EFFECT OF FREQUENCY SPECIFIC AMPLIFICATION ON SPEECH PERCEPTION IN INDIVIDUALS WITH ANSD

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Principal Investigator
Dr. Animesh Barman
Reader in Audiology
Department of Audiology

Co-Investigators
Dr. Sujeet Kumar Sinha
Mr. Prashanth Prabhu
Department of Audiology

Research Officer
Ms. Merry Elizabeth Roy
Department of Audiology

All India Institute of Speech and Hearing
Manasagangothri, Mysore – 570 006

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Dr. Animesh Barman
Principal Investigator

Dr. Sujeet Kumar Sinha
Co-Investigator

Mr. Prashanth Prabhu
Co-Investigator

Ms. Merry Elizabeth Roy
Research Officer

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ABSTRACT

Auditory neuropathy spectrum disorder (ANSD), is a condition with intact cochlear amplification but abnormal neural conduction. Management of this disorder remains a challenge in the field of audiology due to heterogeneity in the clinical population. In the search of such useful management amplification techniques using hearing aids, the present study was conducted to find if specific frequency amplification (in contrast to conventional full band amplification) would benefit individuals with ANSD to improve their speech identification ability. It further aimed to check the influence of number of channels in hearing aid and cut off frequency on speech perception using specific band amplification. It also aimed to assess if aided speech identification performance had any relationship with presence/absence of Long Latency Responses (LLR) and speech identification scores (SIS) obtained at 40dB SL without amplification. A total of 22 individuals between the age ranges of 15 to 42 years were recruited for the study. Testing included, obtaining LLR responses, unaided and aided SI scores with full band and specific frequency amplification settings with a four and a sixteen channel digital hearing aids. Results showed that frequency specific amplification is a better option than conventional amplification during hearing aid fitting as it showed significant benefit in speech identification compared to unaided performance. Such an improvement could be attributed to elimination of upward spread of masking during frequency specific amplification. Further, no significant difference in performance was observed between 4 and 16 channel hearing aid and also between two cut off frequency in 16 channel hearing aid used in the study. Also, LLR responses were not found to be significantly associated with unaided and aided speech identification performance. To conclude, the study results recommend the use of frequency specific amplification with cut off frequency around 1 kHz in individuals with ANSD.

INTRODUCTION

Auditory neuropathy/Auditory Dyssynchrony (AN/AD) is a condition with intact cochlear amplification but abnormal neural conduction (Berlin, Hood & Rose, 2001; Starr, Picton, Sininger, Hood & Berlin, 1996). As the name suggests, it is characterized by loss of synchrony of auditory nerve fibres which disturbs the timing of auditory information reaching the ear preventing the brain from following the dynamic speech. More recently a new term 'Auditory Neuropathy Spectrum Disorder' (ANSD) was adopted. ANSD describes a heterogeneous population who exhibit normal outer hair cell function but disrupted neural conduction along the auditory pathway (International Newborn Hearing Screening Conference, 2008).

The dysfunction in this population could occur at the level of cochlear inner hair cells, the synapse between the inner hair cells and auditory nerve or the auditory nerve itself (Amatuzzi et al., 2001; Starr et al., 1996). The dysfunction can be either demyelinating or axonal type. The demyelinating type involves loss of synchrony in the neural activity at the brainstem whereas axonal neuropathy occurs as a result of overall reduction in the number of neural fibers. The former reduces precision in timing of auditory information whereas the latter involves overall reduction in the neural activity.

The etiology of ANSD has been considered multifactorial. Manchaiah, Zhao, Danesh, and Duprey (2011) reported that a large proportion of ANSD is inherited genetically which could be syndromic, non syndromic or mitochondrial related. For example, mutations of genes namely, OPA1, OTOF, etc are found to be non syndromic causes for ANSD. Other proposed causes in children include prematurity, anoxia (Berlin et al., 2010), genetic mutations and hyperbilirubinemia (Madden, Hilbert, Rutter, Greinwald, & Choo, 2002). In late onset ANSD, infections (measles, mumps), any neurological conditions with peripheral neuropathy (Eg: Fredreich's Ataxia, Charcot-Marie-Tooth disease, etc.) and demyelinating conditions such as multiple sclerosis and HIV infection (Manchaiah, et al., 2011) are reported to be etiologically related. Predisposing factors for late onset ANSD may comprise of low socioeconomic status, exposure to toxic chemicals, family history of the condition, and onset at the pubertal age (Prabhu, Avilala & Manjula, 2012).

The prevalence of ANSD varies according to studies and is estimated that 1 in every 10 children with hearing loss may have ANSD (Sininger, 2002). In India, Kumar and Jayaram (2006) reported the prevalence of ANSD to be 0.54% (1 in 183 persons) among individuals with sensorineural hearing impairment. Mittal, Ramesh, Panwar, Nilkanthan, Nair, and Mehra, (2012) reported a prevalence of 5.3 % in children with hearing problems below 12 yrs of age. Bielecki, Horbulewicz and Wolan (2012) reported a prevalence of 5.1 % among infants with who had risk factors for hearing loss. Others have found a higher prevalence rate of 15 % (Kraus, Ozdamar, Stein, & Reed, 1984) and 11% (Rance, Beer, Cone-Wesson, Shepard, Dowell, & King, 1999) among population with permanent hearing loss. The onset of the problem was reported majorly during the first and second decade of life in Indian population (Kumar & Jayaram, 2006).

As the term indicates, the disorder exhibits a spectrum of clinical characteristics. ANSD may be symptomatized by hearing loss, tinnitus, headache and vertigo (Prabhu, Avilala & Manjula, 2012). The notable clinical feature of this disorder is the significantly distorted speech perception abilities (Berlin et al., 2010; Kumar & Jayaram, 2006; Kraus et al., 2000). Clinical manifestations also include normal oto-acoustic emissions with absent or abnormal auditory brainstem responses. The hearing loss accompanied may vary from normal to profound degrees and may be fluctuating (Kumar & Jayaram, 2006; Kraus et al, 2000; Rance et al., 1999; Starr, Sininger, Winter, Derebery, Oba, & Michalewski, 1998). The condition could be unilateral or bilateral which may be symmetrical or asymmetrical (Jijo & Yathiraj, 2012). Sininger and Oba (2001) found that 43% of individuals with auditory dys-synchrony show a flat audiometric shape, and 28% had a reverse sloping loss with higher thresholds for low-frequency stimuli than for high frequency stimuli. The impaired low frequency thresholds in these individuals could be due to poor timing accuracy in the neural representation of low-frequency stimuli (Rance, 2005).

The Speech Identification Scores (SIS) of individuals with ANSD may range from 0 to 100% in quiet (Berlin et al., 2010; Kumar & Jayaram, 2006; Kraus et al., 2000). These speech perception difficulties are more conspicuous in the presence of background noise (Rance et al., 2007; Kraus et al., 2000). The extremely poor speech perception ability either in quiet/or in noise is proven to be a concrete indication of compromised neural synchrony. Despite having access to the complete spectrum, they exhibit difficulties in speech perception due to the loss of precision at the level of neural processing which possibly disrupts the ability to track dynamic changes within the complex speech stimulus. These dilemmas in perception are often incongruent with the detection levels (Starr et al., 1996) and thus, cannot be inferred from their audiometric thresholds (Zeng Oba, & Starr, 2001; Starr, Sininger, & Pratt, 2000).

