Effect of Hearing aid Processed Speech on Perception in Individuals with Auditory Neuropathy Spectrum Disorder (ANSD)

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MAY, 2014.

Dedicated To

My Family & My Guide

CERTIFICATE

This is to certify that this dissertation entitled "**Effect of Hearing aid Processed Speech on Perception in Individuals with Auditory Neuropathy Spectrum Disorder (ANSD)**" is a bonafide work submitted in part fulfillment for the Degree of Master of Science (Audiology) of the student (Registration No.: 12AUD026). This has been carried out under the guidance of a faculty of this institute and has not been submitted earlier to any of the University for the award of any other Diploma or Degree.

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This is to certify that this dissertation entitled "**Effect of Hearing aid Processed Speech on Perception in Individuals with Auditory Neuropathy Spectrum Disorder (ANSD)**" has been prepared under my supervision and guidance. It is also certified that this has not been submitted earlier in other University for the award of any Diploma or Degree.

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DECLARATION

This is to certify that this dissertation entitled "**Effect of Hearing aid Processed Speech on Perception in Individuals with Auditory Neuropathy Spectrum Disorder (ANSD)**" is the result of my own study under the guidance of Mr. Jijo. P, Lecturer in Audiology, Department of Audiology, All India Institute of Speech and Hearing, Mysore, and has not been submitted earlier in other University for the award of any Diploma or Degree.

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CHAPTER 1- INTRODUCTION

Auditory Neuropathy Spectrum Disorder (ANSD) is a hearing disorder characterized by intact functioning of cochlear outer hair cells and disorganized auditory nerve firings (Starr, Picton, Sininger, Hood, & Berlin, 1996). The possible lesion sites reported are inner hair cells, junction between inner hair cells and type 1 afferent auditory neurons or afferent auditory nerve itself (Starr et al, 1996; Rance et al., 1999; Ammatuzzi et al., 2001). People with ANSD can have hearing thresholds ranging from normal to profound degree (Rance et al., 1999; Kraus et al., 2000; Sininger & Oba, 2001). They exhibit difficulty in understanding speech that is often disproportionate to their degree of hearing loss (Starr et al., 1996; Rance et al., 1999; Sininger & Oba, 2001).

Prevalence studies on ANSD have proven that it is not a rare disorder (Sininger & Oba, 2001; Rance et al., 1999). In India, late onset ANSD is commonly observed than that of congenital ANSD (Kumar & Jayaram, 2006; Jijo & Yathiraj, 2012). Additionally, a large number of individuals with late onset ANSD belong to poor socioeconomic status (Prabhu, Avilala, & Manjula, 2012). Increased prevalence and low economic status of the late onset ANSD group advocates the need for cost effective rehabilitative options.

Several approaches have been reported to improve speech perception in individuals with ANSD. Cochlear implants, hearing aids and clear speech are a few of the rehabilitative options (Zeng & Liu, 2006; Breneman, Gifford, Dejong, 2012; Narne & Vanaja, 2008). Though, cochlear implants have been found to be the most successful option, their cost, invasive nature and failure in a few subjects (Shallop, Peterson, Facer, Fabry,& Driscoll, 2001; Trautwein, Sininger, & Nelson, 2000;

Mason, De Michele, Stevens, Ruth, & Hashisaki, 2003; Peterson et al., 2003) highlights the need for other rehabilitative options.

Successful use of hearing aids has been reported in individuals with ANSD, especially in children (Rance et al., 1999; Berlin et al., 2010; Rance & Barker, 2009). However, among those with late onset ANSD, use of amplification is often limited or even detrimental (Starr et al., 1996; Shallop, 2002; Sininger, Hood, Picton, Berlin, & Starr, 1995). Several possible reasons have been attributed to the unsuccessful use of hearing aids in those with late onset ANSD. Berlin et al. (1996) opined that hearing aids are designed to amplify the signals not to compensate the distorted temporal envelope processing in ANSD. Hood (1998) argued that compression circuits in hearing aids might distorts the temporal envelope and hence deteriorate speech perception in individuals with late onset ANSD. In this context, it may be possible that hearing aids that preserve the temporal envelope of speech will possibly improve speech perception in individuals with ANSD.

Till date, there is only one study that manipulated the compression parameters of a hearing aid to improve speech perception in individuals with ANSD (Spirakis, 2011). It was found that hearing aid with a long attack/release time (5000/5000ms) lead to 64% speech identification score whereas, the aided performance deteriorated to 32% when a fast attack/ release time (20/2000ms) was used. However, this has been observed on a single child with ANSD. Hence, there is a need to study the effect of such compression settings on a larger group of individuals with late onset ANSD.

There are a few reports on aided speech perception improvement in individuals with late onset ANSD (Vanaja & Manjula, 2002; Zeng & Liu, 2006; Jijo & Yathiraj, 2013). Vanaja and Manjula (2002) reported that among the five clients with ANSD one had 40%, aided improvement, other two had 20% and the remaining clients had no improvement. Though, the hearing aid benefit was inadequate, they correlated the aided improvement with the presence of cortical evoked potentials that might have compensated for the brainstem dys-synchrony. In a recent retrospective study, Jijo and Yathiraj (2013) observed that those with better SIS had higher (though insufficient) aided improvement than those who had poor SIS. Though insufficient, the improvement in speech perception using hearing aids, justify the need for further research using amplification.

Need for the study

Prevalence studies on ANSD in India have proven that late onset ANSD is the predominant group compared to the pediatric population (Kumar & Jayaram, 2006; Jijo & Yathiraj, 2012). Additionally, a large number of individuals with late onset ANSD belong to poor socioeconomic status (Prabhu et al., 2012). Increased prevalence and low economic status of the late onset ANSD group advocates the need for cost effective rehabilitative options.

Need for studying the effect compression parameters. It is well known that individuals with ANSD have poor temporal resolution (Zeng, Kong, Michalewski, & Starr, 2005). This distorts the temporal envelope of speech signal and results in reduced speech perception (Zeng, Oba, Garde, Sininger, & Starr, 1999). Enhancement of temporal envelope has been found to improve speech perception in individuals with late onset ANSD (none & Vanaja, 2008; Zeng et al., 1999). However, real time implementation of such strategies is not yet explored. Studies have proven that hearing aids with a long release time might preserve the temporal envelope of the speech signal (Van tassel, 1993). Hence, the effect of such a hearing aid processing in speech perception, need to be investigated in ANSD. If there is any improvement in perception this will be a practical option to help those with ANSD.

