An Evaluation of the Influence of Temporal Processing on Hearing Aid Outcome

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Reg. No.: 13AUD018

A Masters Dissertation Submitted in part fulfillment of final year

Master of Science (Audiology)

University of Mysore

All India Institute of Speech and Hearing,

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May, 2015

Dedicated to my loving family

Where life begins and love never ends...,

CERTIFICATE

This is to certify that this masters dissertation entitled '**An evaluation of the influence of temporal processing on hearing aid outcome'** is a bonafide work submitted in part of fulfillment for the degree of Master of Science (Audiology) of the student **Registration No.: 13AUD018**. This has been carried out under the guidance of a faculty of this institute and has not been submitted earlier to any other university for the award of any diploma or degree.

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May, 2015

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CERTIFICATE

This is to certify that this masters dissertation entitled **'An evaluation of temporal processing on hearing aid outcome'** has been prepared under my supervision and guidance. It is also certified that this dissertation has not been submitted earlier to any other university for the award of any diploma or degree.

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DECLARATION

This is to certify that this masters dissertation entitled **'An evaluation of the influence of temporal processing on hearing aid outcome'** is the result of my own study under the guidance of Dr. P. Manjula, Professor in Audiology, Department of Audiology, All India Institute of Speech and Hearing, Mysore, and has not been submitted earlier to any other university for the award of any diploma or degree.

Mysore, Register No: 13AUD018

May, 2015

Acknowledgement

First of all I would like to express my sincere thanks to **Prof. P. Manjula ma'am**. Ma'am thank you for guiding us though out despite of your academic and professional commitments. Your wisdom and knowledge inspires and motivates us. Your patience and flexibility helped us to finish our work on time. Thank you so much for everything Ma'am.

I would like to render my gratitude and thankfulness to the Director of AIISH, **Prof. S. R. Savithri** for allowing us to undertake the study. I would like to thank HOD of Audiology, **Dr. Ajith sir** for providing us the instrument and time to carry out dissertation in the department.

I would like to convey my heartfelt thanks to **Chudamani Ma'am, Vikas Sir** and **Sharath Sir** for helping us and calibrating the required instrument. I would like to say thanks to Santhosha Sir for helping with the statistics.

Antony sir, you are the best teacher. You have taught me the real meaning of learning is not knowing few things but to its knowing them perfectly. Your knowledge and questions have helped us in looking in depth more into the topic.

I would like to thank all the teachers who have taught us. I would like to remember all my Navodaya teachers who were our second parents and inspired us to reach our goals.

I thank all the participants who took time from their busy schedule to make time for my study.

Well, the time has come to stand on our own feet and see the world with our eyes. It's time to look back and see who made us come this long and say thanks to the people who protected us, helped us choose the right path, brought joy, who were there through the hardship, shared and made cherishable memories all the way.

Mummy and appaji, you have done so much more than just getting us on this earth. I cannot just finish all I need to say in two words. Mummy, I don't know where to begin and what to say. It took a while to realize all you did was to make me better, but I must say you have been the best teacher in my life. You have been the home school for me, taught me the values of life. Thank you so much for all the struggles and sacrifices you have made for us. I promise I will work to make all your dreams come true to make our home sweet home.

Amma and Ayya thank you is such a small word in return to the care and love you have shown us all the way. Whatever I am today, you have been there every little step. Thank you so much for everything.

Kaathi and Neelu, see I found the right words for you both. "Every time I made a mistake, you felt responsible. Every time I was unhappy, you felt accountable. Every time I was hurt, you felt answerable". I think that says it all. Thanks for never leaving my side and always guiding through the right path. And my brother in laws, I must say you both have got the best woman in the world. **Rudresh Bhava and Madhu bhava** thank you both of you for all the timely help. And for all the love and care you show. You make our family complete.

And **Manuanna**, you are my best friend. You are the most caring, loving, charming, protective …. And many more… words are in short, for saying about you… Thanks for being the person who always says "let's see what how we can fix this" instead of "I told you so".

And friends, **Rashmi, Shilpa, Monisha, Priyanka** you have all been my best friends for life. Thanks for sharing those wonderful moments. My life would have been incomplete without you all.

Shruthi, thank you so much for being such an understanding person. You will always be my cute little sister. Take care. Anytime anything ask me. And thanks to your mom for giving me a second home.

Zeena, I would miss all those combined studies (though we did very few of them), late night gossips, small silly fights. Thank you for being there. And my soul mates **Suman and P G**.., I like you guys even if you have irritated me to the core. I think you all should be thankful to me. It was worth having you all in life.

Swathi akka, thank you for all the last moment works which helped be to finish up my work on time. Thank you so much. You are the sweetest person I have ever met in AIISH.

Maddy thank you so much!! You always had the right word in right moment. **Bibek** thank you for improving my knowledge in football. You are truly awesome and remember I still have a wish to be fulfilled by you. **Kiran** thank you for everything you did. **Pooja, Niharika, Harika, Navya, Kavya, Manjula, Pankaja, Preeta** and **Sneha** you are all the coolest people around. Thanks for all those wonderful moments.

And dear juniors you all proved small helps can make big changes in life. **Sumanth, Rajith, Nikhil, Usha, Rashmi** (1^{st} MSc), **Kavya** (2^{nd} year), **Ranjitha**, **Rashmi** (Intern), **Ankitha**, **Neha**. You all bring joy into my life. Thank you all for all the timely help. Wish you all the best for your bright future.

Abstract

The aim of the present study was to investigate the effect of temporal processing on hearing aid outcome measures. The study was done on ten participants with mild sensorineural hearing loss and twelve participants with moderate sensorineural hearing loss. The temporal processing measures included were gap detection thresholds and discriminability index using temporal fine structure sensitivity and their effect on hearing aid measures such as acceptable noise level (ANL), SNR-50 and self-assessment of hearing aid benefits were measured using correlation analysis. The results showed that the gap detection threshold had a significant positive correlation with ANL and SNR-50. As the gap detection threshold increases both ANL and SNR-50 increases and the gap detection threshold could be used to predict the ANL and SNR-50. The effect of temporal fine structure sensitivity on hearing aid outcome remains unclear due to larger variability in the data. The relationship between different outcome measures was assessed to check the correlation of ANL and SNR-50 with self-assessment of hearing aid benefit which showed that there was no relationship between them.

Key words: temporal processing, gap detection threshold, temporal fine structure sensitivity, acceptable noise level (ANL), SNR-50, self-assessment of hearing aid benefit

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Chapter 1

Introduction

The management of hearing loss varies depending on the cause, type and severity of hearing loss. Generally, the audiological management for hearing loss includes the use of amplification devices (hearing aids), assistive listening devices (ALDs) and implantable hearing devices. It has been reported that “in developing countries, fewer than one out of 40 people who need a hearing aid have one” (WHO, 2014). Further, even when they own a hearing aid many of them do not use them regularly or they are not satisfied with their devices.

Smeeth et al. (2002) found that only 60% of the people used their hearing aids regularly and the level of benefit from the device was strongly related to the perceived benefit. There may be numerous reasons for the hearing aids purchased not being used in daily life. Kochkin (2000) has reported some of the top reasons for rejecting the hearing aids. This includes poor benefit from hearing aids (29.6%), annoyance in background noise/noisy situations (25.3%), fit and comfort (18.7%), negative side effects of hearing aids (10.9%, who complained of problems like hurt to ears, too much pressure in the ears, blisters in ears, rashes in ears, itching ears, dizziness, makes them nervous, ears that sweat, wax build up in the ear canal, headaches, hair gets caught in hearing aid, infections in the ear, problems chewing or swallowing, plugs up ears), and the problems related to price including the cost of repairs (10.3%) .

Many studies have tried to establish the causes of dissatisfaction of the hearing aid users. There are several factors contributing to the dissatisfaction of the hearing aid users with their devices. In a study to know the factors important for a hearing aid user, ten factors were established that contributed to the satisfaction(Kochkin, 2010). They are overall benefit (0.71), clarity of sound (0.70), value (performance of the hearing aid relative to price) (0.68), natural sounding (0.66), reliability of the hearing aid (0.65), richness or fidelity of sound (0.65), use in noisy situations (0.63), ability to hear in small groups (0.63), comfort with loud sounds (0.60), and sound of voice (occlusion) (0.60).

There have been efforts made to check whether an audiologist can reliably predict the benefit a person might get from his/her devices. Many studies have been carried out to see if there is any correlation between different audiological and non-audiological factors that can reliably predict the benefits from hearing aids. Several studies have shown a positive correlation between the degree of hearing loss and subsequent use of hearing aids (Ewertson, 1974; Hutton, 1980; Surr, Schuchman & Montgomery, 1978), whereas other studies have not confirmed these associations (Hosford-Dunn & Baxter, 1985; Hutton, 1985; Jerger & Hayes, 1974; Kapteyn, 1977).

Mulrow and Tuley (1992) assessed to know the factors that could predict the hearing aid outcomes in elderly individuals. The factors that predict the likelihood of elderly individuals with hearing loss who would probably benefit from hearing aids included age, education, functional handicap, degree of hearing loss, amount of hearing and speech recognition gain achieved with hearing aid, visual acuity, manual dexterity, number of co-morbid diseases, and number of medications. The outcome measures used in their study to assess the hearing aid included questionnaire for checking the satisfaction, functional handicap, and number of hours of use of hearing aid in a week. Several variables, including baseline perceived functional handicap, education, number of medications, and age correlated with individual success measures. However, none of the variables consistently correlated with all success measures and they concluded that no measures were good enough to separate the successful hearing aid candidate from a non-successful hearing aid candidate.