The perceptual difficulties have been attributed to impaired spectral and temporal resolution. This is apparent from abnormal results found on psychophysical experiments (Rance, McKay, & Grayden, 2004) and also supported by pathophysiological evidences of neural dyysnchrony. For example, Zeng and Liu (2006) reported that these individuals exhibit a marked disturbance with low frequency spectral discrimination which is said to be greatly dependent on neural phase locking. The relatively longer low frequency neural length makes the low frequency spectrum more prone to disruption. The rising audiogram configuration found commonly among these individuals (Jijo & Yathiraj, 2012; Sininger & Oba, 2001) also corroborates to poor pitch processing at low frequencies.

The focus of improving speech perception performance should thus be on enhancing the available spectral and temporal resolution ability rather than just audibility. Available management options include hearing aids, cochlear implants, FM devices, perceptual training, speech reading and cued speech (Kraus, 2001). These options remain questionable in serving all individuals with ANSD due to heterogeneity of the disorder.

Conventional hearing aid fitting has shown evidences of mixed results. Berlin, Hood, Morlet, Rose, and Brashears (2003) over a ten to twenty year span of observation of 260 patients with ANSD, reported that hearing aids did not prove beneficial for individuals with ANSD. Friesen and Cunningham (2003) reported that despite an improvement in detection and awareness in children with ANSD, the long term value of hearing aids in understanding speech was far poorer than predicted based on the audiogram and/or articulation index alone compared to the conventional hard-of-hearing child. Raveh, Attias, Badrana, and Buller, (2006) reported that out of 19 children fitted with hearing aids, only one child showed improved speech recognition scores when aided, thus stated that hearing aids may not help children with ANSD in understanding speech.

There are few reports that document the benefit obtained from the use of amplification in some children with ANSD (Madden et al., 2002; Deltenre et al., 1999; Rance et al., 1999). Deltenre et al., (1999) reported improved open set SIS and language comprehension in a child fitted with conventional amplification. Rance and Barker (2009) reported that children with ANSD using hearing aids performed similar to their implanted peers. Rance et al., (1999) showed that approximately 50% of affected children benefited from amplification similar to that expected in children with a comparable degree of sensorineural hearing loss, and promotes hearing aid trials for individuals with ANSD.

Considering mixed results obtained with amplification, recent research findings suggest cochlear implantation to be a viable management option for individuals with ANSD (Mason, DeMichele, Stevens, Ruth & Hashisaki, 2003; Madden, Rutter, Hilbert, Greinwald & Choo, 2002; Trautwein, Shallop, Fabry & Friedman, 2001). The electrical stimulation provided is expected to improve the neural synchrony and hence improve the speech perception in these individuals (Peterson, Shallop, Driscoll, Breneman, Babb, Stoeckel, & Fabry, 2003; Shallop Jin, Driscoll, & Tibesar, 2003). It is also believed that electrical stimulation would prevent auditory deprivation and hence promote neural survival.

Gibson and Sanli (2007) reported that 75% of their 60 participants with ANSD who were recipients of cochlear implants, performed equally well on measures of speech identification as the implanted control group having sensorineural hearing loss. Successful outcomes have also been reported in adults (De Leenheer, Dhooge, Veuillet, Lina-Granade, & Truy, 2008; Mason, De Michele, Stevens, Ruth, & Hashisaki, 2003; Shallop, 2002). Hence, it appears that cochlear implantation might actually benefit a greater population with ANSD. Jeong, Kim, Kim, Bae, and Kim, (2007); Postelmans and Stokroos, (2006) have recommended cochlear implantation in all individuals with ANSD who get limited benefit from amplification.

Despite these successful research findings, cochlear implantation has not been much popular because majority of individuals in developing countries like India cannot afford the high cost of cochlear implantation. The lesser degree of hearing loss also might preclude cochlear implantation in some individuals. There are also studies which report that children using hearing aids perform similar to implanted peers. Pelosi et al, (2013) conducted a study comparing Infant Toddler Meaningful Auditory Integration Scale (ITMAIS) scores and open set speech perception in children with ANSD using hearing aids and cochlear implant. They concluded that after cochlear implantation, performance of children was similar those who

who were prescribed hearing aids alone with no much additional benefit. Therefore, still hearing aids would be considered the primary management option in individuals with ANSD. However, if hearing aid fails to benefit, cochlear implant is chosen as alternative.

The potential advantage of hearing aids is the audibility, considering the fact that most of these individuals have elevated thresholds. Rance and Barker (2008) on studying amplification benefit in children with ANSD reported that, a small subset of this population is benefitted and probable reason behind being lesser degree of temporal distortion in this subset. Hence, developing new hearing aid algorithms is highly warranted to address the heterogeneity in this group. These new signal enhancing strategies incorporated in hearing aids might enhance retention of the temporal and spectral parameters of speech (Zeng, Oba & Starr, 2001).

Zeng and Liu (2006) conducted a study on 4 individuals with ANSD and found that their speech perception performance in quiet and noise improved significantly for clear speech over conversational speech. They implied this advantage to the enhanced envelope or amplitude modulation in clear speech. Narne and Vanaja (2009, 2008) implemented enhancement of envelope cues in speech and found a speech perception improvement in quiet and noise in individuals with ANSD. However, individuals with very poor unprocessed speech scores showed no benefit from envelope enhancement.

Strategies that manipulate the timing differences in speech have also been found beneficial. Kumar and Jayaram (2010) investigated the perception of CV syllables with lengthened formant transition durations in 30 individuals with ANSD. They found that increased transition durations in turn reduces the modulation frequency and gives significantly better perception than syllables with unmodified transition duration. Hassan (2011) reported that prolongation of consonant duration and pauses between consonant vowel pairs could help individuals with ANSD perceive consonant differences. Tallal et al., (1996) proposed an algorithm for speech processing combining peak enhancement strategy along with prolonging the duration of the speech signal by 50%. Jijo and Yathiraj (2013) studied perception of temporally stretched Vowel-Consonant-Vowel (VCV) syllables processed using Pitch Synchronous Overlap and Add (PSOLA) algorithm in 8 individuals with ANSD. It was found that 25 % of stretching improved the scores significantly and was concluded that consonant perception in individuals with ANSD may be improved by stretching the whole signal by 25 %.

Prabhu, Avilala and Barman (2011) investigated perception of filtered speech in individuals with auditory dys-synchrony and delineated that these individuals primarily depend on high frequency information to understand speech. They found significantly poorer speech identification scores for a 1700 Hz low pass filtered speech with no or very less deterioration seen for 1700 Hz high-pass filtered speech. This high frequency dependability could be ascribed to inability of type I auditory nerve fibres to phase lock low frequency content and/or poor frequency discrimination skills at low frequencies. This information could be utilized in fitting hearing aids for individuals with auditory dys-synchrony. The finding is significant because amplification provided over a wide frequency range could unnecessarily increase the loudness thus reducing the dynamic range. Therefore, selective removal of unused low frequency information during hearing aid fitting should be considered to see its effect on speech perception in individuals with ANSD.

