; SPSS South Asia, Bangalore, India, licensed to our institute). Hierarchical cluster analysis (Ward's method) was used to subgroup the participants based on their hearing aid benefit scores. The Wilcoxon signed rank test (within group comparisons), the Mann–Whitney U test (between group comparisons), and the Kruskal–Wallis test (across group comparisons) were used. The criterion for statistical significance was set at $p<0.01$.

RESULTS

Ear (Left vs. Right) and Gender (Male vs. Female) Difference

The Wilcoxon signed rank test showed that the pure tone hearing thresholds, speech identification scores for monosyllables, and OAE thresholds were not significantly different between the right and left ears ($p>0.01$) (Table 1) or between males and females ($p>0.01$) (Table 2). Therefore, data pertaining to the left and right ears and to males and females were combined in all statistical analyses.

Cortical-evoked potentials for both clicks and speech could be recorded in 36 of the 38 participants with auditory dys-synchrony. The Wilcoxon signed rank test showed that the mean latencies and peak amplitudes of P1, N1, P2, and N2 were not significantly different either between the left and right ears ($p>0.01$) or between the two genders ($p>0.01$). This was true of LLRs for both click and speech stimuli. Therefore, LLR data for the left and right ears and from males and females were combined in all statistical analyses.

Aided and Unaided Speech Identification Score

The mean aided and unaided speech identification scores for words were significantly different ($p<0.01$) (Table 3).

Subgroups Based on Hearing Aid Benefit Score

Thirty-two of the 38 participants improved their speech identification scores with hearing aids. The improvement ranged between 10% and 50% in different participants. Hierarchical cluster analysis using Ward's method was conducted to identify subgroups of individuals with auditory dys-synchrony based on their hearing aid benefit scores. Ward's method is a general agglomerative hierarchical clustering procedure, for which the criterion for choosing the pair of clusters to merge at each step is based on the optimal value of any function that reflects the investigator's purpose. The function at this instance is the hearing aid benefit score. The results of this analysis, resulting in four subgroups, are shown in Figure 2. Based on Ward's method, participants could be clearly subgrouped into four groups without any overlapping at the first level. The first and second subgroups can be combined at the second level, while the third and fourth subgroups can be combined only at the third level. As the four subgroups cannot be combined at the same level, the first level groups were considered in all statistical analyses. The level corresponds to the horizontal distance from the Y-axis and is determined internally based on the principles of Ward's method. The Kruskal–Wallis test showed that the mean unaided speech identification scores were not significantly different between the four subgroups ($p>0.01$) (Table 4).

Table 1. Mean, standard deviation (SD), and the significance of difference between the mean scores of the right and the left ear for some audiological parameters

	Auditory dys-synchrony				
	Right		Left		Wilcoxon signed rank
Tests	Mean	SD	Mean	SD	p
Pure tone average (dB)	35.63	13.49	37.26	13.34	>0.01
OAE (dB)	17.15	4.85	17.86	4.76	>0.01
SIS	59.73	25.06	60.65	28.81	>0.01

SIS: speech identification score (%); OAE: otoacoustic emissions; SD: standard deviation

Table 2. Mean, standard deviation (SD) and the significance of difference of mean scores between males and females for some audiological parameters

	Auditory dys-synchrony				Mann–Whitney U test	
	Males		Females			
Tests	Mean	SD	Mean	SD	Z	p
Pure tone average (dB)	34.05	12.28	38.84	13.80	-1.12	>0.01
OAE (dB)	17.27	4.78	17.96	4.25	-0.27	>0.01
SIS	70.60	12.01	68.50	13.5	-1.13	>0.01
Unaided SIS	53.25	5.99	40.56	10.08	-2.15	>0.01
Aided SIS	66.73	6.07	60.56	9.38	-0.71	>0.01

SIS: speech identification score (%); OAE: otoacoustic emissions; SD: standard deviation

Table 3. The results of the Wilcoxon signed rank test for the significance of difference between the mean aided and unaided speech identification scores