Studies have shown that with linear circuitry hearing aids preserve the temporal envelope of speech similar to one having long release time (Van tassel, 1993). Hence, speech perception performance using linear and long release time setting might be comparable. However, this has not been evaluated experimentally. In this context, Spirakis (2011) suggested to compare the speech perception using linear and non-linear hearing aids. Any difference between them might help to choose the amplification circuitry that may be more beneficial for ANSD.

Aim of the study:

The present study aims to find out the effect of hearing aid processed speech on perception in individuals with late onset ANSD.

Objective of the study:

- To compare the perception of speech processed using four different hearing aid settings in individuals with late onset ANSD.
- Evaluate the effect hearing aid processing on the temporal envelope of speech.

CHAPTER 2-REVIEW OF LITERATURE

Auditory Neuropathy Spectrum Disorder (ANSD) is a form of sensorineural hearing disorder characterized by normal cochlear amplifier function and disordered auditory nerve firings (Starr, Picton, Sininger, Hood, & Berlin., 1996). Commonly reported age of onset of the condition were; either in infancy or early adulthood. Kumar and Jayaram (2006) reported a mean age of onset of 16 years. They found that 59% of the 61 individuals were in the age range of 14 to 24 years. In contrast, Sininger and Oba (2005) reported that among 59 clients, 75% were younger than 10 years.

Each individual with ANSD show unique audiological features. The majority of the ANSD subjects exhibited bilateral symmetrical hearing loss (82%). Asymmetrical (14%) and unilateral hearing loss (4%) were found in a few (Sininger & Oba, 2001). Their hearing thresholds ranged from normal to profound degree (Kumar & Jayaram, 2006; Jijo & Yathiraj, 2012). Audiometric configurations found were flat (41%), rising (29%), sloping (11%), zig- zag pattern (9%) as reported by Starr, Sininger and Pratt (2000). Kumar and Jayaram (2006) reported that among the 61 ANSD subjects, 26 had peaked audiogram, 11 participants exhibited a rising pattern, 11 had a flat audiometric pattern and 5 subjects exhibited the sloping kind of audiometric pattern. Speech perception ability of ANSD varied from 0% to 100% scores (Kumar & Jayaram, 2006; Berlin et al., 2010; Kraus et al., 2000; Jijo & Yathiraj, 2012). Almost 50% of the test population showed no measurable speech perception abilities.

Individuals with ANSD exhibit severe temporal resolution problems (Kumar & Jayaram, 2005; Rance et al., 2004; Zeng et al., 1999; Narne & Vanaja, 2008). The temporal resolution ability was evaluated using Temporal Modulation Transfer

Function (TMTF). In this measurement, the minimum modulation depth that can be identified was obtained across modulation frequencies (Veimester, 1979). The results of TMTF in ANSD showed modulation detection threshold that was significantly higher than normal hearing subjects (Kumar & Jayaram, 2005; Rance, Mckay, & Grayden, 2004). These studies have proven that impairment in temporal resolution is the cause behind impaired speech perception in ANSD.

The available rehabilitative options for ANSD include conventional hearing aids, cochlear implant system and FM systems (Zeng & Liu, 2006; Breneman, Gifford, Dejong, 2012). As a rehabilitative option hearing aids are successful only in a limited group (Vanaja & Manjula, 2002). In the current scenario the cochlear implant become a good option for these subjects (Shallop, Peterson, Facer, Fabry, & Driscoll, 2001; Trautwein, Sininger, & Nelson, 2000; Mason, De Michele, Stevens, Ruth, & Hashisaki, 2003). However, its cost and invasive nature urges the need for other alternates.

Amplification in ANSD

Use of hearing aids as a rehabilitative option for ANSD is a controversial issue. The major argument against amplification is potential damage to outer hair cells that are found to be normal in ANSD. Further, conventional amplification may simply produce louder, but distorted signals that may not compensate the temporal processing deficits in ANSD (Berlin et al., 1996). Hence, many researchers recommended proceeding cautiously with amplification for ANSD (Hood, 1998). However, recent investigations by Rance and colleagues showed significant improvement in aided speech perception, especially in children. In contrast, among late onset ANSD outcome of amplification is generally poor (Berlin et al., 1996; Widen et al., 1995;

Sininger et al., 1995) except a few studies (Zeng & Liu, 2006; Jijo & Yathiraj, 2013; Vanaja & Manjula, 2002).

Rance et al. (1999) investigated aided performance in 15 children with ANSD. They found that 8/15 children showed improvement in aid speech perception compared to the unaided condition, whereas others showed no usefulness from the hearing aid. There was no significant difference in unaided threshold between those who improved and not improved using hearing aids. However, those who showed aided improvement had significantly better aided threshold than their unaided thresholds. In contrast, those who did not improve using hearing aids showed no significant difference between unaided and aided thresholds. Hence, the authors suggested that behavioral hearing level in children with ANSD is not a measure to predict the benefit of amplification. They also recommend that hearing aid trial to be carried in those with ANSD having abnormal hearing thresholds.

Rance et al. (2007a) compared receptive language and speech production abilities of children with ANSD with age and degree matched sensory-neural hearing loss. 12 children with ANSD, who were regular hearing aid users, aged between 57 and 167 months participated in the study. Receptive and production languages were tested with Peabody Picture Vocabulary Test and Diagnostic Evaluation of Articulation and Phonology. Compared to normal hearing children receptive vocabulary and speech production skills in the ANSD group was delayed. However, there was no significant difference between ANSD and sensory neural hearing loss groups. The study concluded that even though the ANSD group has a risk of developing spoken language, some of them might get benefits from the conventional amplification and develop spoken language.

Rance and Barker (2009) studied the speech and language outcomes of children with ANSD they were managed either using cochlear implant or hearing aid. The participants consisted of 3 groups. First group consisted of 10 children with ANSD who were cochlear implant recipients. The second group had 10 implant users with sensory neural hearing loss. The third group involved 10 subjects with ANSD using conventional amplification. All three groups of children underwent language reception (Peabody Picture Vocabulary Tests III A) and production (Diagnostic Evaluation of Articulation and Phonology) assessment. Though receptive vocabulary was delayed in all the subjects, it was not significantly different across the three groups. Similar results were found in the speech production skills. Implanted children with ANSD perform similar to their SN counterparts. All the clients using hearing aids were good performers, because those who were not benefitted using amplification were already implanted. The authors concluded that cochlear implants should not be considered in all the clients with ANSD as a few of them were benefitted using hearing aids.