In support of this idea, Manuel and Barman (2012) reported that a group of individuals with ANSD performed better with only high frequency information than when the speech signal had both high and low frequency information. Speech identification scores obtained when only high frequency information was present was comparable to the scores obtained with no stimulus modifications. Combining both low and high frequency information might have led to excessive upward spread of masking i.e. low frequency energy (which is not used in understanding of speech by individuals with auditory dys-synchrony) masking the high frequency energy and thus deteriorating the scores.

The concept of upward spread of masking has been reported in individuals with normal hearing as well as those with cochlear hearing loss (Gagne, 1982; Humes, 1982; Martin & Pickett, 1970). Hence to reduce the effect of upward spread of masking, low frequency gain reduction has been adopted while hearing aid fitting (Fabry, Leek, Walden, & Cord, 1993; Trees & Turner, 1986). In the context of excessive masking effects seen in individuals with ANSD (Zeng, Kong, Michalewski, & Starr, 2005), it would be interesting to know whether frequency specific amplification would result in differential benefit in these individuals. Zeng et al., (2005) hypothesized that by either eliminating low frequencies or transposing acoustic information to high frequency region may improve speech perception in these individuals. Therefore, the current study would look on the speech perception scores in individuals with ANSD who are provided with full band amplification vs. restricted/specific frequency band amplification (i.e. cutting down low frequency gain).

It would also be interesting to know if any improvement noticed with these hearing aid modifications could be evident in cortical evoked potentials also. Earlier literature has shown that cortical auditory evoked potentials (CAEPs) can been reliably recorded in these individuals in spite of absence of auditory brainstem responses (ABRs). The presence of CAEP has been justified with the fact that they are less dependent on synchronous neural firing as auditory brainstem responses (Kraus et al., 2000). The components of CAEP waveform are broad and separated by around 50 to 100 ms, which makes it relatively resistant to subtle neural timing differences (Starr et al, 1996). Rance, Cone-Wesson, Wunderlich, Dowell, (2002) evaluated unaided and aided open set speech identification scores in 18 children with ANSD and tried to correlate it with event related potentials. Out of 15 children who completed the open set task, 50% had no scores while 50% performed comparable to peers having cochlear hearing loss. Approximately, 50% of children who had recordable cortical responses performed well on open set speech identification performance and also benefitted from hearing aid. Whereas, those with absent cortical responses scored poorly on open set speech identification tasks. Therefore, cortical potentials may serve as a good indicator of the relatively preserved neural synchrony for speech perception.

Narne and Vanaja (2008) examined speech identification scores in 10 individuals with ANSD, based on which they were categorized into good and poor performers. Long latency response (LLR) done on those individuals revealed that N1-P2 amplitude in poor performers were significantly lower than good performers. The authors suggested that N1-P2 amplitude can be used as a predictor of perceptual abilities in individuals with ANSD. Vanaja and Manjula (2004) reported that individuals with ANSD exhibiting higher amplitude cortical potentials would receive greater benefit from hearing aid amplification than those with lesser amplitude. In contrast, Chandra and Barman (2010) and Kumar and Jayaram (2005) found no correlation between any parameters of LLR and speech perception abilities in individuals with ANSD. However, Chandra and Barman (2010) did report that the presence of LLR in individuals with ANSD could be an indicator of good speech perception.

Thus, literature opens a wide research scenario for developing newer algorithms and application of such technology in hearing aids to serve individuals with ANSD. These strategies may help improve the perceptual outcomes in at least a few individuals with ANSD broadening the possibilities of management. The growing number of individuals having ANSD also warrants increased attention towards new approaches in management. The heterogeneity exhibited by the disorder makes it difficult to generalize single management option for all. Hence, it is necessary to try out new strategies which could help at least a subgroup of population having ANSD. Thus, the current study was taken up to look at the possible benefits derived by either providing amplification at mid and high frequencies with reduced gain at low frequencies or providing amplification using conventional method (full band amplification) in individuals with ANSD. The study also would investigate possible relationship between LLR and unaided SIS with aided performance.

Objectives of the study:

1. To study the benefit from conventional full band amplification and specific frequency amplification in speech perception compared to unaided performance.
2. To study the difference in benefit between conventional amplification and specific frequency amplification conditions.
3. To understand whether frequency specific amplification would have varying effects on speech perception when implemented through four vs. sixteen channel hearing aids in individuals with ANSD.
4. To examine whether providing specific frequency amplification with different high pass cut off frequencies have any effects on speech perception in individuals with ANSD.
5. To explore if unaided speech perception ability of individuals with ANSD has effect on aided speech perception performance by considering two groups of ANSD – one with good and other with poor unaided speech identification scores.
6. To investigate whether presence or absence of LLR has any relation with the perceptual benefit from amplification using hearing aids.

METHOD

Participants

A total of 22 individuals (37 ears) with ANSD were selected for the study which included 12 males and 10 females between the age ranges of 15 to 42 years (mean age of 23 yrs). They were selected based on the following selection criteria.

Participant selection criteria

- Pure tone average (PTA, average of pure tone thresholds at 500 Hz, 1 kHz, 2 kHz and 4 kHz) from minimal to severe degree of hearing loss.
- Diagnosed as ANSD based on presence of transient evoked oto-acoustic emissions and or cochlear microphonics but absent auditory brainstem responses (Berlin, 2003).
- Diagnosis was confirmed by neurologist.
- Native and fluent speakers of Kannada.
- No history and presence of middle ear pathology.
- A type tympanogram with absent acoustic reflexes.
- No illness prior to evaluation.

The demographic details and audiological findings of all the participants are given in Table 1.

Table 1: Demographic details and audiological findings of the participants

Participants	Ear	Age	Gender	PTA	SIS	Configuration	LLR
S1	LEFT	17	Female	71.2	44%	Flat	Present
S2	RIGHT	32	Female	38.75	0%	Rising	Present
S2	LEFT			38.75	0%	Flat	Present
S3	RIGHT	26	Male	26.6	52%	Rising	Present
S3	LEFT			35	52%	Flat	Absent
S4	RIGHT	19	Female	32.5	70%	Flat (8 kHz slope)	Present
S5	RIGHT	17	Male	30	40%	Rising	Present
S5	LEFT			32.5	16%	Rising	Present
S6	RIGHT	40	Male	32.5	72%	Rising (2 kHz peak)	Present
S6	LEFT			36.2	60%	Rising	Present
S7	RIGHT	30	Male	77.5	32%	Flat	Present
S7	LEFT			52.2	48%	Rising	Present
S8	RIGHT	15	Female	40	24%	Flat (2 kHz peak)	Present
S8	LEFT			36.3	40%	Rising (2 kHz peak)	Present
S9	RIGHT	19	Female	28.3	64%	Flat	Present
S9	LEFT			33.3	60%	Flat	Present
S10	RIGHT	15	Male	38.7	68%	Rising	Absent
S10	LEFT			45	72%	Rising	Absent
S11	RIGHT	42	Male	31.6	44%	Steeply rising	Absent
S11	LEFT			30	40%	Rising	Absent
S12	RIGHT	22	Female	40	12%	Flat	Absent
S12	LEFT			46.25	8%	Flat (2 kHz peak)	Absent
S13	RIGHT	15	Male	52.5	4%	Gradually rising	Absent
S13	LEFT			38	52%	Saucer	Absent
S14	LEFT	22	Female	73.75	78%	Rising	Absent
S15	RIGHT	18	Male	55	60%	Rising	Absent
S15	LEFT			32.5	60%	Rising	Absent
S16	LEFT	17	Male	31.6	45%	Flat	Absent
S17	RIGHT	22	Male	30	60%	Gradually rising	Present
S17	LEFT			32.5	85%	Flat	Present
S18	RIGHT	23	Female	53.75	44%	Steeply rising	Absent
S19	RIGHT	35	Male	31.25	24%	Rising	Absent
S20	RIGHT	18	Male	40	76%	Rising	Absent
S20	LEFT			63.75	60%	Rising	Absent
S21	LEFT	22	Female	40	64%	Flat	Present
S22	RIGHT	18	Female	42.5	56 %	Rising	Absent
S22	LEFT			57.5	44%	Rising	Absent