Auditory dys-synchrony				Wilcoxon signed rank test	
Aided SIS (%) for words		Unaided SIS (%) for words			
Mean	SD	Mean	SD	Z	p
61.84	21.82	47.63	20.29	–4.44	<0.01

SIS: speech identification score (%); SD: standard deviation

Table 4. Mean, standard deviation (SD), and results of the Kruskal–Wallis test for the significance of difference of mean unaided speech identification scores (SIS) between the four subgroups formed on the basis of hearing aid benefit score

	Unaided speech identification score	
Subgroups	Mean %	SD
1	45.00	5.47
2	55.83	11.14
3	46.00	25.47
4	45.62	23.51
Kruskal–Wallis	>0.01	

SD: standard deviation

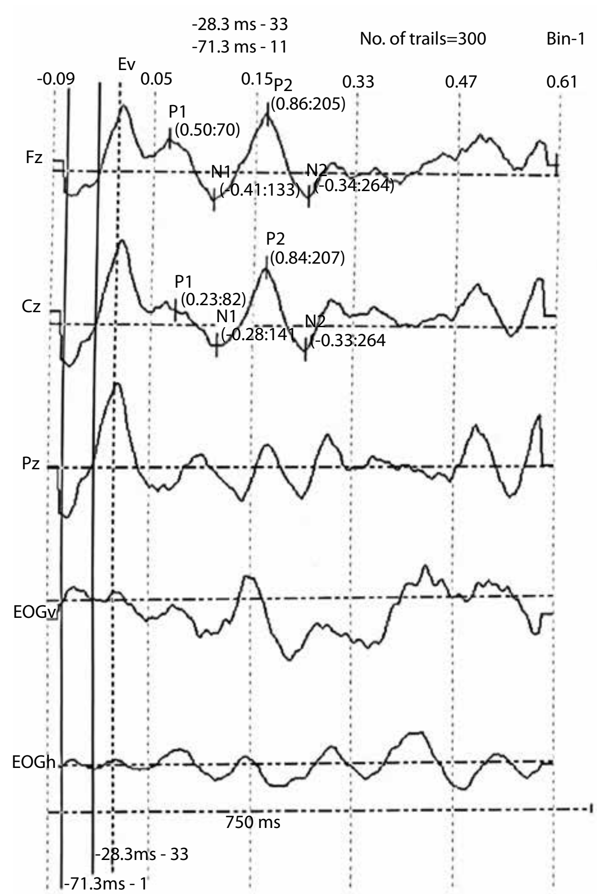

Figure 2. Dendogram derived from hierarchical cluster analysis (Ward's method) based on hearing aid benefit score. Participants in the study (N=38) are listed in the first column. The second column shows the serial numbers of the participants grouped into different subgroups. Based on Ward's method, participants could be clearly subgrouped into four groups without any overlapping at the first level (level corresponds to the horizontal distance from the Y-axis)

Comparison between Subgroups

The Kruskal–Wallis test showed that only the mean latency of speech-evoked P1 and the mean amplitude of speech-evoked N2 were significantly different (p<0.01) between the four subgroups based on the hearing aid benefit score (Table 5). The Mann–Whitney U test showed that the mean P1 latency and mean N2 amplitude of subgroup 1 were significantly different from those of other subgroups. However, subgroups 2, 3, and 4 were not significantly different from each other (Table 6). None of the differences in mean values for click-evoked LLRs were statistically different between the four subgroups (Table 7).

DISCUSSION

The generation of LLRs does not depend on neural synchrony to the same extent as ABRs [26]. This explains the presence of LLRs in the absence of ABRs in individuals with auditory dys-synchrony. However, LLRs were present in a larger percentage of the participants of the present study compared to the figures reported by Rance et al. [10] and Sharma et al [27]. Rance et al. [10] found that N1-P2 was absent in 50% of the participants of their study; they attributed this absence to impaired speech perception. In a retrospective analysis of the results from 21 children with ANSD, Sharma et al. [27] reported that 38% of the children showed LLRs that were normal in all respects; 33% showed LLRs with normal morphology but with prolonged latency and decreased amplitude; and in the remaining 29%, the morphology of the LLRs was so poor that the latency and amplitude could not be measured.