Rance et al. (2007b) compared the effect of background noise on speech perception in children with ANSD and SNHL. Open and closed set scores were obtained from both the groups. In the closed set task signal to noise ratio required to obtain 79.4% score was calculated. In the open set task, CNC was presented in quiet (20 dB SNR) and in noise (0, 5, 10 dB SNR). Results from different groups in the closed set perception revealed that ANSD needed SNR of -2.5 dB to reach the criterion score of 79.4% correct recognition score which was higher than SNHL and normal hearing group. Open set SIS in ANSD when compared with SNHL norms for equivalent thresholds (Yellin, Jerger, Fifer, 1989) revealed that only two clients had low scores. This is because many poor performers in ANSD group were already implanted. Additionally, all the clients were fitted with hearing aids by 10 months of age and had auditory experience of 4 years. The aided improvement in the above studies was attributed to amplification in the critical period of language development. Moreover, Rance and colleagues reported that many of their subjects who performed poorly using hearing aids were already implanted.

There are only very limited studies that evaluated the aided performance in the late onset ANSD groups. Jijo and Yathiraj (2013) studied audiological findings and aided performance in 64 individuals with late onset ANSD. Aided SIS were obtained either using digital BTE or analog body level hearing aids. It was found that amplification improved SIS in 39 of the 104 ears. The aided performance ranged from 4% to 52% with a mean of 19.1% ±14.0%.

Based on aided score participants were divided into 2 groups; group I with higher SIS (improvement is better than -1SD of mean score) and poorer SIS (improvement is less than -1 SD of mean score). In the higher SIS group 16 used digital BTE hearing aids and15 ears used body level hearing aids. But in poorer group, 75.3% were body level users and 24.7% were digital BTE users. Aided performance in the group 1 using digital BTE was 29% (±13.6%) but it was only 16.5% (±9.3%) in the body level users. The difference between hearing aid style was statistically significant.

Relation between audiological findings and aided improvement was studied. The relation between pure-tone average and aided SIS showed mixed results, some clients who had less than 60dB hearing loss showed improvement whereas some clients didn't. However, none of the subjects with severe to profound hearing loss showed improvement in the aided response. The relation between SIS score (PB Max) under headphones and aided improvement showed a positive correlation. Those who got greater than 40% SIS score under headphones showed better aided performance, which ranges from 24% to 52%. Subjects who had poorer SISunder headphones (10% to 40%) showed poor aided performance. The study concluded that the hearing aid might be useful for a few individuals with late onset ANSDs especially for those having lesser degrees of hearing loss and higher SIS.

Vanaja and Manjula (2002) investigated the relation between aided improvement and cortical evoked potentials in late onset ANSD. Five subjects with ANSD in the age range of 16 to 35 years participated in the study. Using insertion gain measurements the hearing aid that best matched with the NAL-R prescriptive target was fitted. Unaided and aided SIS were obtained using a Kannada word list. The results of the study revealed that hearing aid lead to 40% improvement in SIS in one subject, 2 subjects showed only 20% of improvement. Remaining 2 subjects didn’t show any improvement with conventional amplification system. The Long latency response was present in 3 subjects in whom aided improvement was found. In contrast, the 2 subjects who had no aided improvement didn’t have long latency response. The authors attributed that presence of LLR indicate preserved neural synchrony at the cortical level, though the brainstem synchrony is impaired. In contrast, the absence of both LLR and ABR indicate severe dys-synchrony lead to greater distortion and poor aided improvement. The authors concluded that the presence of LLR could be a measure for determining aided benefits in those with late onset ANSD. However, definite conclusion may not be drawn due to small sample size.

Spirakis (2011) studied aided performance in a child with ANSD, fitted with Starkey S Series iQ 11 BTE hearing aid. Child’s performance was evaluated in unaided and two aided conditions. In the two aided conditions, slow (5000msec/5000msec) and fast (20msec/ 2000msec) attack/release times were used.

In both the aided conditions, knee point and compression ratio were kept constant. CID W-22 words were presented at 60dBHL, via a loudspeaker placed at 0 degree azimuth.

It was found that slow compression times lead to significant improvement in speech perception compared to unaided and faster time constants. Performance improved by 20% in slower time constants, when compared to unaided condition. Slower time settings showed 32% improvement in word recognition compared to faster time constants. The authors attributed that faster compression time constants that reduce the amplitude fluctuations in temporal envelope cause impaired speech perception in ANSD who rely heavily on temporal fluctuations. However, the study was carried out in a single subject with ANSD highlighting the need for investigation in a large group. Moreover, the authors recommended comparing the effect of slow compression time constants and linear settings as they both are known to preserve the temporal envelope of speech signal.

From the above literature, it is clear that management of ANSD using hearing aids, often lead to limited improvement in speech perception. Among adults, hearing aids are rarely successful. This might because hearing aids just amplify the sound rather than improving the temporal modulations of speech. Certain compression settings in hearing aids are shown to preserve the temporal envelope of speech (Van Tassel 1993). Hence, using the appropriate compression settings in digital hearing aids might be an effective way to preserve the temporal envelope and hence improve speech perception in ANSD.

Importance of Temporal Envelope Information for Speech Perception

Psycho-acoustical studies have proven that temporal processing deficits are the major reason for impaired speech perception in ANSD. Zeng, Oba, Garde, Sininger, and Starr (1999) showed poor gap detection thresholds as well as impaired peak modulation detection thresholds in ANSD. They attributed that poor performance on temporal resolution (gap detection and TMTF) explained the impaired speech perception in individuals with ANSD. This was again supported by simulation of temporal processing impairment in normal hearing individuals that showed speech perception deficits similar to that of ANSD. Similarly, Kumar and Jayaram (2005) showed a significant correlation between temporal processing abilities that was evaluated using TMTF and SIS obtained. Rance, McKay, and Grayden (2004) demonstrated impaired temporal resolution that leads to poor speech perception in children with ANSD. From the above studies it was clear that the impaired temporal resolution in ANSD worsens the ability to process amplitude fluctuations in speech, hence leading to poor speech perception abilities.