Equipments used:

The following equipments (calibrated as per standards by manufacturer) were used for the routine audiological evaluation for participant selection.

Pure Tone Audiometer

A two channel diagnostic audiometer OB 922 coupled to impedance matched TDH 39 earphones and a bone vibrator (Radio ear B-71) was used to obtain air conduction and bone conduction pure tone thresholds and speech identification scores.

Immittance meter

An immittance meter Grason Stadler Inc. Tympstar (GSI-TS) was used for Immittance testing. Each ear of the participant was tested for the type of tympanogram and presence or absence of ipsi-lateral and contra-lateral acoustic reflexes.

Oto-acoustic emission Analyser

Otodynamics ILO v.6 OAE analyzer was used to obtain Transient Evoked Oto-acoustic Emissions (TEOAEs).

Auditory Evoked Potentials

Biologic Navigator Pro (Bio-logic, Mundelein, IL) AEP system with ER 3A insert earphones was used to record ABR and LLR.

Equipments used for hearing aid fitting

Hearing Aids

Two behind the ear digital hearing aids which differ in number of channels namely; Una SP (4 channels) and Versata SP (16 channels) from Phonak Hearing Systems were used. Hearing aid specifications are given in Table 2.

PC with software

PC with Windows 7 operating system, loaded with NOAH hearing aid fitting software was used to access the Phonak hearing aid programming module.

Table 2: Details related to specifications of hearing aids used in the study

Characteristics (Ear Simulator)	**4 channel hearing aid**	**16 channel hearing aid**
Frequency Response	100 Hz to 6800 Hz	125 Hz to 8 kHz
Channels (center frequencies)	300, 1 k, 2.5 k, 5.5 kHz	140, 320, 480, 640, 800, 960, 1.1 k, 1.3 k, 1.5 k, 1.8 k, 2.2 k, 2.5 k, 2.9 k, 3.7 k, 5.1 k, 8.2 k Hz.
Maximum gain	75	75
MPO	139	139
Number of Programs	4	5

Stimuli used for Speech Identification Testing

Four lists of phonemically balanced bi-syallabic words in Kannada developed by Yathiraj and Vijayakshmi (2005) were used to assess the unaided and aided speech recognition scores in all participants. Each list contains 25 bi-syllabic words. The order of words in each list was randomized to make two lists. Thus, a total of eight lists were used for the testing.

Test Environment

Testing was carried out in an electrically shielded and sound treated room where noise levels were maintained within the permissible limits as per ANSI S3.1 (1999).

Tests used for the selection of participants

Pure tone Audiometry

Pure tone air conduction (AC) and bone conduction (BC) thresholds were estimated using Modified Hughson and Westlake procedure (Carhart & Jerger, 1959). AC thresholds were obtained for pure tones from 250 Hz to 8 kHz and BC thresholds from 250 Hz to 4 kHz in octave frequencies.

Speech Audiometry

Unaided speech identification scores were obtained for phonemically balanced words with 25 words in each list developed for adults in Kannada by Yathiraj and Vijayalakshmi, (2005). Recorded word lists with 25 words in each list were routed from a PC through a 2 channel diagnostic audiometer (OB-922) to TDH 39 headphones at 40 dB SL (re: SRT).

Tympanometry and Acoustic Reflexes

Tympanogram and acoustic reflexes were obtained for a probe tone frequency of 226 Hz. Acoustic reflexes were measured using 500, 1000, 2000 and 4000 Hz pure tones, presented to both ipsi-lateral and contra-lateral ears.

Transient Evoked Oto-acoustic Emissions

After ensuring probe fit, TEOAEs were measured for non-linear click trains presented at 80 dB pe SPL. Waveform reproducibility of more than 50% (Kemp, 1990), and an overall signal to noise ratio of more than 3 dB SPL (Harrison & Norton, 1999) at least at two frequency bands was required to be considered as presence of TEOAEs.

Auditory Brainstem Responses (ABR)

The clients were seated on a reclining chair. The skin surface on the two mastoids, and forehead were cleaned with skin abrasive. Gold cup electrodes were used to record responses. The electrodes were placed with the help of skin conduction paste and surgical plaster was used to hold the electrodes tightly on the respective places. Absolute electrode impedance was maintained below 5k K with inter electrode impedance below 2k K. Before starting the recording, participants were instructed to relax and refrain from extraneous body movements to minimize artifacts. Single channel recordings were obtained with inverting electrode on the test ear mastoid (M2/M1), non inverting electrode on the high forehead (Fz) and ground electrode on the non test ear mastoid (M1/M2). Click evoked ABR was recorded twice and replicated for 100 µsec click stimuli delivered at a repetition rate of 11.1

clicks/second at 90 dB nHL. The recording was obtained for a total of 1500 sweeps and a filter setting of 100 Hz to 3000 Hz was used.

Procedure used to obtain data

Long Latency Responses (LLR)

Participants were made to sit comfortably on a reclining chair. They were instructed to sit relaxed without much body and eye movements. To keep them awake during testing they were allowed to watch DVD movies played without sound. The stimulus was 500 Hz tone burst with 2 ms rise/ fall time and a plateau of 10 ms gated with a Blackman window. The stimulus was presented at 80 dB nHL with a repetition rate of 1.1 Hz. A total of 200 sweeps were analyzed for a time window of 533 ms having a pre stimulus window of -50ms. Responses were recorded using a gain of 30 K with a low pass filter of 30 Hz and a high pass filter of 1 Hz. During recording, two waveforms were obtained to check for replication. The electrode montage used was same as the one used to record ABR.

Assessment of aided performance

The two non-linear digital behind-the-ear hearing aids which differed in number of amplification channels were used for aided testing. Each of the hearing instruments had the facility to adjust the cut off frequencies for each channel separately. Details of a few important specifications of the hearing aids are provided in Table 2. The procedure was carried out in two phases; Phase I: Hearing Aid Programming and Phase II: Assessment of aided speech recognition performance.

Phase I: Hearing Aid Programming

The pure tone thresholds (from 250 Hz to 8 kHz for air conduction) of the test ear were fed into the NOAH fitting software. The client was fitted with the digital hearing aid on the test ear. The hearing aid was connected to a computer having the programming software through the HI-PRO interface. The hearing aid was programmed by the hearing aid programming module with the 2 cc coupler based NAL-NL1 prescriptive formula.