Staehelin et al. (2011) studied the effect of different variables in hearing aid outcomes. The variables considered were type and degree of hearing loss, type of hearing aid, previous experience with the hearing aid, age, gender, attitude towards hearing aid use, difficulties faced in day-to-day situation, perceived self-efficiency in handling advanced hearing aids. They found that the non-audiological factors such as positive attitude towards the hearing aid use, difficulties experienced in everyday situation and higher self-perceived efficiency in handling the advanced devices contributed more to the hearing aid outcomes.

In a similar study done by Hickson, Meyer, Lovelock, Lampert, and Khan (2014), assessment of the contribution of different audiological and non-audiological factors on hearing aid outcomes was carried out. The audiological factors considered were degree of hearing loss, insertion gain of the hearing aid, clarity of the aided sound, comfort with loud sounds. The non-audiological factors considered were self-reported hearing difficulties, attitude towards hearing aid, support of others in using the hearing aid and previous experience with the hearing aid. They found that the higher insertion gains, higher self-reported hearing handicap and positive attitude towards hearing aid use led to better hearing aid outcomes.

From these studies it can be inferred that a several factors contribute to the outcome of the hearing aid in individuals with hearing loss. Considering the influence of hearing loss on everyday life, it is not surprising that the communication demands, needs and habits, their life style, and the personality and other entities of an individual will interact with the physical characteristics like degree of hearing loss, type of hearing loss, and physical electroacoustic characteristics of the hearing aids to produce unique constellation of outcomes from the audiological rehabilitation process.

Need for the study

The primary complaint of the hearing aid user is the difficulty in perception in the presence of background noise (Guimaraes et al., 2006). Hence, the primary goal of the rehabilitation has been to improve the signal to noise level (SNR) for the hearing aid users (Kochkin, 1993, Killion et al., 1998). The commonly used strategies for the improvement in SNRs are use of directional microphones in hearing aids, use of digital noise reduction algorithms, and use of assistive listening devices (ALDs).

The subjective ability to perceive speech in quiet and in the presence of noise may contribute to the variability in the outcomes seen in the hearing aid users. The ability to perceive speech in complex listening situations may not be directly correlated to the regular audiological outcome measures such as degree of hearing loss. The subtle psychophysical difficulties faced by the hearing aid users may actually contribute to the outcome measures. In literature, speech perception abilities in noise are largely correlated to the temporal processing abilities (Dreschler & Plomp, 1980; Hopkins, King, & Moore, 2012; Moore & Lorenzi, 2006; Tyler, Summerfield, Wood, & Fernandes, 1982). The temporal parameters of stimuli can be slow varying overall envelope cues and the temporal fine structure (TFS) cues.

In younger listeners with hearing impairment, it has been found that the temporal processing abilities affect the speech perception in quiet and noise. For example, gap detection threshold correlated well with the speech perception in quiet and in noisy situations(Dreschler & Plomp, 1980; R. S. Tyler, Summerfield, Wood, & Fernandes, 1982). Irwin and Mcauley (1987) showed that the gap detection is also related significantly to the recognition of speech in noise and reverberation by young listeners with hearing loss. It has been inferred by many investigators that the ability to use TFS plays a critical role while listening in the background dips (Hopkins et al., 2012; Lorenzi & Moore, 2009). The authors hypothesized that, when there is a fluctuating background noise the auditory system will analyze the stimulus which is present in the valley. The decision is made whether the stimulus is speech or noise based on the phase locking of the neural fibers to the stimulus. If there are any changes in the phase locking of the auditory neurons in the dips or in the region where the noise energy is less, the system considers it as speech. And uses that information to resolve what is heard. This information is used to understand speech in noise. Therefore, TFS processing abilities also affect speech perception in noise performance.

There exists an individual variability in taking advantage of the dips in the background stimulus to understand the desirable stimulus(Gatehouse, Naylor, & Elberling, 2003). Hopkins, Moore, and Stone (2008) showed that the amount of benefit obtained from introducing additional TFS cues into the speech varied in a group of individuals with moderate cochlear hearing loss. Some of them showed benefits similar to that of normal hearing, whereas a few of them did not show any improvement.

Hence, it can be hypothesized that the ability to use TFS information can be varying in individuals with similar degree of hearing loss. Thus, there is a variability of patterns in real-life performances like listening in background noise which may affect the hearing aid outcome among this group of individuals. In individuals with hearing impairment, the studies have found that the temporal resolution is poor irrespective of the comparisons made at equal sensation levels (SL) or equal sound pressure levels (SPL) (Fitzgibbons & Wightman, 1982). Cudahy (1977) also reported cases of elevated gap thresholds in subjects with high frequency hearing loss.

Based on the studies mentioned in literature, it can be deduced that the temporal processing abilities among individuals with hearing impairment might be affecting the performances in real-life situations in addition to the other variables such as the hearing threshold. The hypothesis can be extended to their effects on the hearing aid outcomes. Good temporal processing abilities become critical for better perception through hearing aid, since there are alterations of the original signal after hearing aid processing. In the present study, efforts were made to see the effect of temporal resolution and TFS processing abilities on the hearing aid outcomes in the individuals with cochlear hearing loss.

The outcome measures used to check the effect of these temporal processing in measuring the benefits from the hearing aid included, aided acceptable noise level (ANL), aided speech to noise ratio required for 50% performance (SNR-50), and the subjective rating on the hearing aid benefit questionnaire.

It has been reported that the ANL measure correlates well with the hearing aid benefits. Researchers have found that the ANLs are much smaller in the full time hearing aid users when compared to non-users (Freyaldenhoven, Thelin, & Muenchen, 2008). Freyaldenhoven et al. (2008) demonstrated that the ANL could predict hearing aid usage with 68% accuracy. The prediction accuracy increased to 91% when the ANL measures were combined with the Ease of Communication (EC) and Background Noise (BN) sub-sections of the Abbreviated Profile of Hearing Aid Benefit (Freyaldenhoven, Nabelek, & Tampas, 2008).

Manjula and Megha (2012) showed a good correlation between the SNR-50 and speech in noise performance measure. They compared the performance of aided and unaided SNR-50 measures with scores on the Hearing Handicap Index. They found that the participants who had poorer SNR-50 had greater difficulties on speech in noise perception on the questionnaire. Rowland, Dirks, Dubno, and Bell (1985) showed poorer correlation between the SNR-50 measure and the self-assessment scale performance.

Since these measures take less time for administration, it would be interesting to know if ANL and / or SNR-50 could replace the questionnaire and thus help in making a decision about hearing aid recommendation even before the purchase of a hearing aid.

Further, since the main complaint of hearing aid users is understanding speech in noise, finding out the role of evaluating temporal processing abilities would also help in informing the clients about the amount of benefit that a person with HL may derive before the purchase of a hearing aid. Thus, it would be interesting to investigate the role of temporal processing, such as resolution and fine structure, on hearing aid benefit including speech perception.

Aim and objectives of the study

The aim of the study was to investigate whether the temporal processing can be used to predict the hearing aid outcome. The specific objectives of the study are given below.

1. To assess the relationship of temporal processing with the acceptable noise levels. In case if there is a correlation, to analyze the ability of temporal processing to predict ANL.
2. To assess the relationship between temporal processing and SNR-50 measures. In case if there is a correlation, to analyze the ability of temporal processing to predict SNR-50.
3. To evaluate the temporal processing and its relation to the benefit of hearing aid through self-assessment hearing aid benefit scales.
4. To evaluate the relationship of ANL and SNR-50 with the self-assessment of hearing aid benefit scale.

The null hypotheses in the present study were

1. There is no relationship between the temporal processing, ANL and SNR-50 measures.
2. There is no relationship between the temporal processing measures and the hearing aid benefit scale.

Chapter 2

Literature Review

The aim of the present study was to investigate the effect of temporal processing on the hearing aid outcome measures. The gap detection test (GDT) and temporal fine structure processing test (TFS1) were utilized to measure the temporal processing. The hearing aid outcome measures included the aided ANL, aided SNR-50 and the subjective questionnaire benefit rating. The relevant literature is reviewed and it is categorized under the following sections:

1. Auditory temporal resolution abilities measured using gap detection test
2. Temporal fine structure processing
3. Review on the hearing aid outcome measures such as
    - Acceptable noise level
    - SNR-50
    - Subjective questionnaires for benefit rating

Auditory temporal resolution

Auditory temporal resolution is defined as the shortest time period over which the ear can discriminate two signals, i.e., auditory temporal discrimination (Gelfand, 2004). The processes involved in the temporal resolution include, detection of the small gap between the stimuli or detection of the amplitude modulations in a stimulus. Forward masking and backward masking can also be regarded under the temporal resolution. The most commonly used paradigm to study temporal resolution is the gap detection threshold (GDT).

Physiology of gap detection

To understand whether the cochlear hearing loss hampers the temporal resolution it is important to know the model of temporal processing in the normal auditory system. Then the effects of cochlear hearing loss on different stages of the model can be correlated to the deficits seen in them.

The widely accepted model of gap detection includes four stages of processing. This is as follows,

a. Bandpass filter

They reflect the auditory filters. When a brief signal passes through this filter the output of the filter is not equal to the input but the output is longer. And the general trend is the narrower the filter, the longer the output of the filter. This affects the gap detection ability. The bandwidth of the auditory filters decreases as the frequency decreases (Glasberg & Moore, 1990) and hence there are less temporal resolution abilities at the lower frequencies.

b. Non-linear filter

Every filter is followed by a non-linear device. It reflects several processes occurring at the level of peripheral system. The non-linearity here involves half wave rectification (only one of the polarities of the stimulus being passed and the other sent to zero) and compressive input-output functioning of the basilar membrane (Oxenham & Moore, 1994; Moore, Peters & Glassberg, 1996).

c. *Sliding temporal wave integrator*

The output of the non-linear device is given to a smoothing device called as sliding temporal integrator (Moore et al., 1988) or a low pass filter (Viemeister, 1979). This process usually occurs above auditory nerve and hence it is a more central process. The auditory system takes some time to build up and decay in response to input stimulus, as a result, rapid fluctuations are smoothened and the slow fluctuations are preserved. The brief rapid gaps will be represented as filled dips.

d. *Decision device*

The decision device responds according to the task. If it is to find the gap in the stimulus it looks for the dips in the output of the integrator and if the task is to identify the amplitude modulations it assesses the amount of modulation in the output.