Recent investigations using envelope enhancement strategies showed the importance of temporal envelope on speech perception in individuals with ANSD. Name and Vanaja (2008) showed that the enhancement of temporal envelope leads to improvement in speech perception in ANSD. They studied the perception of different consonants /p, b, t, d, k, g, s, l, r, t̯, d̯ tʃ, ʃ/ in the context of vowel /a/. Each stimulus was enhanced by 15 dB in four different modulation bandwidth (3 to10Hz, 3 to 20Hz, 3 to 30Hz, 3 to 60Hz). Among the 8 ANSD participants, 6 showed significantly improved consonant identification after the envelope enhancement. Envelope enhancement, improved manner of articulation maximally followed by the place and voicing.

In a simulation study, Narne and Vanaja (2009) investigated the effect of temporal smearing of unprocessed and envelope enhanced stimuli on speech perception in listeners with normal hearing. Further, the effect of envelope enhancement on speech perception in individuals with ANSD was also evaluated. SIS obtained for temporally smeared speech in normal hearing listeners was similar to that of individuals with ANSD. Further, normal group revealed that SIS decreased as temporal smearing increased. Envelope enhancement improved the SIS in individuals with ANSD when signals were simulated to mild and moderate degree of temporal processing.. However, only a marginal improvement was noted for severe degree of impairment. Envelope enhancement did not improve SIS in normal when simulated for severe to profound degree of ANSD. Lack of improvement in these normal hearing listeners, even after envelope enhancement, was attributed to poor consonant-vowel distinction in the stimuli that was simulated for severe degree of impairment

Zeng and Liu (2006) compared the effect of clear speech over conversational speech in 13 subjects with ANSD. Sentience perception was studied in quiet and in the presence of speech spectrum noise. Clear speech showed significant improvement in perception than the conversational speech in both quiet and noisy conditions. Improvement was present in all the listening modality conditions like acoustical, electrical and combined stimulation. This improvement in speech perception was attributed to improved temporal envelope cues in clear speech.

The above literature shows that enhancing the temporal envelope of speech is an effective way to improve speech perception in ANSD. However, real time implementations of such signal enhancement strategies are not yet successful. Adjusting certain compression parameters of hearing aids are shown to improve speech perception similar to that of envelope enhancement scheme (Spirakis, 2011). However, this needs to be investigated in a larger group.

Linear vs Compression Hearing aids

Jenstad & Souza (2005) evaluated the effect of release time in a compression hearing aid on speech acoustics as well as speech intelligibility. There were 16 participants in the age range of 21-81 yrs. Among the 16 participants, 4 were normal hearing and 12 had moderate to moderately severe SNHL. The stimuli used were VC syllables from the nonsense syllable test (NST; Dubno & Schaefer, 1992, 1995). Consonants (stops, liquids, fricatives, nasals) in the context of vowel /i/ were used. Vowel /i/ was chosen due the evidence of larger vowel effect on consonant perception in the context of vowel /i/ (Kennedy, Levitt, Neuman, & Weiss, 1998). A compression ratio of 3:1 and compression threshold (45 dB SPL) that was below the mean presentation level was chosen. Attack time kept was between 2 to 5 ms and three different release times were 12, 100, 800ms. The output of the hearing aid was recorded using stimuli presented at three different input levels. For the acoustic analysis Envelope Difference Index (EDI) and consonant vowel ratio (CVR) were used.

Results revealed that though release time has an effect on EDI, larger effect was found at higher presentation levels. At 50dB SPL small EDI values were found for all three release times indicating a minimal effect on temporal envelope. As the input level increased from 65 dB SPL to 80dB SPL large EDI values were found especially for the short release time. With this authors concluded that release time has an effect on EDI but it depends on the stimulus level. Similarly, shorter release time had a significant effect on the CVR which also depends on the stimulus level. Highest values in CVR were observed in the high stimulus input level. Speech intelligibility measures showed no significant difference across three release times. However, compression amplification leads to higher recognition scores than linear amplification, especially at lower presentation levels. The benefit derived from compression amplification reduced as the input level increased.

The authors concluded that though there was a significant effect of shorter release time on the stimulus acoustics, speech intelligibility did not vary significantly across release time. This they have attributed to the availability of spectral cues, though the temporal envelope is altered by compression time constants. However, at higher presentation levels, poor recognition scores using compression amplification over linear might be due to altered acoustics using compression.

Aided performance with linear and 2 channel wide dynamic range compression hearing aid was assessed in 55 individuals with sensory-neural hearing loss (Humes et al., 1999). All the participants were regular hearing aid users for 1 year. Aided performance was evaluated using monosyllabic words and sentences presented at three different intensity levels in quiet and noise. Evaluations were done after one month use of linear or wide dynamic range compression hearing aid. Speech identification scores using both words and sentences in quiet condition showed significantly higher perception using wide dynamic range compression than linear amplification. Similarly, ease of listening and quality were also significantly higher using wide dynamic range compression hearing aid than linear. Significantly higher performance using compression hearing aid over linear was attributed to nonlinear gain characteristics of compression hearing aid that provided more gain to lower input signal than higher level input. Hence, participants might have heard more amount speech signal using compression aid than linear. The difference in output due to the prescriptive formulae used in the linear (NAL-R) and wide dynamic range compression (DSL i/o) also attributed.

Laurence, Moore, and Glasberg (1983) compared performance using a linear and 2 channel compression hearing aid in 8 participants with SNHL. Speech intelligibility was measured in both the quiet and noisy condition. Then the overall effectiveness of each hearing aid system was measured using questionnaires. Evaluations were done after wearing the hearing aid for one week. Speech intelligibility in quiet and noise was significantly higher for linear hearing aid when they compared compression condition. This difference was highest for low level input.

Hearing aid Release Time and Speech Quality

Neuman, Bakke, Hellman, and Levitt (1994) investigated the effect of compression ratio in a slow acting compression system on perceived quality of speech. The compression ratios that used were, 1:1 (linear), 1.5, 2, 3, 5 and 10:1. Other compression parameters such as compression threshold (65 dB SPL), attack time (5ms) release time (200 ms) were fixed. 20 participants with sensorineural neural hearing loss were evaluated. Paired comparison of quality judgement was significantly altered by the compression ratio. The most preferred compression ratio was 1.5 or 2:1. Preference reduced as the compression ratio increased. There was no significant difference in selection rate between the ratios of 1, 1.5:1, 2:1, but was significantly higher than that of 5:1 and 10:1. The authors concluded that compression ratio greater than 2:1 should not be used in hearing aids using slow acting compression time settings.