In the four channel hearing aid, only two programs were stored. Program one (P1) had full band amplification. The second program (P2) had specific band amplification where in low frequency channel having centre frequency of 300 Hz had 15 dB lesser gain compared to the P1. The gain curves obtained for a subject with mild degree of hearing loss for 2 programs are given in Figure 1. Each figure shows frequency gain curve for 3 levels of input mainly, 40, 60 and 80 dB SPL.

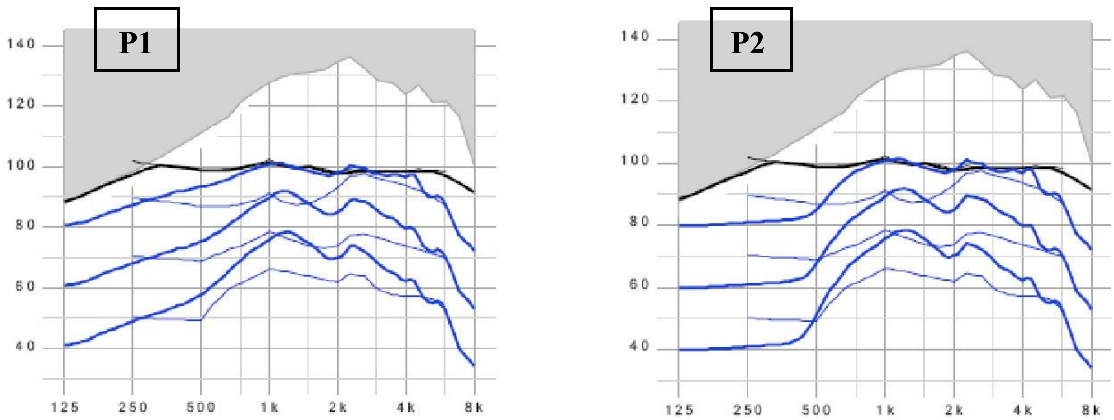

Figure 1: Gain curves for 2 programs, P1 and P2 respectively in a 4 channel hearing aid.

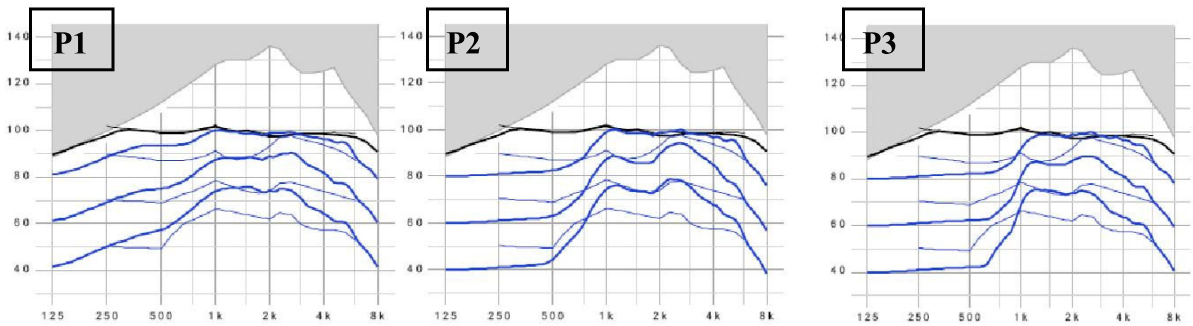

Figure 2: Gain curves for 3 programs P1, P2 and P3 respectively, in a 16 channel hearing aid.

In the sixteen channel hearing aid, three programs were stored. Program 1 was used to store the full band amplification which is similar to the four channel hearing aid. The second and the third program (P2 and P3) had adjusted gain such that a slope of -10 dB/band was maintained below the cut off frequency. The cut off frequencies used for P2 and P3 were 1.1

kHz and 960 Hz respectively. The gain curves for the same participant with mild hearing loss for 3 programs are given in Figure 2.

Phase II: Assessment of aided speech recognition performance

The aided speech identification scores were determined at 40 dB HL for individuals with degree of hearing loss above mild and 30 dB HL for individuals with mild degree of hearing loss. The testing was carried out in a double room setup with participant seated at 1 meter distance from the loudspeaker. The recorded word lists were presented through loudspeaker kept at 0° azimuth with respect to the articipant. Initially unaided speech identification scores were obtained, which was followed by aided testing two hearing aids. In case of unilateral hearing loss, the non test ear was masked with foam ear plug. The hearing aid was then fitted on the participant and the aided testing was conducted for 3 programs in 16 channel hearing aid and 2 programs in 4 channel hearing aid. To avoid ear effect, the order of testing of hearing aids as well as programs P1, P2 and P3 was randomized for each participant. The participants were instructed repeat the stimuli heard and correct responses were scored by counting number of words correctly repeated. Percentage of SI scores was calculated using the following formula:

Number of words correctly identified *
100 Total number of words presented

Data Analysis

The speech identification scores were tabulated and were subjected to appropriate statistical analyses. The SIS obtained in unaided and each of the aided conditions were then compared. Analysis was also done to see if there was any relation with presence or absence of LLR.

RESULTS AND DISCUSSION

The current study aimed to find out whether frequency specific amplification in hearing aids would have any effect on aided speech identification scores (SIS) in individuals with auditory neuropathy spectrum disorder (ANSD). Aided SIS were obtained with a four channel and a sixteen channel hearing aid. Each hearing aid accommodated separate programs for providing both frequency specific amplification as well as full band amplification. Full band amplification provided adequate gain at low, mid as well as high frequencies, whereas, frequency specific amplification provided less than adequate gain at low frequencies and appropriate gain at mid and high frequencies. LLR was also recorded to see if any relation exists with perceptual abilities in frequency specific amplification and presence or absence of LLR. The data from 22 subjects (37 ears) were analyzed using Statistical Package for Social Sciences (SPSS) software version 16. Details of the analyses carried out are given below.

1. Descriptive statistics (Mean & standard deviation for SIS across unaided and aided conditions and mean & standard deviation for aided benefit across aided conditions).
2. Repeated Measure ANOVA was done to compare the unaided and aided speech perception abilities across unaided and aided conditions.
3. Bonferroni's multiple comparisons were done to test pair wise differences, as repeated measure ANOVA result showed significant difference across conditions.
4. MANOVA was done to see if any significant difference in aided speech perception abilities exists between groups (poor listeners versus good listeners and LLR present versus LLR absent).

The results obtained are discussed under the following headings:

1. Mean and standard deviation for SI scores across conditions.

2. Comparison between aided and unaided SIS in individuals with ANSD.
3. Comparison between full band amplification and frequency specific amplification conditions on speech identification performance.
4. Effect of providing frequency specific amplification with different high pass cut off frequencies in the sixteen channel hearing aid on SIS.
5. Effect of number of channels in a hearing aid on SIS in individuals with ANSD.
6. Relationship between unaided SIS obtained at 40 dB SL and aided SIS (studied by comparing two groups of ANSD, where in groups where formed based on unaided SIS obtained at 40 dB SL).
7. Association between LLR and SIS in individuals with ANSD.