Effect of pathological changes in auditory system,

The effect of different pathologies includes pathology from the cochlea to the cortex. The effect depends on many factors such as the influence of presentation level, change in compressive non-linearity and type of pathological condition.

Influence of type of pathological condition

In case of **conductive hearing loss,** there is attenuation in the energy reaching the cochlea. If the presentation level is kept at higher level there will not be any effect on the gap detection performance since the other parts of the model are intact.

In case of **sensorineural hearing loss having the cochlear origin,** the gap detection threshold is going to be affected because of its influence on different stages of the model. The effect is on the band pass filtering stage and the compressive non-linearity.

Influence of change of compressive non-linearity in case of cochlear hearing loss

There is a rapid growth of loudness due to the change in the compressive non-linearity in individuals with cochlear hearing loss. . Hence, the inherent fluctuations in the noise will be over amplified (Moore, Wijtczan, & Vickers, 1996) which will be potentially confused as the gaps in them. Hence, this phenomenon is not noticed in the stimuli such as pure tones, which does not possess any internal fluctuations **(**Moore & Glasberg, 1998, Moore, Glasberg, Donaldson et al., 1989)**.** In such stimuli, the gap detection threshold is similar to that in normal hearing.

To assess this theory Glassberg and Moore (1992) assessed the effect of higher amplitude fluctuations on normal hearing. The unprocessed steady-state stimuli were given to individuals with hearing impairment. The normal hearing individuals were given with processed stimuli having greater fluctuations. The individuals with normal hearing got the scores similar to the group of individuals with hearing impairment when the higher fluctuations were given in the stimulus. Hence, they suggested that the possible reason for the abnormal gap detection in these individuals is because of the cochlear process.

Influence of degree of hearing loss

As explained earlier the listeners with hearing impairment of cochlear origin will have problem in temporal resolution when the stimulus has fluctuating energy. The studies were done to assess the influence of the degree of hearing loss on the gap detection threshold of cochlear origin.

Matos and Frota (2013)studied the influence of degree of hearing loss on gap detection threshold. They compared the performance on gap detection test (using broad band stimuli) in 22 individuals with normal hearing with 17 individuals having mild and 18 individuals having moderate sensorineural hearing loss. The mean age range of the participants were 45.4 (9.6 standard deviation) with the range of 20-59 years. The results showed that there were no differences in the mean gap detection threshold between the groups.

Florentine and Buus (1984) compared the performance on gap detection threshold in individuals with normal hearing, up to moderate degree of sensorineural hearing loss and simulated sensorineural hearing loss using a broad band stimulus of energy below 7 k Hz. The results revealed that both the groups with simulated hearing impairment and sensorineural hearing loss yielded poorer gap detection threshold than the group with normal hearing. Although there were differences between the simulated and actual hearing loss group, the overall mean remained similar. They showed that the gap detection threshold ranged from near normal to 8 ms with the low pass noise (having low cut 7 kHz) which is in agreement with our study. They suggested that the auditory filter that might be wider in the actual hearing loss group is responsible for the difference. They suggested that the temporal resolution ability depends on the trade off between the widened auditory filters (the wider the filter lesser is the ringing in the output causing better gap detection) and the sliding temporal integrator (the greater the integration time poorer will be the gap detection). In cochlear hearing loss group they have wider auditory filters and slower temporal integrator. Hence, the gap detection threshold will depend on the width of the auditory filter and the amount of time taken in the sliding temporal wave integrator.

It has been suggested that the individuals who have a larger GDT for the stimuli with lesser inherent fluctuations (example: pure tone) or for broadband stimuli (e.g., broadband noise) may have a higher degree of hearing loss or they must have some **retro cochlear involvement** (Glassberg & Moore, 1992). In case of retrocochlear involvement, the problem will be in the sliding wave integrator where the output may not be smooth due to dys-synchronous firing.

The studies have been done to assess the effect of **cortical lesions** on gap detection threshold and it was found that, the lesion at the level of auditory cortex deteriorates the performance on gap detection. Hence, the temporal gap detection is also considered as a central auditory process.

Syka, Rybalko, Mazelová, and Druga (2002) studied the effect of bilateral cortical ablations on the gap detection threshold in rats. The primary auditory cortical ablation was carried out in the rats and their gap detection thresholds were measured before and after the ablation (immediate and 1 month post-ablation). The mean gap detection thresholds for broadband stimuli showed that even though thresholds improved after one month of ablation, the thresholds were still poorer than the pre-ablation conditions. They suggested that the cortical lesions may impair the mechanisms involved in temporal resolution, learning and retention of memory traces.

Musiek et al. (2005) studied the gap detection threshold in confirmed cortical lesions. He studied the gap detection threshold using the GIN test in 50 control participants with no hearing loss and 18 participants having a central auditory nervous system (CANS) lesion. They had lesions confined to brain stem (caudal to the medial geniculate body) or the cerebrum (rostral to medial geniculate body). The pure tone threshold of the individuals with CANS lesion had normal pure tone thresholds. All the participants with CANS lesion showed significantly larger gap detection threshold (mean gap detection threshold of 7.8 ms) than the control group (mean gap detection threshold of 4.9 ms). These findings suggest that the gap detection requires normal cortical functioning.

Effect of gap detection threshold on speech perception

Dreschler and Plomp (1980) studied the effect of the loudness perception, gap detection threshold and frequency selectivity on the speech perception (using nonsense CVC syllables). 25 participants in the age range of 13-20 years, having hearing sensitivity within normal limit were considered for the study. All the mentioned psychophysical measurements were done for the frequencies 500, 100, 200 Hz. They showed that there was an effect of temporal resolution and frequency selectivity on speech perception. The phoneme recognition scores, reduce with the increase in the gap detection threshold and frequency selectivity. They mentioned that there is a trade off between the temporal resolution and the frequency selectivity (with increase in gap detection threshold the frequency selectivity reduces). This might influence the speech sound discrimination.

Lutman (1990) studied the effect of frequency resolution and the temporal gap detection threshold on the sentence identification in noise in older individuals (age greater than 55 year). The results showed that the temporal resolution influenced the speech perception more than the frequency resolution. The poorer the temporal resolution there is more deterioration in the speech perception in noise. They noticed that, when the individuals with extremely poor temporal resolution were eliminated from the study, this effect was not present. The variability in this study compared to other studies can be due to the highly redundant speech material used in the study. Sentences are easier to identify when compared to non-sense syllables and the words which are used in other studies.

Snell, Mapes, Hickman, and Frisina (2002) studied the effect of aging on frequency selectivity and temporal resolution and their effect on speech perception (using NU-6 words). They measured the gap detection threshold using the white noise and it's relation to the speech perception in the presence of noise (white noise and the babble) was measured. The results showed that with the increase in the gap detection threshold, the speech perception scores reduced in the presence of babble but there was no difference in the presence of white noise. This might be because the babble has more fluctuations in the noise spectrum compared to the white noise. The better the gap detection thresholds the better will be the separation of speech and noise in the valleys of the noise. Hence this may help in better speech perception.

The individuals with good temporal gap detection will be able to use the speech information whenever there is a valley (reduction) in the spectrum of the noise by separating it from the background noise. But when they have poor temporal resolution they will not be able to separate the speech information. This was tested by Glasberg, Moore, and Bacon (1987) by assessing the gap detection threshold relation to the forward masking paradigm. They noticed that the larger gap detection thresholds were associated with the slower recovery from forward masking in individuals with hearing impairment.

The other factors affecting gap detection thresholds include:

Age influences the gap detection threshold. The younger group with age less than 10-12 years performs poorer (Irwin, Ball, Kay, Stillman, & Rosser, 1985) than adults. The older adults may perform poorer than younger adults (Fakruddin & Rajalakshmi, 2006). The gap detection threshold may depend on the stimulus. It also depends on the location of the gap in the stimulus. It is found that the gap detection thresholds are best for the stimuli having gap in the center of the stimuli (Green & Forrest, 1989).

The broadband stimuli have better gap detection threshold when compared to the narrow band stimuli (Irwin & Purdy, 1982). In a broad band noise (BBN) stimulus the gap detection threshold depends on the actual gap without many cues derived from the abrupt envelop changes, whereas the narrow band stimuli will have the rapid fluctuations present in them.

Hence, it can be concluded that the gap detection thresholds are affected in the individuals with hearing impairment. In individuals with hearing impairment the effect on gap detection depends on the degree of hearing loss, type of hearing loss and the amount of fluctuations in the stimuli. They play a significant role in the perception of the speech both in quiet and in the presence of noise.

Temporal fine structure processing

An incoming stimulus consists of fluctuations in the envelope (the relatively slow variations in amplitude over time) and fluctuations in the temporal fine structure (TFS, the rapid oscillations with the rate close to the center frequency of the band). The use of temporal fine structure increases the accuracy of coding the periodicity in the stimulus. But it requires greater phase locking and it is usually present till 4 to 5 kHz, and above this frequency the information of frequency is largely given by the overall change of envelop of the signal.