In a Similar study, Neuman, Bakke, Mackersie, Hellman, and Levitt (1998) evaluated the quality of hearing aid processed speech using two different experiments.

Initially the effect of different compression ratios (linear to 10:1) on quality was evaluated. In a second experiment the effect of compression ratio (1.5:1, 2:1, and 3:1) and release time (60ms, 200ms, 1000ms) were investigated. Other parameters such as compression threshold (65 dB SPL peak) and attack time (5ms) were kept constant. Rating of quality using different scales in lower compression ratios (1, 1.5, 2:1) was significantly higher than, higher compression ratios (5:1 & 10:1). Rating of pleasantness using release time of 200 ms and 1000ms was significantly higher than the release time of 60 ms. Further, the effect of release time on quality was minimal when lower compression ratios were used. At higher compression ratio (3:1) short release time (60 ms) resulted in a significantly lower quality rating compared long release times (200 ms or 1000 ms). Hence, the authors concluded that release time does not have a significant effect when lower compression ratio was used.

Similarly, Neuman, Bakke, Mackersie, Hellman, and Levitt (1995) studied hearing aid processed sound quality using different release times. In this study 20 SNHL subjects were participated to judge the quality of speech in different compression settings. Compression ratio (1.5:1, 2:1, and 3:1) and release time (60ms, 200ms, 1000ms) was manipulated whereas; compression threshold (65 dB SPL peak) and attack time (5ms) kept constant. Participants were asked to choose the signal with better quality using a round robin tournament. Results showed that mean preference scores for the release time of 200 and 1000ms were significantly higher than that of 60ms release time in competing cafeteria noise.

It is evident from the above literature that hearing aids with long release time preserves the temporal envelope of speech signal. Additionally, studies have shown that superior speech quality was noted using slow compression settings. Moreover, compression amplification was found better than linear, especially at low levels.

CHAPTER3- METHOD

The study aimed to investigate the perception of hearing aid processed speech in individuals with Auditory Neuropathy Spectrum Disorder (ANSD). The study was carried out in two phases. In the first phase, recording of stimuli was carried out. In the second phase, the recorded stimuli were presented to eighteen young adults with ANSD.

Participants

Eighteen individuals with ANSD in the age range of 15 to 35 years were chosen for the study. All the participants were native speakers of Kannada, a south Indian Dravidian language. All of them were evaluated and diagnosed at the Dept of Audiology, AIISH. The diagnosis of ANSD was carried out using the criteria given by Starr et al. (2000) and Berlin et al. (2005). As per the above criteria, clients who had preserved cochlear amplification, impaired neural response (absent or abnormal brainstem responses and middle ear reflexes), normal otological function and no space occupying lesion (identified based on clinical neurological examination) were included.

Audiological evaluation showed that participant’s hearing sensitivity ranged from normal to moderately- severe degree and SIS ranged from 20% to 60%. Individuals with hearing loss greater than moderately severe degree or no measurable SIS were not included in the study. This was based on the observation that hearing aids might not improve speech perception in those with a higher degree of hearing loss or no measurable speech perception (Jijo & Yathiraj, 2013). All the participants had normal middle ear status that was confirmed through immittance evaluation. Further, transient evoked Otoacoustic emissions were present in all the participants indicating normal functioning of OHCs. However, ABR and acoustic reflexes were absent in all the participants showing impaired neural functioning. The demographic and audiological details of the participants can be found in Table 1.

In addition to those having ANSD, there were 10 normal hearing subjects who were recruited to evaluate the intelligibility of the recorded stimuli. All the normal hearing participants had hearing thresholds < 15 dB HL in both ears. Immittance evaluation showed 'A' type tympanogram with acoustic reflex present bilaterally. None of them had any problem with understanding speech.

Table 1*:*

Demographic and audiological details of the participants with ANSD

SL no	**Age(yrs)/Gender**	**PTA (dB HL)**		**SIS (%)**		**Tympanogram type (bil)**	**AR (bil)**	**TEOAE (bil)**	**ABR (bil)**
		Right ear	Left ear	Right	Left				
1	27/F	33.75	31.25	40	28	A	NR	P	NR
2	35/M	63.75	58.75	12	20	A	NR	P	NR
3	55/M	57.5	56.25	64	60	A	NR	P	NR
4	25/M	47.5	51.25	52	56	A	NR	P	NR
5	28/M	58.75	53.7	40	32	A	NR	P	NR
6	22/F	47.5	71.2	60	20	A	NR	P	NR
7	37/M	57.5	43.75	32	36	A	NR	P	NR
8	25/M	47.5	21.25	40	60	A	NR	P	NR
9	20/F	30	35	52	28	A	NR	P	NR
10	20/F	26.25	11.25	72	80	A	NR	P	NR
11	35/M	21.25	58.75	68	32	A	NR	P	NR
12	43/F	22.5	35	48	40	A	NR	P	NR
13	27/F	33.75	31.25	40	28	A	NR	P	NR
14	52/M	63.75	51.25	20	48	A	NR	P	NR
15	32/F	71.25	58.75	20	28	A	NR	P	NR
16	27/M	26.25	11.25	68	72	A	NR	P	NR
17	23/F	35	32.5	24	20	A	NR	P	NR
18	20/M	31.25	20	32	12	A	NR	P	NR

Note: PTA=Pure tone average, SIS=speech identification score, AR=Acoustic reflex, P=Present, NR= No response

Instrumentation

A calibrated diagnostic audiometer (*GSI-61*) was used to carry out pure- tone audiometry as well as speech audiometry. A calibrated diagnostic immittance meter (*GSI-tympstar*) was used to record tympanogram and acoustic reflex. Oto-acoustic emissions and auditory brainstem response were recorded using *ILO 292 DP- Echoport (V-6)* and Biologic navigator pro respectively. Output from a Starkey S series iQ 11, receiver in the canal hearing aid was recorded to make the stimuli. This Wide Dynamic Range Compression (WDRC) hearing aid has option to adjust attack and release time. The electro-acoustic characteristics and compression parameters of the hearing aid were measured using a hearing aid analyzer (Phonix 7000) using IEC standards (IEC 60118-7 (2005). A sound level meter (B & K 2270) that had the option to record hearing aid processed speech was used for recording. A personal computer loaded with Adobe Audition (version 3) was used to present the stimuli for recording and testing. While recording the stimuli were played in a personal computer (Intel(R) core (TM) i3-3110M, 4GB RAM, 64 bit operating system) and presented via a loudspeaker (Genelec®).