1. Mean and standard deviation for SIS across conditions.

Speech identification scores were obtained from 37 ears in both unaided and aided conditions. Aided conditions included, SIS obtained when the four channel hearing aid was programmed for full band amplification as well as frequency specific amplification and sixteen channel hearing aid was programmed for full band amplification as well as frequency specific amplification with 1.1 kHz and 960 Hz cut off frequencies. Mean and standard deviation for unaided and aided speech identification scores were computed, tabulated and is provided in Table 3.

Table 3 shows that unaided SIS obtained at 30 or 40 dB HL (Presentation level was 30 dB for individuals with hearing loss lesser than or equal to mild degree and 40 dB HL for loss greater than mild degree) is poor (mean SIS < 40%), with large variation in performance as indicated by high standard deviation in individuals with ANSD. Further, on analyzing the mean SIS across unaided and aided conditions, it can be observed that there is a slight improvement in the scores on providing amplification i.e. aided benefit of about 10 to 15% across five aided conditions (Note: *Aided benefit = Aided SIS - unaided SIS*).

Table 3: Mean and standard deviation of unaided and aided SIS

Conditions	**SIS(%)**	
	Mean	**SD**
Unaided	38.48	30.95
Full band amplification in 4 channel hearing aid *(4 channel FB)*	48.54	22.99
Frequency specific amplification in 4 channel hearing aid *(4 channel SF)*	53.73	24.78
Full band amplification in 16 channel hearing aid *(16 channel FB)*	49.84	25.97
Frequency specific amplification having 1.1 kHz cut off frequency in 16 channel hearing aid *(16 channel SF 1.1 kHz)*	52.22	24.38
Frequency specific amplification having 960 Hz cut off frequency in 16 channel hearing aid *(16 channel SF 960 Hz*)	50.70	25.83

2. **Comparison between unaided and aided speech identification scores.**

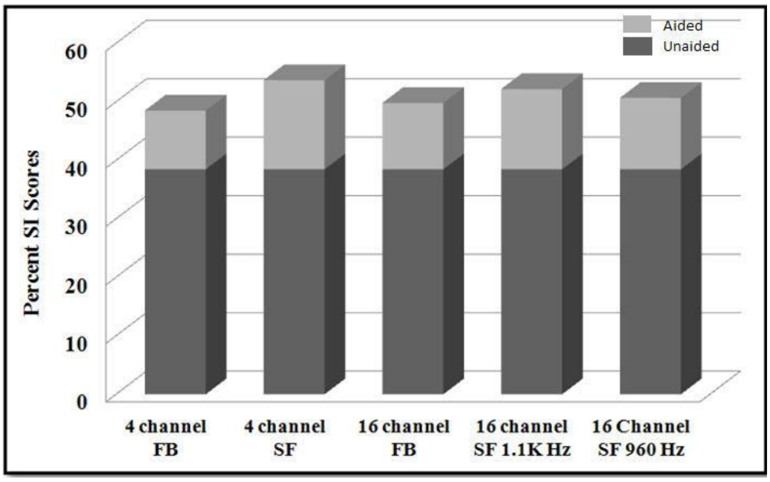

Figure 3: Aided benefit across different amplification conditions.

The mean data showed improved aided SIS compared to unaided in all the five aided conditions for both the hearing aids. Figure 3 depicts aided benefit across different amplification conditions over mean unaided SIS. To see if this improved scores was significant or not, repeated measure ANOVA (6 conditions) was done. The results showed a significant effect of testing conditions on SIS [F (5, 180) = 7.025, p<0.01]. Bonferroni's pair wise comparisons were also done to see which of the two conditions differed significantly from each other. The results of pair wise comparison can be seen in Table 4.

Table 4: Results of Bonferroni's pair wise comparisons

	4 channel FB	**4 channel SF**	**16 channel FB**	**16 channel SF 1.1 kHz**	**16 channel SF 960 Hz**
Unaided	0.401	**0.017***	0.253	**0.047***	0.122
4 channel FB		**0.026***	1.000	0.550	1.000
4 channel SF			0.881	1.000	1.000
16 channel FB				1.000	1.000
16 channel SF 1.1 kHz					1.000

*Statistically significant (p<0.05)

It can be seen in the Table 4 that the unaided SIS were not significantly different from aided SIS obtained with full band amplification. However, SIS obtained for frequency specific amplification for 4 channel and 16 channel hearing aid having 1.1 kHz cut off frequency were significantly higher than unaided scores. Literature on benefit from hearing aids in individuals with ANSD has shown mixed results. One group of studies have shown that hearing aids are beneficial (Madden , Rutter, Hilbert, Greinwald & Choo, 2002; Deltenre et al., 1999; Rance et al., 1999), while other set of studies have observed that hearing aids are not a good management option as benefit is questionable (Berlin et al., 2003; Friesen & Cunningham., 2003; Raveh et al., 2006). It has to be noted that in all these studies, conventional amplification was used.

On comparing these results to the earlier reports, it can be commented that, this study supports the concept that conventional amplification in individuals with ANSD is a bad option and modified amplification techniques (like frequency specific amplification used in this study) might prove to be a better choice. Probable reasons behind why frequency specific amplification was better than full band and why only 1.1 kHz cut off frequency resulted in significantly better performance compared to unaided speech identification will be discussed in later sections.

3. Comparison between full band and frequency specific amplification on speech identification in individuals with ANSD.

It can be seen in the Table 1 that, the mean SIS obtained in frequency specific amplification was better than full band amplification. This was observed for both 4 channel and 16 channel hearing aids. Pair wise comparison of SIS obtained between these two conditions (Table 4) showed that frequency specific amplification was significantly better compared to full band amplification only for 4 channel but not for 16 channel hearing aid.

This finding is important since the effect of low frequency reduction in amplification or not providing any amplification is found to be significantly benefiting these individuals (in 4 channel hearing aid). The characteristic feature of ANSD is the impaired ability of type I auditory nerve fibres to phase lock to the low frequency information (Zeng & Liu, 2006). Providing low frequency amplification in these individuals might not help in improvement in speech perception and in fact might lead to deterioration in speech identification performance as amplified low frequency speech can mask intact high frequency information. Thus, restricting access to low frequencies as in frequency specific amplification might actually be preventing unwanted upward spread of masking which might have affected preserved high frequency information.

It was found that only in 4 channel hearing aid, specific frequency amplification was beneficial but not in 16 channel hearing aid. Such a finding might have been obtained because in four channel hearing aid, gain was reduced in only 300 Hz channel and adequate gain was provided from next channel (1 kHz onwards) but in the sixteen channel hearing aid gain was reduced at more number of frequencies. This could have possibly resulted in increased distortion of the input signal. Also studies in individuals with cochlear hearing loss (Bor, Souza & Wright, 2008) have shown that increase in number of channels in a hearing aid does not improve the speech identification, though proven useful for other features like feedback reduction. Increase in number of channels is assumed to reduce the spectral contrast (Plomp, 1988) which might have aggravated the inherent spectral discrimination difficulties in these individuals with ANSD. Hence, prescription of multichannel hearing aids over single or fewer channel hearing aids in individuals with ANSD may not be indicated.