Coding of the temporal fine structure cues in auditory system will be based on spectro-temporal mechanism (Moore, 1982, 2003). The acoustic input will pass through the bank of band pass filters which will be transduced to the neural impulses in the specific place. This part of the model is the spectral portion of the spectro-temporal mechanism. The neural spikes generated will be in specific intervals corresponding to the fundamental frequency of the incoming stimuli. These intervals are maintained well for the low frequency but not for higher frequencies because of reduced phase locking in the higher frequencies. In most mammals, phase locking is weak for frequencies above 5000 Hz (Palmer & Russell, 1986), so TFS information is presumably not conveyed to the brain, or is conveyed with reduced accuracy, for frequencies above 5000 Hz. Change in the phase of any component of the fine structure may result in change in the overall envelop of the stimulus. Hence in the higher frequencies the information is majorly conveyed through the overall envelop change rather than the TFS cues.

Effect of cochlear hearing loss

The cochlear hearing loss is usually associated with reduced frequency selectivity and the broader auditory filters. Hence the place mechanism might be affected in the cochlear hearing loss which may lead to poorer temporal coding.

The ability to utilize the TFS cues in moderate cochlear hearing loss is noticed to be reduced (Hopkins & Moore, 2007). In the study the authors compared nine individuals having normal hearing and seven individuals having hearing impairment on their performance in identification of the harmonically shifted tones above 11^{th} or 18^{th} harmonic.

Lorenzi, Debruille, Garnier, Fleuriot, and Moore (2009) assessed the low frequency TFS processing in the individuals having high frequency sloping hearing loss. The participants had near normal thresholds (<20 dB) below 1.5 k Hz frequency and TFS processing was assessed in that region. The results indicated that the processing of temporal fine structure information was reduced even in the region with near normal threshold. Hence, they concluded that normal audiometric thresholds may have strong TFS processing deficits.

From these studies it is clear that the individuals with cochlear hearing loss may have poorer TFS sensitivity. The effect of cochlear hearing loss can be noticed even with less degrees of hearing loss as mentioned above or even in the region where the pure tone thresholds are normal.

Effect of temporal fine structure processing on speech perception

Whenever speech is presented in the presence of background noise, the intelligibility is more when it is presented in the presence of modulated noise. It is referred to as “listening in dips”. The possible hypothesis for the improvement is identification of the temporal fine structure in the dips which helps to identify the message.

To test this Shannon, Zeng, Kamath, Wygonski, and Ekelid (1995) measured the intelligibility of speech using only the envelope cues in quiet and in the presence of noise. They developed noise-vocoded sentences. The results revealed that the removal of temporal fine structure cues had little effect on the speech perception when it was presented in quiet. But in the presence of noise the performance with the noise-vocoded speech reduced. This indicates that the speech perception in noise requires use of temporal fine structure cues. Similar findings were suggested by Dorman, Laboratories, and Haven (1977), and Stone, Moore, and Fullgrabe (2011). This reduction in intelligibility is likely to be partly due to the reduced spectral information available in the vocoded signal.

Gilbert, Bergeras, Voillery, and Lorenzi (2007) measured the VCV identification with natural stimuli, stimuli having only envelope cues and stimuli having only fine structure cues. The performance was compared across young individuals having normal hearing, young and older individuals with moderate SNHL. The outcome revealed that the individuals with hearing impairment performed on par with individuals with normal hearing for unprocessed stimuli and for stimuli having envelope cues. Their performance was significantly poorer when the TFS alone was given showing poorer sensitivity of these individuals to process the TFS cues.

The ability to utilize temporal fine structure in cochlear hearing loss is limited and it is variable in individuals with similar audiometric patterns (Hopkins, Moore, & Stone, 2008; Hopkins & Moore, 2010b; Strelcyk & Dau, 2009). There was a good correlation noticed between the monaural temporal fine structure sensitivity and the speech reception threshold (SRT) but there was no correlation of SRT to binaural TFS sensitivity (Hopkins & Moore, 2011). Thus, it can be hypothesized that the ability to utilize the temporal fine structure information might influence the hearing aid outcomes.

The importance of temporal fine structure in identification of consonants was assessed in individuals with normal hearing (Sheft, Ardoint, & Lorenzi, 2008). The natural stimulus was filtered to selectively eliminate the envelop cues and fine structure cues. The study revealed that the TFS cues are important for recognition of place of articulation and the envelop cues are important for recognition of manner cues.

Other functions of TFS processing

There are several assessments done to assess the role of temporal fine structure in everyday listening situations. The temporal fine structure information mainly contributes to the pitch perception of complex tones (Xu & Pfingst, 2003; Zeng et al., 2004), and speech in noise (Apoux & Healy, 2011; Lorenzi & Moore, 2009).

Hence, it is clear that the cochlear pathology affects the processing of temporal fine structure irrespective of presence or absence of hearing loss. The temporal fine structure processing is important for speech in noise perception.

Hearing aid outcome measures:

Acceptable noise level

In an attempt to find the reasons for dissatisfaction of the hearing aids from hearing aid users Surr, Schucham, and Montgomery (1978) identified background noise as the major reason of dissatisfaction. The hearing aid benefit or the use was weakly correlated with the performance on speech in noise (SPIN) test and the self-assessment of communication performance (Benter, Neibuhr, Getta, & Andeerson, 1993), speech perception scores obtained with the nonsense syllables and sentences (Humes, Halling, & Coughlin, 1996).

Hence, to see the effect of background noise on hearing aid users, Nabelek, Tucker, and Letowski (1991) assessed the 'tolerable speech to noise ratios (SNR)', now referred to as 'acceptable noise levels' or 'ANL'. They considered 15 older and younger adults with hearing impairment using hearing aids. They were grouped on the basis of hearing aid use as full-time hearing aid users, part-time hearing aid users and non-users. They were tested to find the maximum tolerable background noise (speech babble, speech spectrum noise, traffic noise, music and pneumatic drill noise) for a speech stimulus (story read by a female set at comfortable level). And also they assessed the self-assessment of hearing handicap while wearing the hearing aid. They found a significant interaction of noise and the hearing aid use. The full-time users of hearing aid tolerated higher level of speech spectrum noise and music compared to the part-time users and non-users. In addition, full-time users assessed themselves as less handicapped in everyday listening situations compared to the part-time users and non-users.

This study led to the development of the procedure called 'acceptable noise level' (ANL) to assess the amount of background noise that a listener is willing to accept when listening to speech. The ANL is defined as the difference between the most comfortable listening level (MCL) for running speech and the maximum background noise level (BNL) that a listener is willing to accept.

Physiology behind acceptable noise level

There have been many attempts made to find out the physiology behind variability in acceptable noise level among different listeners. The studies have tried to correlate different physiological measures with acceptable noise level in order to assess whether it is a central or a peripheral phenomenon.

Harkrider and Smith (2005) assessed the relationship between ANL and middle ear impedance measures, acoustic reflex thresholds using tonal or broadband noise stimuli and with the contralateral suppression of click evoked otoacoustic emissions (CEOAEs). But ANLs were unrelated to any of the measures considered. Hence, they concluded the variability in ANL is not due to partition of middle ear characteristics, acoustic reflex pathway or medial olivocochlear bundles (MOCB). They found that the monotic and dichotic ANLs were related. Hence, they inferred that the non-peripheral pathways might be mediating ANL.

Tampas and Harkrider (2006) conducted a study to find the source of variability in ANL among 21 female participants having normal hearing. Ten of them had ANL of ≤7 (low ANL group) and 11 had ANL ≥13 (high ANL group). The testing was carried out at 35 dBHL presentation level, MCL and at 70 dB to find out the ANL. To find the source of group difference of the ANL measures, differences in the auditory brainstem responses (ABR), auditory middle latency responses (AMLR), Auditory Long latency responses (ALLR) among these participants were assessed. They found significant difference in amplitude of AMLR (Na-Pa) and ALLR (P1-N1, N1-P2) compared to the ABR in these groups. The low high ANL group had smaller amplitude compared to high ANL groups. The possible explanation given was the central efferent mechanisms are stronger and the responses are not suppressed or the central afferent mechanism is less active in high ANL group. Hence, they concluded that more of central phenomenon contributes to ANL variability.

Harkrider and Tampas (2006) in a similar study including the female participants with low (Number of participants=6) and high ANL (number of participants=7) with normal hearing were assessed for differences in CEOAEs, ABRs measured binaurally, and MLRs. The group differences were noticed in amplitude of wave V of ABR, Na-Pa component of MLR. Hence, they suggested that the central region of auditory system may mediate the background noise acceptance.

A similar study (Shetty, Mahadev, & Veeresh, 2014) measured the signal to noise ratios and amplitude differences in speech evoked ABR (complex ABR) and ALLR in 23 individuals with normal hearing. The participants were divided as Low ANL group (number of participants=14) and High ANL group (number of participants=9). The differences were noticed in the peak to peak amplitude of V-A of cABR and N1-P1 of LLR.

All these studies suggest that the ANL variability mainly arises from the central auditory nervous system and it is not a peripheral phenomenon. But there is no study in literature investigating the source of variability in individuals with hearing impairment.

Effect of hearing loss on acceptable noise level

Recker and Edwards (2013) compared the ANL for 10 normal hearing individuals to 10 individuals with hearing loss. They found that the ANL did not differ between group of individuals with normal hearing and hearing loss. The possible reason for this might be that the ANLs are the central measures and hence, it can be concluded that the ANL is not affected by the hearing loss.

Factors affecting the acceptable noise level

As the presentation level increases the ANL decreases (Freyaldenhoven, Plyler, Thelin, & Hedrick, 2007; Franklin, Thelin, Nabelek, & Burchfield, 2006; Agarwal & Manjula, 2008). The ANLs are similar for both monaural and binaural conditions (Rogers, Harkrider, Burchfield, & Nabelek, 2003). But the differences can be noticed when there is a difference in inter-aural processing. The noise reduction strategies are noticed to improve ANL include, directional microphones (Nabelek, Freyaldenhoven, Tampas, Burchfield, & Muenchen, 2006), digital noise reduction strategies (Mueller, Weber & Hornsby, 2006; Agarwal & Manjula, 2008) and FM devices (Bhavya & Mamatha, 2009).