Stimuli

Phonemically balanced words in Kannada, developed by Yathiraj and Vijayalakshmi (2005) were used as stimuli. This material had four lists in it, each having 25 words. The recorded version of the word list was presented and re-recorded through the digital hearing aid. Each list was re-recorded using one linear and three non-linear settings of the hearing aid. Hence, there were four hearing aid processed outputs (one linear and three non-linear), each having four lists.

Test Environment

All the measurements that included recording of stimuli and speech perception testing were carried out in an acoustically treated room, where the level of ambient noise is well within the permissible limit (ANSI S3.1.1999).

Procedure

Procedure for selection of participant. Prior to data collection all the participants with ANSD had undergone a detailed audiological evaluation. Pure-tone thresholds were obtained via the modified Hughson and Westlake procedure, using a diagnostic audiometer (GSI 61) that was calibrated in a regular interval. Calibrated immittance instrument (GSI-Tympstar) was used to obtain tympanograms and acoustic reflex thresholds. SIS were obtained using a phonemically balanced word test in Kannada, developed by Yathiraj and Vijayalakshmi (2005). Any one of the four equivalent lists of the test that contained 25 words was used. Transient Evoked Otoacoustic emissions were recorded using Otodynamics ILO 292 or Madsen Capella 1.3. Non-linear clicks were presented at 80 dB peak SPL. Responses having signal to noise ratio more than 6 dB and reproducibility above 80% were considered as responses. ABR was recorded using two channel Auditory Evoked Potential systems (Biologic Navigator Pro).

Calibration. The recording set-up was calibrated so that the stimuli were presented well above the compression threshold of the hearing aid (55 dB SPL). In order to calibrate the recording setup, the SLM that was connected to a half inch microphone was kept 1 meter away from a loudspeaker at an angle of 0^0 azimuth. A calibration tone of 1 k Hz was played in a personal computer and presented through the loud speaker. The level of the calibration tone was adjusted so that an output of 60 ± 3 dB SPL was recorded on the SLM. Using a similar procedure CD/Tape input of the audiometer that used for testing was also calibrated.

Hearing aid programming. The hearing aid was programmed using a personal computer, in which NOAH software (version-3) and hearing aid specific software (Inspire- 2013.3) were installed. A HiPro, which was connected to the computer, provided an interface between the computer and the hearing aid to be programmed. The hearing aid was programmed for a flat 40 dB HL sensori-neural hearing loss. Programming was used a linear (NAL-L) and a non-linear (NAL NL-2) prescriptive formula. In the non-linear settings three different attack/release times were kept, they were slow (5000ms attack time and 5000ms release time), medium (20ms attack time and 2000ms release time) and fast (5ms attack time and 10ms release time). Additional settings such as directionality, noise reduction, volume control and feedback cancellation were switched off while programming.

Phase I. Stimulus recording. In order to record the hearing aid processed speech, the programmed hearing aid was connected to a 2cc coupler which in turn connected to one inch pressure microphone that was inserted to the SLM. The stimuli were played using a personal computer loaded with Adobe Audition (version -3) software and were presented at 60 dB SPL via a loudspeaker. A distance of 1 meter, and 0^0 azimuth was maintained between loudspeaker and SLM. Initially, output was recorded from the hearing aid that was programmed using a linear prescriptive formula. Hearing aid output was again recorded using a similar procedure, but programmed using a nonlinear prescriptive formula. In the nonlinear settings the hearing aid output was recorded thrice each time with a different attack/release times. Figure 1 shows the sample waveform of word /dheepa/ that was recorded through the hearing aid using four different settings. The recorded stimuli were presented to 10 normal hearing young adults to assess the intelligibility. Entire list was re-recorded in case any stimulus in that list was rated poor or unintelligible.

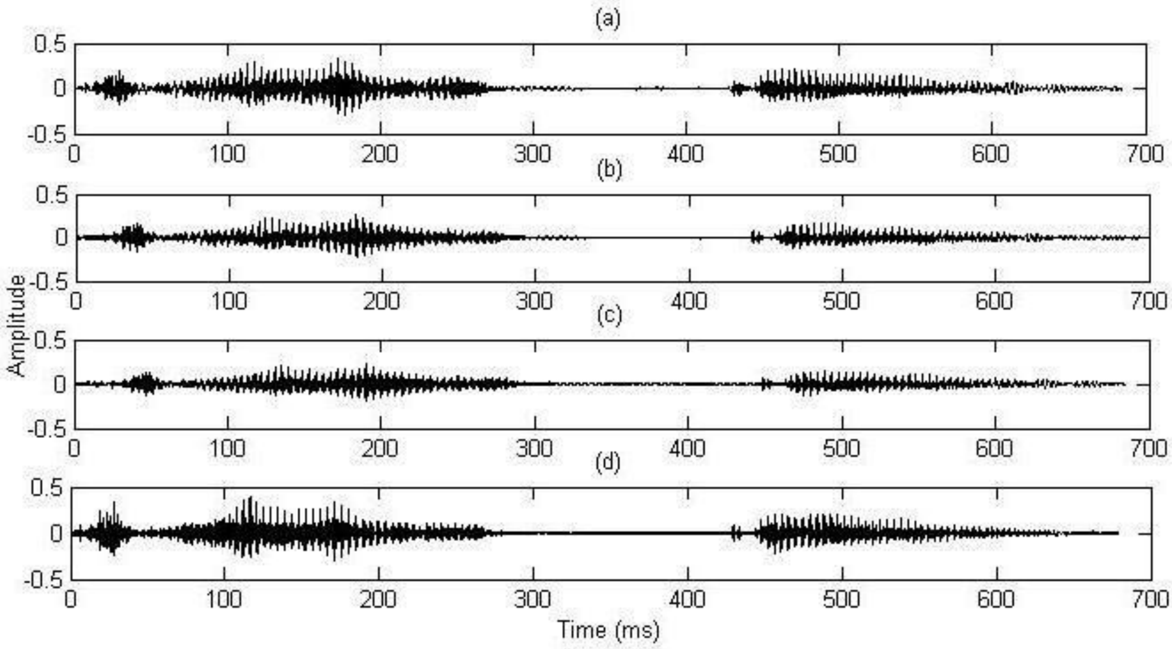

Figure 1: Sample wave form of hearing aid processed speech in three different release times (a) fast, (b) medium (c) slow and (d) linear settings**.**

Phase II. Testing. The hearing aid processed stimuli were played on a personal computer and were routed through a calibrated clinical audiometer (GSI-61). The participants with ANSD received the stimuli through a loudspeaker placed at a distance of 1 meter and at 0^0 azimuth. The presentation level was maintained at SRT +40 dB HL or at the most comfortable level. Each participant listened to four hearing aid processed output (one linear and three non-linear). It was ensured that none of the participants heard the same list again. The order of presentation of list varied across participants. The participants were instructed to repeat the stimuli and the responses were noted by the experimenter. Each correct response was given a score of one. The speech recognition scores were calculated by counting the number of words correctly repeated.