Table 5: Mean and SD of frequency specific aided benefit across conditions

Condition	**Frequency specific aided benefit (SIS)**	
	Mean (%)	**Standard deviation**
4 channel SF – 4 channel FB	5.19	9.33
16 channel 1.1 kHz SF – 16 channel FB	2.38	10.81
16 channel 960 Hz SF – 16 channel FB	0.86	8.6

Further, frequency specific aided benefit was also calculated. Frequency specific aided benefit was obtained by subtracting SIS obtained in full band amplification conditions from frequency specific amplification conditions. The results are shown in Table 5.It can be seen in the above table that the frequency specific aided benefit was maximum for 4 channel hearing aid and least for 16 channel hearing aid having 960 Hz cut off frequency. To know whether these three conditions had any significant effect on frequency specific benefit, Repeated Measure ANOVA was done. The results did not show any significant effect of condition [$F (2, 72) = 2.4$, $p > 0.05$]. This implies that, though frequency specific amplification was proved to be beneficial in 4 channel hearing aid when compared to full band amplification condition, obtained results are questionable as the difference in frequency specific aided benefit is not significant. It is difficult to come to a clear conclusion in this regard due to higher standard deviation and unavailability of literature reports regarding this issue.

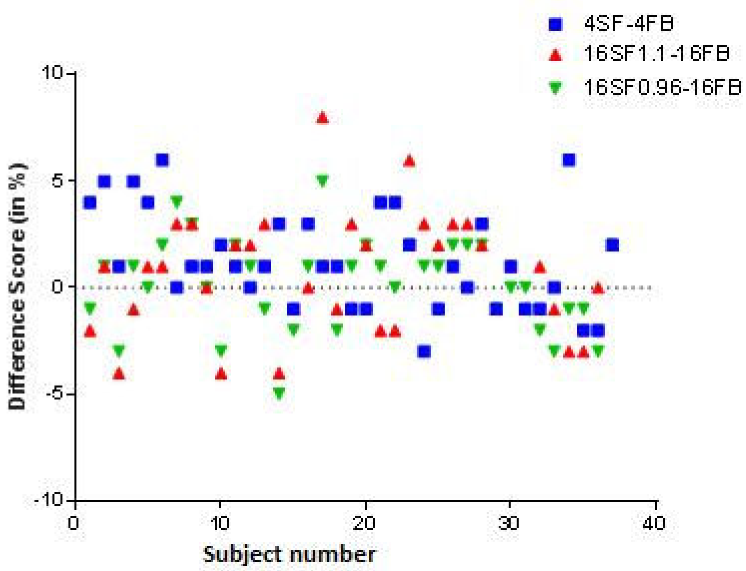

Figure 4: Difference in speech identification scores between full band amplification and frequency specific amplification.

The distribution of frequency specific aided benefit across the participants can be seen in Figure 4. It should be noted that, no specific pattern can be observed in the figure which also suggest high variability of the data.

4. Effect of providing frequency specific amplification with different high pass cut off frequencies in a sixteen channel hearing aid on SIS.

In sixteen channel hearing aid, the mean specific frequency aided benefit was greater for 1.1 kHz compared to 960 Hz cut off frequency (Table 5). Bonferroni's comparison to check if these two cut off frequency had any effect on frequency specific amplification benefit showed that the difference was statistically insignificant. However, a probable reason behind the difference in mean data could be accounted to the finding by Prabhu, Avilala and Barman (2011). They reported that information above 1200 Hz is primarily important for speech understanding in Kannada language which is efficiently preserved when using both cut off frequencies. But with 1.1 kHz cut off, more low frequency reduction occurs. This could be probably lead to more reduction in upward spread of masking effect and resulting in slight improvement in SIS for only 1.1 kHz cut off frequency.

5. Effect of number of channels in a hearing aid on SIS in individuals with ANSD.

It can be seen from Bonferroni's pair wise comparison test results (Table 4) that the number of channels has no significant effect on aided SIS. This is the same for full band as well as frequency specific amplification. It can be observed from mean data (Table 3) that, there is no considerable improvement in SIS for 16 channel full band and frequency specific amplification conditions compared to respective amplification conditions with 4 channel hearing aid. High standard deviation could be one of the probable reasons behind not getting significant difference. Also, as discussed earlier, more number of channels in 16 channel hearing aid, could have lead to some distortion and thus not resulting in any improvement (Starr et al., 2001; Plomp, 1998).

6. **Relationship between SIS obtained at 40 dB SL and aided SIS.**

To see the relationship between SIS at 40 dB SL and aided SIS, entire data was divided into two data sets based on SIS obtained at 40 dB SL. Participants who obtained less than 50% SIS at 40 dB SL were put into group 1 and above 50% were put into group 2. Participants in group 1 were considered as poor listeners and participants in group 2 as good listeners. Aided benefits were calculated for all the individuals by subtracting unaided SIS from aided SIS for full band and frequency specific amplification. Mean and standard deviation of aided benefit for five different conditions are given in Table 6.

Table 6: Mean and SD of aided benefit obtained across different conditions by group 1 and 2

Condition	Group	Mean(%)	SD
4 Channel FB	1 (Poor listeners)	16.00	27.58
	2 (Good listeners)	4.42	24.8
4 Channel SF	1 (Poor listeners)	19.33	26.33
	2 (Good listeners)	11.37	26.07
16 Channel FB	1 (Poor listeners)	16.22	27.97
	2 (Good listeners)	6.74	27.07
16 Channel SF 1.1 kHz	1 (Poor listeners)	20.00	24.00
	2 (Good listeners)	7.79	27.79
16 Channel SF 960 Hz	1 (Poor listeners)	17.11	24.73
	2 (Good listeners)	7.58	27.96

It can be seen in the above table that the aided benefit obtained by poor listeners was more than that obtained by good listeners in all five aided conditions. However, it should also be noted that variability is very high for both the groups.

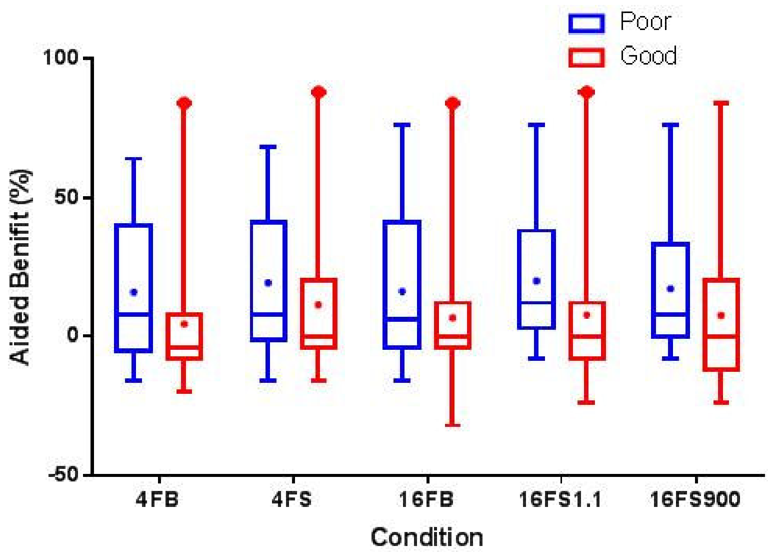

Figure 5: Mean, median and 95 percent confidence interval aided benefit obtained by group 1 and group 2.