N2 reflects the ability of an individual to encode acoustic features of a sound into a sensory representation [20], including the reali-

Table 5. Mean, standard deviation (SD), and results of the Kruskal–Wallis test for the significance of difference in mean latency and amplitude of speech-evoked LLR between the four subgroups

		Speech			
		Latency (ms)		Amplitude (µv)	
		Mean	SD	Mean	SD
	Subgroups				
P1	1	72.50	2.28	2.54	0.23
	2	64.42	3.43	2.35	0.39
	3	54.09	29.18	1.87	1.05
	4	68.88	2.26	2.35	0.34
Kruskal–Wallis p		0.007		0.33	
N1	1	124.03	0.89	-0.45	0.13
	2	114.01	8.57	-0.37	0.11
	3	93.03	49.72	-0.38	0.27
	4	114.28	8.12	-0.35	0.17
Kruskal–Wallis p		0.02		0.59	
P2	1	154.54	4.27	2.53	0.16
	2	149.13	4.32	2.75	0.43
	3	123.25	65.05	2.09	1.17
	4	149.81	5.20	2.99	0.46
Kruskal–Wallis p		0.22		0.03	
N2	1	207.49	5.63	-1.19	0.23
	2	203.05	8.12	-1.33	0.23
	3	162.48	85.75	-1.18	0.65
	4	195.47	8.87	-1.37	0.36
Kruskal–Wallis p		0.06		<0.01	

LLR: late latency responses; SD: standard deviation; ms: milliseconds; µv: microvolt

Table 6. Results of the Mann–Whitney U test of significance of difference between subgroups with respect to P1 latency and N2 amplitude of speech-evoked LLR

	Mann–Whitney U test			
	P1 latency (ms)		N2 amplitude (µv)	
Subgroups	Z	p	Z	p
1 vs. 2	-2.88	<0.01	-2.88	<0.01
1 vs. 3	-1.95	<0.01	-3.03	<0.01
1 vs. 4	-2.50	<0.01	-3.03	<0.01
2 vs. 3	-0.97	>0.01	-0.21	>0.01
2 vs. 4	-2.43	>0.01	-0.79	>0.01
3 vs. 4	-0.89	>0.01	0.00	>0.01

ms: milliseconds; µv: microvolt; LLR: late latency responses

Table 7. Mean, SD, and results of the Kruskal–Wallis test for the significance of difference of mean latency and amplitude of click-evoked LLR between the four subgroups

		Clicks			
		Latency (ms)		Amplitude (µv)	
		Mean	SD	Mean	SD
	Subgroups				
P1	1	69.48	1.67	2.56	0.28
	2	65.91	5.28	2.18	0.19
	3	54.71	29.04	2.05	1.10
	4	68.97	3.51	2.29	0.27
Kruskal–Wallis p		>0.01		>0.01	
N1	1	119.0	4.18	–0.43	0.13
	2	114.9	1.96	–0.36	0.06
	3	93.92	50.38	–0.38	0.25
	4	116.19	6.02	–0.47	-0.14
Kruskal–Wallis p		>0.01		>0.01	
P2	1	154.9	2.68	2.90	0.13
	2	149.7	1.96	2.90	0.39
	3	122.0	64.52	2.15	1.18
	4	150.1	4.47	2.83	0.28
Kruskal–Wallis p		>0.01		>0.01	
N2	1	204.3	5.45	–1.96	0.33
	2	202.2	9.04	–1.37	0.34
	3	165.6	87.49	–1.25	0.71
	4	197.5	7.01	–1.46	0.31
Kruskal–Wallis p		>0.01		>0.01	