To summarize, the ANL is not affected by cochlear hearing loss and it involves more of a central processing. Studies show that the ANL can be effectively used to study the hearing aid outcomes.

SNR-50

It is the signal to noise ratio required to achieve 50% of speech intelligibility (Killion, 1997). Since the majority of the patients complain about the poor speech in noise perception through the hearing aids, aided SNR-50 may give better picture of the outcome of the listening in daily life situation. There are different measures used to evaluate the performance of speech in the presence of noise. Some of them include Hearing in Noise Test (HINT) and Speech in Noise test (SIN). But these procedures require more time to administer. Hence, a relatively quick measure which is gaining popularity is SNR-50 measure.

A study was done to predict the hearing aid outcomes using audiological and non-audiological factors (Walden & Walden, 2004). studied many factors affecting hearing aid outcomes such as age of the patient, pure-tone average (1, 2, 4 kHz) in better ear (dB HL), unaided articulation index (0–100; “count the dots”), aided articulation index (0–100; “count the dots”), recorded NU-6 word identification in quiet at 80 dB HL in better ear (%), unaided QuickSIN (SNR loss in dB), aided QuickSIN (SNR loss in dB), experience with current hearing aids (months), the duration of experience with amplification (years), use of hearing aid per day (hours). The SNR loss which was measure using the QuickSIN test provided best predictor of hearing aid outcome.

Aided SNR-50 measures have been potentially used to measure the outcome of the middle ear implants. Wolframm, Giarbini, and Streitberger (2012) measured the directional microphone benefits used in the middle ear implants by comparing the SNR-50 in omnidirectional and directional modes. The SNR50 showed a significant directional advantage for the directional processing.

Effect of hearing loss

Dirks, Morgan, and Dubno (1982) measured the SNR-50 in individuals with normal hearing and in individuals with mild SNHL. The SNR-50 was measured for monosyllabic and spondee words in the presence of speech noise. They found that the individuals with SNHL required higher SNRs to obtain 50% scores even though the performance in quiet of both the groups was comparable.

Dubno, Dirks, and Morgan (1984) studied the effect of hearing loss on SNR-50 among individuals with normal hearing and mild SNHL across young (less than 45 years) and older population (greater than 65 years). They measured the SPIN word identification in the presence of the multitalker babble noise. They noticed poorer performance of older group compared to younger group and SNR required were higher for the groups with SNHL.

Manjula and Megha (2012) measured SNR-50 among different groups of individuals. They found that the SNR-50 increases with the increase in the degree of hearing loss. The individuals with SNHL required higher SNRs followed by conductive hearing loss group further followed by those with normal hearing.

Effect of noise reduction strategies

SNR-50 is shown to be better in the hearing aids having noise reduction strategies and directional microphones (Boymans & Dreschler, 2000; Peters, Kuk, Lau, & Kunan, 2009).

Aleantara, Moore, Kuhnel, and Luner (2003) measured the SNR-50 with and without the DNR in aided condition. There was no significant difference noticed across the conditions. Manjula and Megha (2012) measured the effect of DNR on the SNR-50 measures. They found that there was a significant improvement in SNR-50 with the DNR 'on'.

Subjective benefit assessment

The subjective questionnaires are important as an outcome measure as the laboratory results may not always be truly applicable in the natural situations that the hearing aid user faces in day-to-day life. Simply by asking yes / no questions, the examiner may miss out the extent of challenges faced by the hearing aid wearer (Abrams, 2001). Hence, a questionnaire needs to be comprehensive. Often we are not only interested in the aided performance, but also in the improvement in the aided condition over the unaided condition. This is generally referred to as a 'measure of benefit, rather than performance' (Humes, 2004). Humes opines that if the same questionnaire of handicap measure is administered before and after the hearing aid usage, then it can be termed as a benefit scale. The author has recommended using subjective benefit rating along with the aided tests in the laboratory set-up to give better measure of outcome of the hearing aids.

Relationship among the outcome measures

Acceptable noise level and the subjective measures of outcome or handicap

Freyaldenhoven, Nabelek, and Tampas (2008) measured the relationship between the ANL and Abbreviated Profile of Hearing Aid Benefit (APHAB) collected from 191 hearing aid users. The results showed that there was no significant correlation between the APHAB and ANL. The prediction of hearing aid outcome was 60% accurate using Ease of Communication (EC) and Background Noise (BN) of APHAB and with the ANL it was 85% accurate. The prediction accuracy increased to 91% when both the measures were combined.

The relationship between the ANL and speech perception in noise scores (SPIN) were measured in 41 full-time users and 9 part-time users of hearing aid (Nabelek, Tampas, & Burchfield, 2004). The results showed that the two measures were unrelated as the SPIN was not related to hearing aid use or satisfaction.

SNR-50 and the subjective measures of outcome or handicap

Tyler and Smith (1983) compared the performance of individuals with hearing impairment on CID sentences at 0 dB SNR (using speech spectrum noise) with the Social Hearing Handicap Index (SHHI) and Hearing Measurement Scale (HMS). The results showed that the poorer the speech in noise performance the higher the rating on handicap scale. They attributed the lack of correlation to the influence of non audiological factors like the desire not to appear handicapped.

Manjula and Megha (2012) showed a good correlation between the SNR-50 and speech in noise performance using a self-assessment of hearing handicap questionnaire. They compared the performance of aided and unaided SNR-50 (using the speech noise) measures with scores on the Hearing Handicap Index. They found that poorer the SNR-50 the higher the speech in noise difficulties on the questionnaire. Whereas Rowland, Dirks, Dubno, and Bell (1985) showed poorer correlation between the SNR-50 measure and the self-assessment scale performance.

To summarize, the temporal processing might be a potential variable affecting the hearing aid outcomes as it affects the speech perception in quiet as well as in noise. There is a dearth of studies done in this area to assess the influence of temporal processing on hearing aid outcomes. Hence, two measures of temporal processing were evaluated in the present study, temporal resolution which is a representation of coding of overall envelope of the signal and processing of temporal fine structure which is found to affect speech in noise performance. A combination of outcome measures has been used to find out the relationship of these measures on the outcome with the hearing aid.

Chapter 3

Method

The aim of the study was to investigate whether the temporal processing affects the hearing aid outcomes. The temporal processing measures included in the study were gap detection threshold and temporal fine structure; whereas the hearing aid outcome measures included ANL, SNR-50 and hearing aid benefit questionnaire.

The specific objectives were:

1. To assess the relationship of temporal processing with the acceptable noise levels. In case if there is a correlation, to analyze the ability of temporal processing to predict ANL.
2. To assess the relationship between temporal processing and SNR-50 measures. In case if there is a correlation, to analyze the ability of temporal processing to predict SNR-50.
3. To evaluate the temporal processing and its relation to the benefit of hearing aid through self-assessment hearing aid benefit scales.
4. To evaluate the relationship of ANL and SNR-50 with the self-assessment hearing aid benefit scale.

3.1. Participants

All the participants were native Kannada speakers in the age range from 15 to 55 years (mean age of 37 years). Two groups of ears of participants were considered, one group having 10 ears with mild sensorineural hearing loss (SNHL) and the other group having 12 ears with moderate SNHL.

3.1.1. Inclusion criteria

Ten naive hearing aid users in the mild SNHL category were considered in Group I. Experienced hearing aid users with moderate SNHL were considered were considered in Group II. The ear in which they used the hearing aid was tested. The ear with lesser degree of hearing loss was tested in case of participants using binaural hearing aid. All the participants had flat audiogram configuration, i.e., the thresholds across frequencies did not vary by more than 20 dB (Pittman & Stelmachowicz, 2003). Written informed consent was taken from each of the participant prior to the data collection. The guidelines put forth by AIISH ethical committee were followed during the study.

3.1.2. Exclusion criteria

Any individual with apparent middle ear dysfunction or retrocochlear pathology was excluded. Individuals with any history or complaint of cognitive, behavioral or neurological problems were excluded.

3.2. Test environment

All the tests were conducted in an air-conditioned sound treated single or double room set-up having permissible ambient noise level.

3.3. Instruments and material used

- A calibrated the diagnostic audiometer with the loud speaker located at one meter distance and 0^0 Azimuth was used to measure the GDT, ANL and SNR-50.
- **For measurement of temporal processing**
  a) Freely downloadable software (TFS1 software, 2009) was installed on the Dell Inspiron 1545 laptop. The test was administered by presenting the stimulus through Sennheiser HDA 200 headphones connected to the laptop. The stimulus output through the headphones was calibrated.
  b) The gap detection thresholds were measured through the calibrated diagnostic audiometer. The stimuli were presented through calibrated TDH-39 headphones encased in circumaural ear cushion. The Gap Detection Test prepared by Shivaprakash and Manjula (2003), was used to establish the gap detection threshold.
- For measurement of ANL, a recorded Kannada passage and Kannada four-speaker multi talker babble developed by Kumar (2012) were used.
- For measurement of SNR-50**,** Phonemically Balanced (PB) test material in Kannada developed by Manjula, Geetha, Kumar, and Antony (2014) consisting of

21 lists, each list consisting of 20 bi-syllabic words were used to obtain the SNR-50. In addition, Kannada four-speaker multi talker babble (Kumar, 2012) was used to obtain the SNR-50.

- The hearing handicap scale titled Self-Assessment of Hearing Handicap (Vanaja & Nikam, 2000) was used with modification in rating from a three-point to five-point rating scale. As this questionnaire was administered without and with the hearing aid usage, the questionnaire was called Self-Assessment of Hearing Aid Benefit (Humes, 2004).