MANOVA was carried out to see if the aided benefit obtained across conditions differ significantly between groups. The results (Table 7) did not show any significant difference.

Table 7: F and p values of MANOVA results for difference between group 1 and 2 across conditions

Aided Condition	**F value and significance level**
4 channel FB	$F(1, 35) = 1.81, p>0.05$
4 channel SF	$F(1, 35) = 0.86, p>0.05$
16 channel FB	$F(1, 35) = 1.10, p>0.05$
16 channel SF with 1.1 kHz	$F(1, 35) = 2.04, p>0.05$
16 channel SF with 960 Hz	$F(1, 35) = 1.20, p>0.05$

As the aided benefit did not show any significant difference between the groups, frequency specific aided benefit was calculated. It was calculated by subtracting SIS obtained in full band condition from SIS obtained in frequency specific amplification condition. Mean and standard deviation was calculated and tabulated in Table 8).

Table 8: Mean and SD of frequency specific aided benefit between conditions for group 1 and group 2

Condition		**Frequency specific aided benefit (SIS)**	
	Group	**Mean(%)**	**Standard deviation**
4 channel SF – 4 channel FB	1 (Poor listeners)	3.33	9.33
	2 (Good listeners)	6.95	9.22
16 channel 1.1 kHz SF – 16 channel FB	1 (Poor listeners)	3.78	9.15
	2 (Good listeners)	1.05	12.28
16 channel 960 Hz SF – 16 channel FB	1 (Poor listeners)	0.89	8.95
	2 (Good listeners)	0.84	8.49

To see significant difference between mean frequency specific aided benefit obtained between groups, MANOVA was done. The results did not show any significant difference for

4 channel hearing aid [$F(1, 35) = 1.40$, $p>0.05$], for 16 channel hearing aid having 1.1 kHz cut off frequency [$F(1, 35) = 0.58$, $p> 0.05$] and also for cut off frequency of 960 Hz [$F(1, 35) = 0.00$, $p> 0.05$]. However, mean data (Table 6) showed better aided benefit in poor listeners than good listeners. This could be possibly because at least one third of the poor listeners (7 out of 18) had moderate or more than moderate degree of hearing loss resulting in unaided SIS to be zero or almost zero, thus leading to significantly improved aided scores. In contrast, good listeners having scores 50% and above had less chances of improvement.

7. Association between LLR and aided SIS in individuals with ANSD.

To investigate the association between LLR and SIS in aided and unaided conditions, the whole data was divided into two groups – I and II. Group I and II consisted of individuals having LLR present and absent respectively. Descriptive statistics were carried out to find mean and standard deviation of SIS obtained in all the conditions and are given in Table 9.

Table 9: Mean and SD of SIS obtained in different conditions by group I and group II

Condition	Group	Mean(%)	SD
4 Channel FB	I (LLR present)	52.44	23.4
	II (LLR absent)	44.84	22.98
4 Channel SF	I (LLR present)	60.89	22.69
	II (LLR absent)	46.95	25.33
16 Channel FB	I (LLR present)	57.33	25.89
	II (LLR absent)	42.74	24.62
16 Channel SF 1.1 kHz	I (LLR present)	58.89	27.05
	II (LLR absent)	45.89	20.28
16 Channel SF 960 Hz	I (LLR present)	58.00	26.68
	II (LLR absent)	43.79	23.64
SIS obtained at 40 dB SL	I (LLR present)	46.17	24.18
	II (LLR absent)	47.32	21.99

It can also be observed in the above table that the mean aided SIS obtained by group I was more than that obtained by group 2 for all the aided conditions. However, mean SIS obtained at 40 dB SL was almost same for both the groups. It can be noticed that the variability in SIS scores for all six conditions are very high.

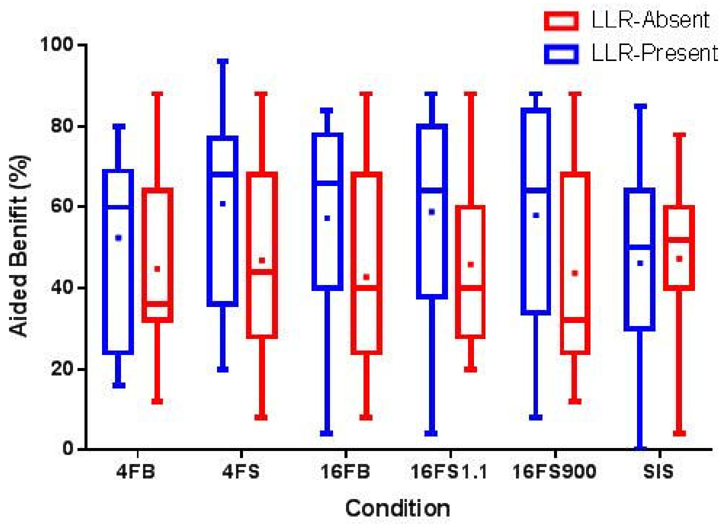

Figure 6: Mean, median and 95 percent confidence interval aided benefit obtained by Group I (LLR present) and Group II (LLR absent).

To see whether the mean SIS scores obtained in all six conditions obtained for both groups differ significantly of not, MANOVA was used. The results did not show any significant difference between the groups. The results can be seen in Table 10.

Table 10: F and p values of MANOVA results between groups I and II across different conditions

Aided Condition	F (1, 35)	p-value
4 Channel FB	1.01	0.087
4 Channel SF	3.1	0.088
16 Channel FB	3.09	0.106
16 Channel SF 1.1 kHz	2.75	0.095
16 Channel SF 960 Hz	2.95	0.881
SIS obtained at 40 dB SL	0.23	0.087

Like previous reports which show evidence that LLR might be a predictive tool for good speech identification ability, (Narne & Vanaja, 2008; Vanaja & Manjula, 2004; Rance et al., 2002), the current study also showed that the group having LLR present had 8 to 15% better aided scores than those who had absent LLR. However, the current study, a statistically significant difference in aided SIS could not be obtained. This finding was in contrast to results obtained by Narne and Vanaja (2008) and Vanaja and Manjula (2004). In most of the earlier studies sample size chosen was very small in contrast to this study where 22 individuals (37 ears) have been recruited. In the study by Narne and Vanaja, (2008), only 10 individuals were considered with 5 individuals forming good and poor listener group. Thus, such a difference in sample size may preclude making any conclusions regarding this finding. Results of the current study are in close agreement with the results obtained by Chandra and Barman (2009) and Kumar and Jayaram (2005). A better picture may be obtained if the duration and causation of the disorder are also taken into consideration, to compare its effect on amplification benefit.

CONCLUSION

It can be concluded that specific frequency amplification can be used as an efficient alternative technique in contrast to conventional amplification during hearing aid fitting for individuals with ANSD. Also, this study results recommend the cut off frequency around 1000 Hz during specific frequency amplification in order to obtain better benefits. Individuals with LLR present could show better aided performance but may fail to show statistically significant difference. However, the results of the study are limited to results obtained by fitting the gain curve with the coupler based NAL-NL1prescriptive formula. Further research needs to be taken up before making a conclusive statement regarding this issue.

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