ms: milliseconds; µv: microvolts; SD: standard deviation

zation of temporal features of the speech signal. The amplitude of N2 for speech was significantly the lowest in subgroup 1 of the present study (highest benefit from hearing aid) compared to the other 3 subgroups. While P1, N1, and P2 are obligatory responses, N2 depends on the perception of the signal. Therefore, the characteristics of speech stimuli such as voice onset time (VOT) and place of articulation influence LLR waveforms [28]. Thus, N2 of LLR reflects higher-level stimulus processing [15]. The N2 amplitude also reflects greater inhibitory control of the cortical auditory mechanisms, a necessity for suppressing unwanted background noise [21]. The greater the inhibitory ability (as reflected in a lower N2 amplitude) of the cortical auditory mechanisms, the higher the suppression of unwanted effects of background noise [20]. It is generally understood that higher suppression of background noise may lead to better perception of speech. If this assumption is valid, then participants in subgroup 1 who demonstrated the lowest N2 amplitude should have also demonstrated higher unaided speech identification scores. However, the results of the present study on mean unaided speech identification scores (Table 4) do not support this general assumption.

Spectral contrast and signal overshoot are the two major consequences of processing of speech in hearing aids with wide dynamic range compression features that adversely affect speech identification [29]. Spectral contrast refers to the intrinsic ratio between high amplitude low frequency sounds and high frequency low amplitude sounds in a CV syllable. According to Schaub [29], fast acting compression and a higher number of channels in a hearing aid combine to reduce spectral contrast. Thus, the loss of spectral contrast as well as signal overshoot results in an output signal that is different from the input signal, which leads to distortion. Temporal processing is severely affected in individuals with auditory dys-synchrony [19]; therefore, they may not be able to benefit from amplified speech from a hearing aid. VOT and burst duration are some of the temporal events of speech that individuals with auditory dys-synchrony find it difficult to perceive [30]. Rance et al. [10] demonstrated significantly improved open set speech perception in 50% of children with auditory dys-synchrony fitted with hearing aids. Furthermore, Rance et al. [10] were able to relate improvement seen in aided speech identification to the presence of recordable LLRs in their subjects. As N2 amplitude is related to perception of the signals, a lower N2 amplitude in some participants with auditory dys-synchrony means that they have an intrinsic ability to better perceive speech. It is hypothesized here that this residual ability to better perceive speech in some individuals with auditory dys-synchrony can overcome the disadvantage associated with processing of speech in a hearing aid (distortion of temporal parameters of speech). Thus, a subsection of individuals with auditory dys-synchrony may benefit from hearing aids.

The mean latency of speech-evoked P1 was significantly longer in subgroup 1 compared to other subgroups. As P1 reflects the transmission of a signal to higher cortical centers, it remains to be explained whether the observed association between P1 latency and higher benefit from hearing aids in the present study is a chance observation or has any physiological basis. Evidence from both humans and animals suggests that the neural generators of P1 originate from the thalamo-cortical projections to the auditory cortex [31]. P1 latency is a reflection of synaptic delays in the peripheral and central auditory pathways. As P1 latency varies as a function of age, it is taken as an index of cortical auditory maturation [32]. However, it is not possible to comment on the cortical auditory maturation of the participants of the present study, as they are all adults and not much information is available on the age of onset of their hearing problems. In conclusion, the present study provides evidence for the association between benefit derived from hearing aid amplification and higher level cortical processing in individuals with auditory dys-synchrony.

Ethics Committee Approval: Ethics committee approval was received for this study from the Institute ethics committee of the National Institute of Mental Health and Neurosciences, Bangalore (wide letter No. NIMH/65th IEC/2009, Item 11.01 dated 19.3.2009).

Informed Consent: Participants were explained the purpose as well their role in the study in their own language. Following this, each participant completed a consent form agreeing to participate in the study.

Peer-review: Externally peer-reviewed.

Author Contributions: Concept - P.Y., J.M.; Design - P.Y., J.M.; Supervision - J.M.; Resources - P.J., J.M.; Materials - J.M., P.Y.; Data Collection and/or Processing - P.Y.; Analysis and/or Interpretation - J.M., P.Y.; Literature Search - P.Y.; Writing Manuscript - P.Y., J.M.; Critical Review - J.M.

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