Analyses

Data obtained using 4 stimulus condition were tabulated. Descriptive and inferential statics were carried out using SPSS for windows (17). Prior to the inferential statistics, the data were subjected checks the assumptions of parametric statistics. The normality of distribution was tested using Shapiro-Wilk test. Results showed normally distributed data in all the four stimuli conditions ($p > 0.05$). Hence, parametric statistics was chosen for analysis.

CHAPTER 4- RESULTS AND DISCUSSION

The study aimed to investigate the effect of hearing aid processed speech on perception in individuals with late onset ANSD. In this experimental research, the effect of stimuli that were processed using four different settings of a hearing aid (independent variables) on speech identification scores (dependent variable) was measured. The four settings included were three different attack/release times (slow, medium and fast) and one linear amplification setting. Speech identification scores were measured in 18 young adults with ANSD. Finally, the change temporal envelope that resulted from hearing aid processing also calculated.

Effect of Compression Settings on SIS

Table 2 shows the mean and standard deviation of SIS obtained using four different hearing aid processed stimuli. It can be found that highest SIS was obtained using stimuli that was processed using the hearing aid with slow compression time constants. Other time constants of medium and fast had SIS poorer than slow. However, lowest SIS were founded in the linear hearing aid settings.

Table 2:

The mean and standard deviation of SIS obtained using four different hearing aid processed speech stimuli

Hearing aid settings	*Mean*	*Standard deviation*
Slower-attack/release time	***29.29***	***14.54***
Medium-attack/release time	***26.82***	***16.047***
Fast attack/release time	***24.00***	***13.19***
Linear settings	***22.35***	***13.42***

In order to find out any significant difference in SIS obtained using four types of hearing aid processed stimuli, one way repeated measures ANOVA was carried out. Results revealed a significant effect of hearing aid setting on speech identification scores ($F(3, 48) = 4.781$, $p<0.005$). Further, the Bonferroni pair wise comparison was done to find out the stimulus condition pairs that were significantly different. As there were six pairs of stimulus conditions the 'p' value that was considered to be significant was 0.016. Among the six stimuli condition pairs, the SIS obtained using slow release times was significantly higher than fast release time ($p <0.016$). However, no significant difference in SIS was found between other stimuli condition pairs (Table 3 & Figure 2).

Table 3.

Results of Bonferroni pair wise comparison of SIS obtained using six pairs hearing aid processed stimuli

	Slow	Fast	medium	linear
Slow		0.006**	1.000	0.031
Fast			1.000	1.000
Medium				0.434
Linear				

Significant difference ** $p < 0.016$

The present study showed a significant improvement in speech perception using slow compression time over the fast compression settings. This is in accordance with the findings of Spirakis (2011). However, the improvement noted in the present study was minimal compared to Spirakis (2011) who showed 32% improvement using slow time settings over fast. This might probably because Spirakis (2011) showed data from a single subject with ANSD whereas; the present data shows mean improvement. Moreover, this child had a relatively good amount of speech perception (44%) in the unaided condition. Author attributed that, improvement in speech perception might be due to the preserved temporal envelope using slow compression time settings. It was hypothesized that fast compression time settings might alter the temporal envelope of speech signal, whereas the long release might preserve the amplitude fluctuations. Hence, individuals with ANSD having a temporal processing deficit might benefit using hearing aids with slow compression time constants. However, extend of the temporal envelope change using hearing aid settings was not evaluated in their study.

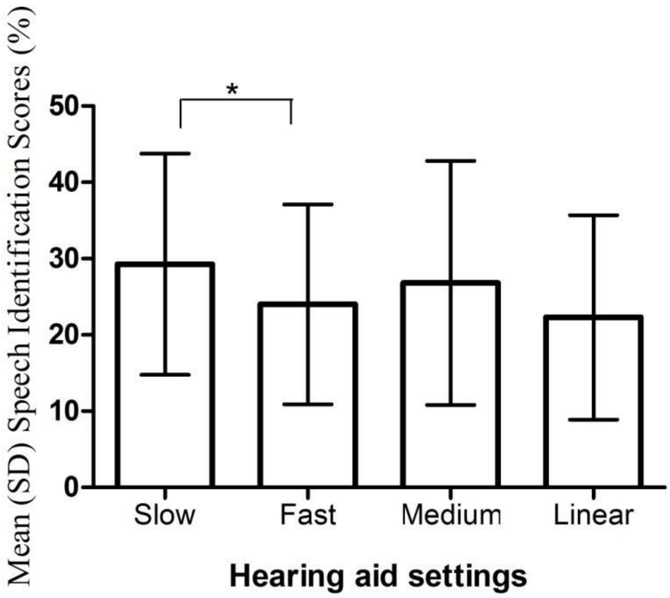

Figure 2: Mean and SD of speech identification score obtained using four different hearing aid settings (* $p< 0.016$).

Effect of compression settings on temporal envelope

In order to find out any difference in envelope between two hearing aid processed stimuli, envelop difference index (EDI) was calculated using MATLAB software. The procedure to calculate EDI was similar to that given by Fortune, Woodruff, & Preves (1994). Initially the envelopes of two signals were extracted using a sixth order Butterworth filter. The mean amplitude of the one of the signals (reference) was calculated. Each sampled data point of the envelope was then scaled to mean amplitude by dividing every value by the mean. This provided a common reference for comparing the two envelopes. Similar steps were administered on the other signal (comparison signal). EDI was calculated using the following formula.

$$\boldsymbol{EDI = \sum_{n-1}^{N} |Env1n - Env2n)|/2N}$$

Where N is the number of sample points in the waveform, $Env1n$ is the envelope of the reference waveform and $Env2n$ is the envelope of the comparison waveform. The output of the formula generates a number between zero and one. Zero represents identical envelopes and one represent the total difference in the envelopes. EDI values were calculated for randomly selected words that were processed using four different settings of the hearing aid. Table 4 shows the EDI values for six pairs of stimulus conditions using a sample word.