3.4. Procedure

Within the group experimental design was used for the study. For each participant, data on the following measures were collected:

1. Temporal processing measures
    a) The temporal fine structure (TFS) sensitivity
    b) The gap detection thresholds (GDT)
2. Hearing aid outcome measures
    a) The acceptable noise level (ANL) in aided condition
    b) SNR-50 in aided condition
    c) Self-Assessment of hearing aid benefit scale was administered for the experienced hearing aid users having moderate SNHL.

3.4.1. Measurement of Temporal fine structure (TFS) sensitivity

The sensitivity to TFS was measured using TFS1 test (Moore & Sek, 2009). The testing was carried out monaurally. The ear which fulfilled the inclusion criteria was tested. The task of the participant was to discriminate the tones having a harmonic complex from another complex stimulus having a shift in the frequency of harmonic component by certain Hertz.

- The hearing threshold was established for the two fundamental frequencies (i.e., F_0 of 100 and 500 Hz). The TFS testing was carried out at 20 dBSL (re: hearing threshold of the F_0) (Hopkins & Moore, 2010a; Moore & Sek, 2009) in the test ear.
- The test stimuli consisted of two types of stimuli. One being harmonic complex (H) having multiple harmonics of the fundamental frequency (F_0) added, each starting in sine phase. The other stimulus was inharmonic complex (I) where the harmonic complexes of F_0 were shifted upwards in frequency (in Hertz) by some amount called ΔF. The shifts in ΔF of the harmonics were generated for the harmonics above 9^{th} harmonic to have all the harmonics unresolved.

  For example, for a F_0 of 100 Hz, the HHHH pattern had all the components having harmonics of 100 Hz. The HIHI patterns with ΔF of 50 Hz had alternating stimuli of one component having all the harmonics of 100 Hz (H) and the other component having a shift of 50 Hz in the harmonics above 900 Hz (I). Figure 3.1 depicts an example of harmonic and inharmonic components.

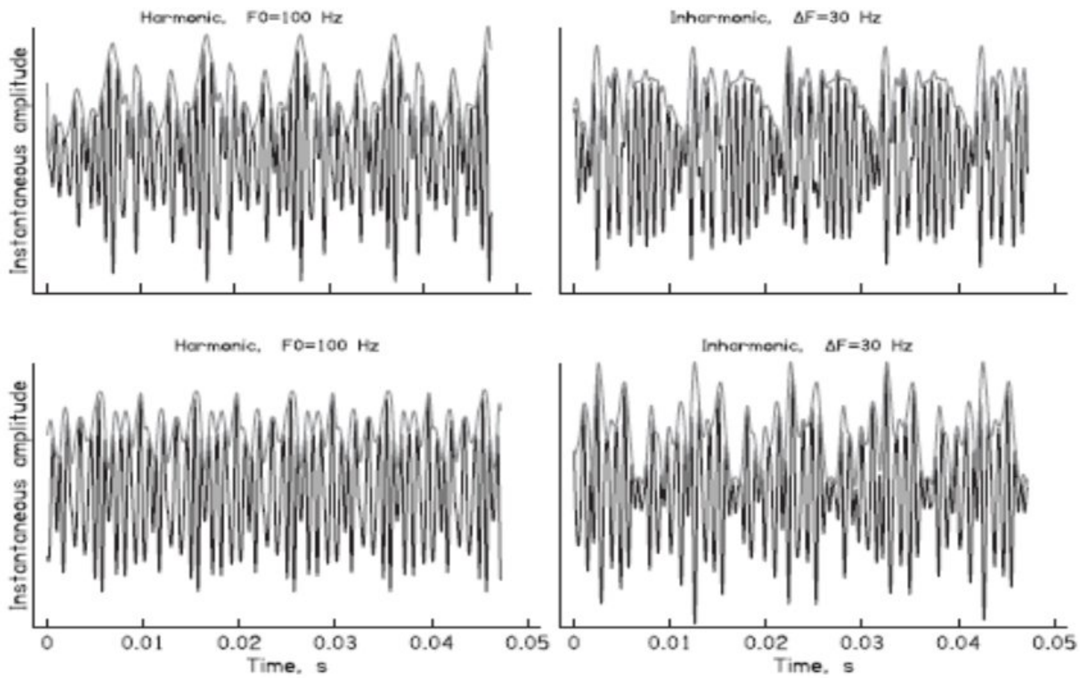

Figure3. 1 *Sample waveforms depicting the stimuli (thin lines) and their envolopes (thick gray lines). The left panel is showing the harmonics of* F_0 *of 100 Hz and the left down pannel depicting the same stimulus after bandpass filtering at 1100 Hz. right handed top pannels are showing the same stimuli with inharmonic tone generated by a shift in frequency (ΔF) of 30 Hz.*

Note: "Development of a fast method for determining sensitivity to temporal fine structure" by Moore and Sek, 2009, *International Journal of Audiology, 48,* p. 163. Reprinted with permission.

- During the testing, the participant was presented with two sets of stimuli each having four complex tones in it. One of the sets (either 1st or 2nd) had all the tones having harmonic complex (making the pattern HHHH) and the other in the set had alternating harmonic and inharmonic complex (HIHI pattern). The participant was asked to identify the set having the fluctuating signal (i.e., HIHI pattern). This was done by clicking on the appropriate box on the computer screen. Figure 3.2 shows the response screen provided in the TFS1 software.

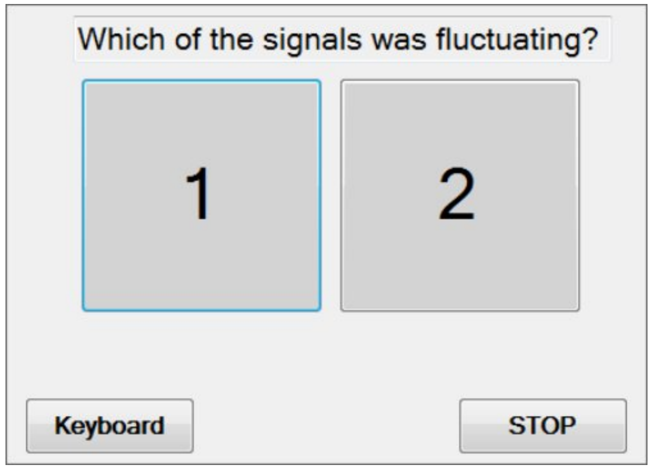

Figure3. 2: *The response screen provided in the TFS1 software*

- The sensitivity thresholds were measured adaptively using a two-interval two-alternative forced choice (2I-2AFC) method.

- The value of ΔF was varied adaptively using a 2I-2AFC method to estimate the 'sensitivity threshold'. The sensitivity threshold was defined as the minimum shift of frequency required for the participants to identify the change in the stimuli corresponding to 70.7% correct responses.

- The ΔF was calculated using two down-one up procedure. A minimum of two stimuli were presented at each ΔF condition. The change in the direction of the ΔF variation was considered as one turn point. For example, the test begins with ΔF of 0.5 of F_0. It reduces adaptively if the individual is able to discriminate the stimuli correctly for two presentations. This will be considered as one turn point.

- However if the participant is not able to discriminate, the ΔF will not increase above 0.5 of F_0. One more set of stimuli (second stimuli with $0.5*F_0$) will be presented to the participant. If he/she is unable to discriminate again the procedure will change into the non-adaptive run.

- That is, when the participant was not able to discriminate the two sets of stimuli even when the maximum ΔF was reached, twice before the second turn point, the adaptive procedure was automatically stopped and the program reverted to non-adaptive procedure. Here, the ΔF is fixed at the maximum value (i.e., $0.5*F_0$) and 40 trials were presented. The total numbers of items correctly recognized out of 40 stimuli were obtained.
- To compare the results obtained from adaptive run and the non-adaptive run, all the results were converted into Discriminability Index (d') values (Green & Swets, 1974) using m-alternative forced-choice procedures table (Hacker & Ratcliff, 1979).
- According to Hacker and Ratcliff (1979), the d' value for 2AFC method arriving at 71% correct score is 0.78.
- To obtain d', this value of 0.78 was divided by the sensitivity threshold obtained through the adaptive procedure and it was then multiplied by $0.5F_0$.

  $d' = (0.78/\Delta F)*0.5F_0$
- The non-adaptive run d' was obtained by multiplying the $0.5F_0$ with the number of correct responses.

  d'= (x/40)*0.5F0 where, x= correctly identified trials
- A masking noise was given along with the stimulus to avoid the combination tones. The noise used was Threshold Equalizing Noise (TEN SPL) (Moore et al.,

2000), extending from 50 to 11,050 Hz at 35 dB below the presentation level as recommended by Moore and Sek (2009). The provision for presenting the noise is in-built in the software. This noise was used as it is designed to mask all the frequency components equally. This, when given at a lower level, helps to mask the combination tones.

- The fundamental frequencies used were 100 Hz and 500 Hz which had changes in the fine structure of the harmonic from 9^{th} harmonic component, i.e., 900 Hz and 4500 Hz respectively.

Thus, the sensitivity threshold for TFS was computed for each test ear of all the participants. This measure was tabulated for statistical analysis.

3.4.2. Administration of Gap Detection Test

The Gap Detection Test developed by Shivaprakash and Manjula (2003) was used to obtain the gap detection threshold.