Table 4.

EDI value obtained for hearing aid processed stimuli using a sample signal

	Slow	**Fast**	**medium**	**linear**
Slow		0.08	0.06	0.08
Fast			0.06	0.08
medium				0.08
linear				

The EDI values were less than 0.1 for all the six stimuli condition pairs. This indicates minimal changes in temporal envelope as a result of hearing aid processing. Figure 3 shows the temporal envelope of a word that was processed using the hearing aid with slow and fast compression time constants. It is evident that there are only minimal changes in the temporal envelope.

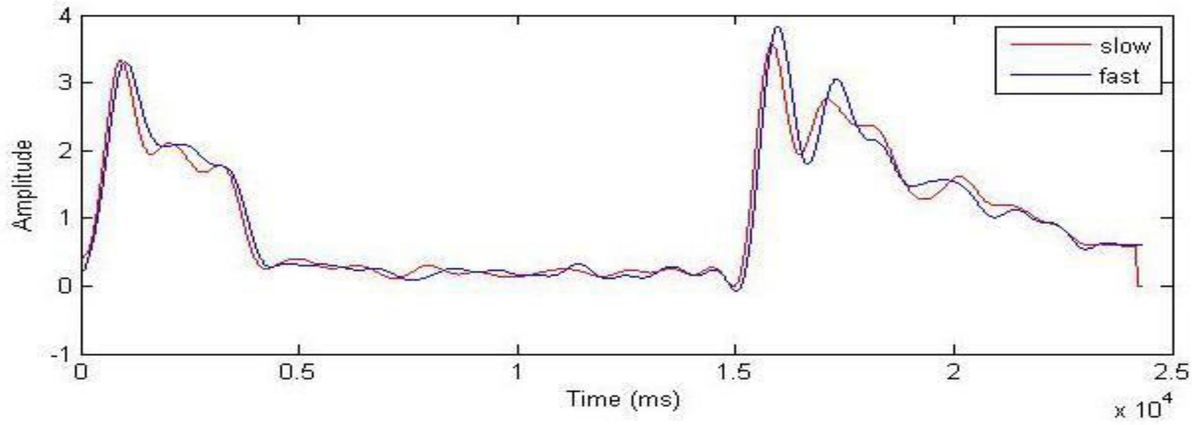

Figure 3. The temporal envelope of a word that was processed using fast and slow compression time constants of the hearing aid.

Though the earlier investigation that used long compression time settings showed improvement in speech perception over fast settings, the change in the temporal envelope after hearing aid processing, was not evaluated in their study (Spirakis, 2011). Hence the present study investigated the amount of temporal envelope change using EDI. The output of EDI showed minimal change in temporal envelope in all the pairs of stimulus conditions. This might probably due to the lower presentation level that was used while recording the stimuli. The level of presentation used was 60 dB SPL that was just above the compression threshold of the hearing aid (55 dB SPL). Hence, some portions of speech signal might have fallen below the compression threshold of the hearing aid leading to minimal changes in temporal envelope. Similarly, Jenstad and Souza (2005) showed small EDI values when the presentation level was 50 dB SPL. The compression threshold of the hearing aid used was 45 dB SPL. In contrast, increasing input levels of 65 dB SPL to 80dB SPL resulted in increased EDI values.

It is clear from the EDI measurement that all four hearing aid processing lead to minimal alteration in the temporal envelope. Hence, the improvement noted using slow compression settings might not be attributed to preserved temporal envelope. The possible reason for improvement might be improved speech quality using long compression settings. Earlier investigations have shown that long compression setting found to have superior speech quality, especially when small compression ratios were used (Neuman, et al., 1994, 1995, 1998). Hence, the slow compression time settings along with the small compression ratio used in the present study might lead to better speech quality and higher speech perception. Many clients also reported ease of listening while listened to speech stimuli processed using slower compression time.

It was found that linear setting resulted in lowest speech perception performance compared to other settings such as slow, fast and medium though it was not significant. Several investigators have shown reduced speech perception using linear amplification compared to wide dynamic range hearing aids (Jenstad & Souza, 2005; Humes et al., 1999; Laurence et al., 1983). Jenstad and Souza (2005) showed that at lower presentation level the scores obtained using a compression system was significantly better than linear system. In contrast, higher presentation level resulted in reduced speech perception using compression. Humes et al. (1999) attributed that significantly higher performance using compression hearing aid over linear might be due to nonlinear gain characteristics of compression hearing aid that provided more gain to lower input signal than higher level input. Hence, participants might have heard more amount speech signal using compression aid than linear. Hence, the lower presentation level of 60 dB SPL used in the present study might have caused poor speech perception using linear over the other three compression settings.

CHAPTER 5 - SUMMARY AND CONCLUSION

The present study investigated the perception of hearing aid processed speech in individuals with late onset ANSD. The hearing aid settings used were slow, fast medium and linear settings. The speech perception was assessed using hearing aid processed PB word lists. 18 individuals with ANSD in the age range of 15 to 35 years were participated in the study.

The speech identification scores obtained using four hearing aid processed stimuli were analyzed by using one way repeated measure ANOVA. The results showed significant effect of hearing aid settings on speech perception. The Bonferrroni paired comparison revealed that the slower compression time constant (5000ms attack time/5000ms release time) showed significantly higher performance than with the faster compression time constant (5ms attack time and 10ms release time). However, other hearing aid settings were not significantly different.

Measures of temporal envelope using EDI showed minimal alteration in temporal envelope in all the four hearing aid processing. This might be due to the low presentation level that used while recording the stimuli. Hence, the improvement using slow compression time may be attributed to superior speech quality that was reported earlier. The clients in the present study also reported higher quality when slow processed stimuli were presented. Stimuli processed using linear time settings lead to poor speech perception scores. This might be due to the superior performance of WDRC hearing aid at a low presentation level.

Hence, the results of the study suggest that slower compression time will help in improving the speech perception in ANSD subjects rather than giving a usual faster compression time constants. Linear amplification though it preserves the temporal envelope of speech might lead to reduced speech perception than WDRC hearing aid.

Future direction

Though slower compression time constants was shown to improve speech perception, this was evaluated using a hearing aid processed stimuli rather than hearing aids in the ear. Hence, speech perception needs to be evaluated using a hearing aid in the ear in different listening conditions, and also for a long term.

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