- The participant was seated comfortably and they were made to wear the headphones of the calibrated audiometer.
- The instruction given was, "Please listen to the set of three noise bursts. One of the three noise bursts in the set will have a gap. You have to identify the burst with the gap and write the number of the burst which contains the gap (i.e., 1^{st} or 2^{nd} or 3^{rd}) on the sheet given. If none of the bursts have a gap, write it as zero. This gap within the burst will be of varying duration. For practice please listen to the sets

now and tell me which of the three bursts has the gap”. The following steps were followed to obtain the GDT:

- Before the actual testing, four stimulus sets were given as practice items. They had gaps of 20, 16, 12 and 10 ms duration. This was meant for practice in order to identify the gaps.
- The actual test had the fifty-six stimuli including six catch trials. The stimulus was presented at 40 dB SL (re: pure tone average) to the test ear using the headphones of the calibrated double channel audiometer.
- The participant had to detect the gap embedded in one of the three bursts.
- Each time the participant identified the gap, the size of the gap was reduced in order to find out the minimum gap that could be detected by him/her. The bracketing approach was utilized for finding out the GDT of the test ear of the participant.
- The minimum gap identified by the participant for each test ear was considered as the gap detection threshold (GDT).

The GDT for each test ear of the participant was thus computed and tabulated for further statistical analysis.

3.4.3. Measurement of Acceptable noise level (ANL)

The procedure described by Nabelek, Freyaldenhoven, Tampas, Burchfield, and Muenchen (2006) was used for establishing the ANL. The ANL measurements were done in the aided condition. The most comfortable level (MCL) for speech and the maximum acceptable background noise level (BNL) were established to compute the

ANL. Though ANL is generally used as a hearing aid predictive measure, in the present study it was used as a hearing aid outcome measure.

- The participant was made to sit comfortably in the test room and was made to wear the hearing aid to the test ear. The non-test ear was blocked using the ear plugs and the ear muff to avoid the participation of the non-test ear. The following steps were followed to compute the ANL for each test ear of the participant.
  - To find out the MCL, the speech stimulus (a Kannada passage) was initially presented at 40 dB HL. Then the level was adjusted by increasing or decreasing the level. The level was varied in five-dB steps initially and then in two-dB steps to establish a reliable MCL level.
  - The instruction given to the participant was, "You will listen to a story through the loudspeaker placed in front of you. The level of the story will be varied. You have to indicate to increase the level or to reduce it, such that the speech is at the most comfortable level".
  - Once the MCL was obtained, the speech was kept constant at this level and the four speaker multi-talker babble (MTB) was introduced. The initial level of presentation of MTB was 30 dB HL. Then, the participant was asked to indicate to the experimenter to adjust it to a point at which they are willing to accept without becoming tired or tensed while following the passage. This maximum level of noise was considered as acceptable background noise level (BNL).
  - Instruction given for this was, "You will now listen to the story with a background noise. After you have listened to it for a few moments, indicate to

adjust the level of background speech babble to a level that you will be able to accept or 'put-up-with', without becoming tensed or tired while following the story".

- The ANL for each participant was calculated by subtracting the BNL from MCL.

  ANL= MCL-BNL

Thus, the ANL was established for each participant and tabulated for further analysis. It must be noted here that the lesser the value of ANL, the better is the performance. That is, an individual performs well even when the difference between the noise and speech is less.

3.4.4. Measurement of SNR-50

The SNR-50 was measured in the aided condition. The following steps were used to find out the SNR-50 for each participant in the sound field condition.

- The PB word list was presented through the loudspeaker of the audiometer located at one meter distance and 0^{o} Azimuth. The MCL for each participant was established. . Then, the presentation level of the test stimuli was kept constant throughout the testing at the MCL.
- Four-speaker multi talker babble was then routed through the same loudspeaker. The initial presentation level of the MTB was 30 dB HL below the level of the speech. Then, the noise level was varied to find out the minimum level of noise where the participant correctly repeated 50% of words presented. At each SNR level, four words were presented.

- The level of the babble was then increased in 5-dB steps, till the participants repeated two out of four (i.e., 50 %) words being presented to them. From this level onwards, the noise was varied in 2-dB steps to obtain more precise level of babble required to elicit 50% of the correct responses. This level of MTB was noted.
- At this point, the difference between the intensity of speech and MTB was considered as SNR-50 measure.

This procedure was administered on all test ears of the participants and tabulated for statistical analysis.

3.4.5. Measurement of hearing aid benefit

The self-assessment of benefit from the hearing aids was obtained using the Self-Assessment of Hearing Handicap (Vanaja & Nikam, 2000). This questionnaire consisted of 22 questions and it typically required 10-15 minutes to administer. This was administered only on the participants with moderate SNHL who had at least six months of experience in hearing aid use.

- These questions investigated the difficulty experienced in different listening situations. The questions were sub-divided into four different categories as understanding speech in quiet, understanding speech in noise, environmental sound awareness and psychological aspects of the hearing problem.
    - The participant was asked to rate the difficulty faced by him/her in different listening situations on a five-point rating scale depending on the amount of difficulty, in the unaided and aided conditions. The rating in a particular situation was such that he/she had to indicate the difficulty by

choosing 0% or 25% or 50% or 100%, where 0% indicated that there was no difficulty and 100% indicated that there was most difficulty.

- The scoring for the rating varied from 1 to 5. The scoring was done in such a way that higher scores (e.g., 5) showed lesser difficulty (0%) in that situation and lower scores (e.g., 1) showed more difficulty (100%). The questionnaire is given in the section Appendix A and Appendix B.
- The benefit from the hearing aid under each of the sub-divisions and the overall benefit were calculated by subtracting the unaided scores from aided scores.
- The questionnaire had 11 questions in speech in quite category giving maximum score of 55, 16 questions in speech in noise section with maximum score being 80, environmental sound section had 13 questions with the maximum score of 65, the psychological aspects section had 8 questions with maximum score of 40 and the overall section in total had 48 questions with maximum score of 240.
- Since the number of questions varied under each subsection the scores were converted to percentage for comparison. The benefit was calculated in percentage for each of those subsections of the questionnaire by dividing the obtained score from the total score of the section and then multiplying it by 100.

$$\text{Benefit of hearing aid in percentage} = \frac{\text{Score obtained on the section}}{\text{Maximum score of the section}} * 100$$

Thus, the questionnaire was administered for each participant. The scoring was computed and tabulated for quiet, noise, environmental sound awareness and psychological aspects sub-divisions, apart from the overall scoring.

Statistical analyses

After obtaining the data on temporal processing (TFS sensitivity threshold and gap detection threshold) and hearing aid outcome measures (ANL, SNR-50 and Questionnaire rating) statistical analyses were carried out using Statistical Package for Social Science (SPSS 20.0 for windows version). The analyses done included,

1. The descriptive statistics to obtain mean, median, standard deviation and range for all the parameters.
2. The Pearson's correlation coefficient to assess the relationship between the hearing aid outcome measures, i.e., self-assessed hearing aid benefit with the aided ANL and aided SNR-50.
3. The Pearson's correlation coefficient to assess the effect of temporal processing on hearing aid outcome measures. The following correlations were analysed,
    a. The relationship of temporal processing with the ANL
    b. The relationship between temporal processing and SNR-50
    c. Temporal processing and its relation to the benefit of hearing aid through self-assessment hearing aid benefit scale
4. The linear regression analysis was carried out on the measures which were related.

Chapter 4

Results

The aim of the current study was to evaluate the relationship between the temporal processing (gap detection threshold and temporal fine structure processing) in individuals with SNHL hearing loss (mild and moderate) and hearing aid outcome measures (acceptable noise level, SNR-50 and self-assessment of hearing aid benefits). The specific objectives included were,

1. To assess the relationship of temporal processing with the acceptable noise levels. In case if there is a correlation, to analyze the ability of temporal processing to predict ANL.
2. To assess the relationship between temporal processing and SNR-50 measures. In case if there is a correlation, to analyze the ability of temporal processing to predict SNR-50.
3. To evaluate the temporal processing and its relation to the benefit of hearing aid through self-assessment hearing aid benefit scales.
4. To evaluate the relationship of ANL and SNR-50 with the self-assessment hearing aid benefit scale.

The data were collected from individuals with mild and moderate SNHL on the gap detection threshold, sensitivity discriminability index (d') of temporal fine structure (TFS), ANL, SNR-50 and subjective assessment of hearing aid benefits. All the data were tabulated and subjected to statistical analyses using Statistical Package for Social Science (SPSS 20.0 for windows version).

The statistical treatment applied to them included,

1. Descriptive analysis of temporal processing measures (gap detection threshold, discriminability index of TFS) and hearing aid measures (ANL, SNR-50 and self-assessment hearing aid benefit scale).
2. A bivariate correlation analysis using Pearson's Correlation coefficient to evaluate the influence of temporal processing on hearing aid outcomes.
    - Temporal processing (gap detection threshold and TFS d') with ANL
    - Temporal processing (gap detection threshold and TFS d') with SNR-50
    - Temporal processing (gap detection threshold and TFS d') with self-assessed hearing aid benefit.
    - ANL and SNR-50 with self-assessed hearing aid benefit.

- The regression analysis was carried out on the related measures to assess whether the temporal processing could predict the hearing aid measures (ANL and SNR-50). The linear regression was selected based on the scatter plot. When assessing the relation between the parameters the correlation was assessed for both (mild and moderate) the groups individually and then for the combined group data if there were no variance between them.
- To assess the variance between mild and moderate hearing loss groups:
    - Initially, the normality of the distribution was assessed ausing Shapiro-Wilk test.
    - Then, the homogeneity of varience between the groups was assessed using Levene's test. For normally distributed values the test was

applied directly and for non-normal distribution the data were transformed to normal distribution data and then the test was applied. If the groups were homogenous, the combined group data were considered for analysis.

The results will be discussed under following headings,

4.1. Temporal processing measures

4.1.1. Gap detection threshold (GDT)

4.1.2. Temporal fine structure (TFS) sensitivity using discriminability index (d')

4.2. Hearing aid measures

4.2.1. Acceptable noise level (ANL)

4.2.2. SNR-50

4.2.3. Self-assessed hearing aid benefit (SAHAB)

4.3. The relationship between the hearing aid measures, i.e., self-assessed hearing aid benefit with the aided ANL and aided SNR-50.

4.4. The effect of temporal processing on hearing aid measures

4.4.1. The relationship of temporal processing with the ANL

4.4.2. The relationship between temporal processing and SNR-50 measures

4.4.3. Temporal processing and its relationship to the benefit from hearing aid assessed through self-assessment hearing aid benefit scales

4.1 Temporal processing measures

The temporal processing measures included gap detection threshold and TFS discriminability index (d'). The analysis was carried out for mild SNHL group and moderate SNHL group. The data from the two groups were combined to form the combined group data, whenever there was no statistical difference in the variance between the groups.

Gap detection threshold

Descriptive statistics were used to get the mean, median, standard deviation (SD), and range (minimum and maximum) for gap detection thresholds for the two groups of ears. The results of the gap detection test are listed in the Table 4.1 and Figure 4.1.

Table 4.1: *Mean, median, standard deviation and range of gap detection threshold, in ms*

Groups	*Gap detection threshold, in ms*				
	Mean	*Median*	*Standard deviation*	*Minimum*	*Maximum*
Mild SNHL	5.90	6.00	1.45	4.00	8.00
Moderate SNHL	5.92	6.00	1.24	4.00	8.00
Combined group	5.91	6.00	1.31	4.00	8.00

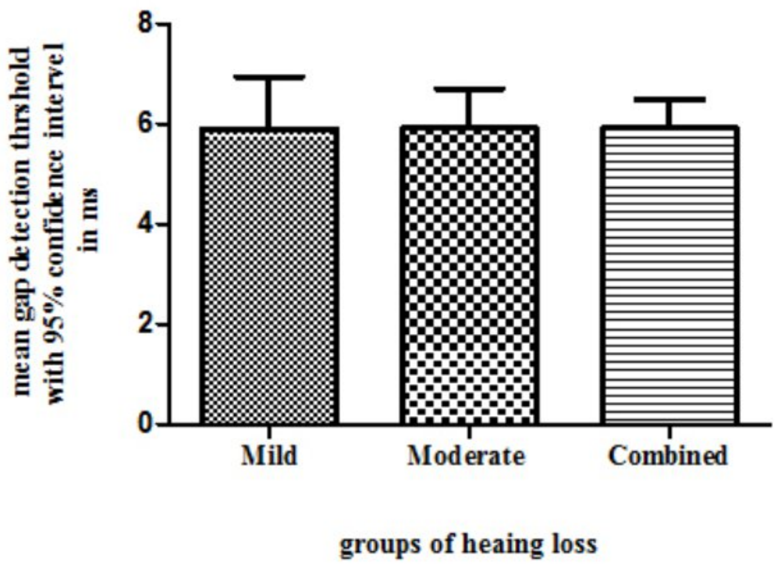

Figure 4. 1: *The error bars showing the mean gap detection threshold and the 95% confidence levels for different groups mild, moderate and combined group data.*

The Shapiro-Wilk's test revealed that the data of mild and moderate SNHL groups were normally distributed ($p<0.05$). A parametric Levene's test ($p<0.05$), visual examination of Table 4.1 and Figure 4.1, showed that there is homogeneity in the variance between both the groups. Hence, the parametric test was performed. The independent samples t-test revealed that there was no significant difference between mild and moderate SNHL groups for ANL at the level of significance of $p<0.05$. Since the two groups of ears did not differ, the data from the two groups were combined to form the combined group data for gap detection threshold.

Temporal fine structure (TFS) processing

Using the descriptive statistics the mean, median, standard deviation (SD), and range (minimum and maximum) for TFS d' was calculated. The results of the TFS d' are listed in the Table 4.1 and Figure 4.1 for fundamental frequency (F_0) of 100 Hz and in Table 4.2 and Figure 4.2 for F_0 of 500 Hz.

Table 4.2. *Mean, median, standard deviation and range of TFS discriminability index (d') for F_0 of 100 Hz*

Groups	*Temporal fine structure discriminability index (d') for F_0 of 100 Hz*				
	Mean	*Median*	*Standard deviation*	*Minimum*	*Maximum*
Mild SNHL	10.59	3.71	13.36	0.00	31.25
Moderate SNHL	14.15	10.52	14.85	0.00	35.00
Combined group	12.53	3.74	13.98	0.00	35.00

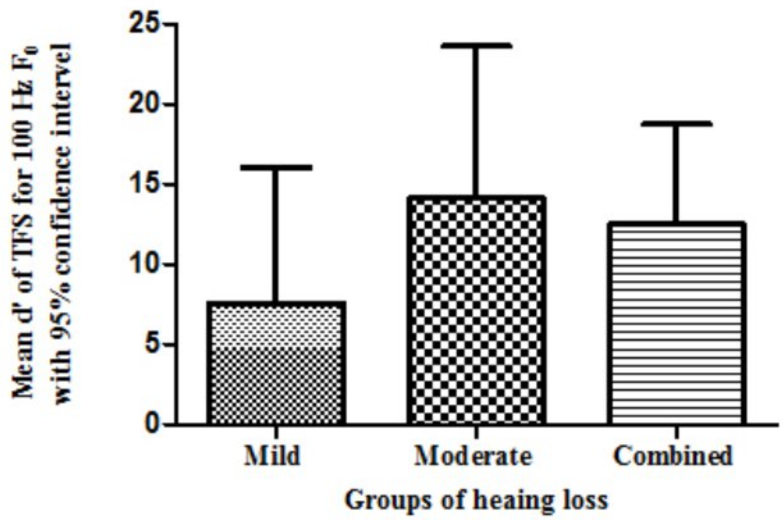

Figure 4.2. *The error bars showing the mean TFS d' and the 95% confidence level for TFS test at F_0 of 100 Hz for different groups (mild, moderate and combined group)*

The Shapiro-Wilk's test (p>0.05) revealed that the data on d' of both mild and moderate SNHL groups were not normally distributed. A Levene's test (p>0.05), visual examination of Table 4.1 and Figure 4.1 showed that there was no homogeneity in the variance between both the groups. The Mann-Whitney U test revealed that there was a no significant difference between the two groups ($p<0.05$). Hence, the combined group data were also computed for gap detection threshold.

Table 4.3. *Mean median, standard deviation and range of TFS discriminability index for 500 Hz F0*

Groups	*Temporal fine structure discriminability index (d') for F0 of 500 Hz*				
	Mean	*Median*	*Standard deviation*	*Minimum*	*Maximum*
Mild SNHL	55.15	6.44	77.97	0.00	181.25
Moderate SNHL	43.75	0.00	67.84	0.00	181.25

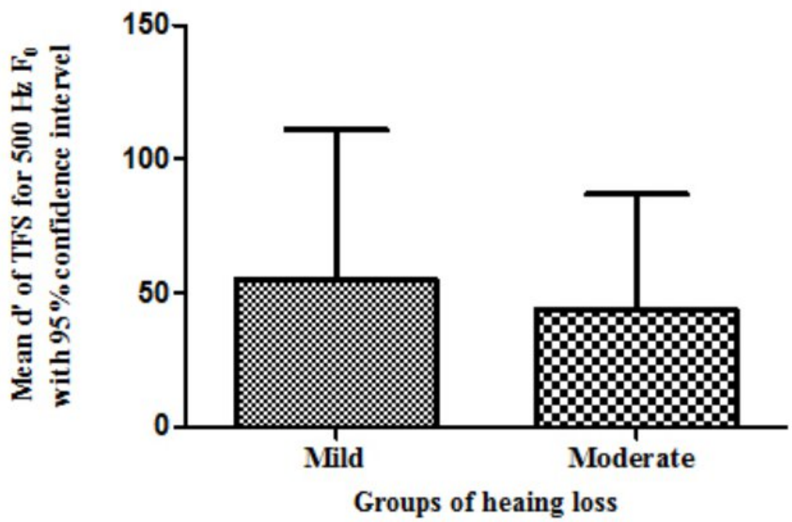

Figure 4.3. *The error bars showing the mean TFS d' and the 95% confidence level for TFS test at F_0 of 500 Hz for different groups (mild, moderate and combined group data)*

The Shapiro-Wilk's test revealed that the data on d' of TFS of mild and moderate SNHL groups were not normally distributed ($p>0.05$). Hence the data were transformed into normal distribution data and Levene's test was administered. The Levene's test ($p>0.05$), visual examination of Table 4.1 and Figure 4.1 showed that there is no homogeneity in the variance between both the groups. Hence, combined datawas not computed for the measure of TFS discriminability index. Comparing d' of TFS for F_0 of 500 Hz of the mild and the moderate SNHL groups using Mann-Whitney U test, it was seen that there was no significant difference in the mean between the two groups ($p<0.05$).

The comparison was made between the d' TFS at 100 Hz and 500 Hz F_0 in mild and moderate hearing loss groups using the Wilcoxon signed rank test ($p<0.05$). It revealed that in mild SNHL group the 500 F_0 had significantly higher d' TFS values than 100 Hz. Showing TFS cues discrimination was better for the lower center frequency. But, in moderate hearing loss group there was no difference noticed in mean between the d' of TFS of F_0 100 Hz and the d' of TFS 500 Hz.

4.2. Results of hearing aid measures

4.2.1. Hearing aid measure: Acceptable noise level (ANL)

The descriptive statistics was used to obtain the mean, median, standard deviation (SD), and range (minimum and maximum) for ANL. The results are listed in the Table 4.4. and Figure 4.4.

Table 4.4. *Mean median, standard deviation and range of ANL in dB*

Groups	*Acceptable noise level, in dB*				
	Mean	*Median*	*Standard deviation*	*Minimum*	*Maximum*
Mild SNHL	5.20	4.00	5.51	0.00	14.00
Moderate SNHL	7.41	8.50	5.21	0.00	15.00
Combined group	6.40	4.50	5.21	0.00	15.00

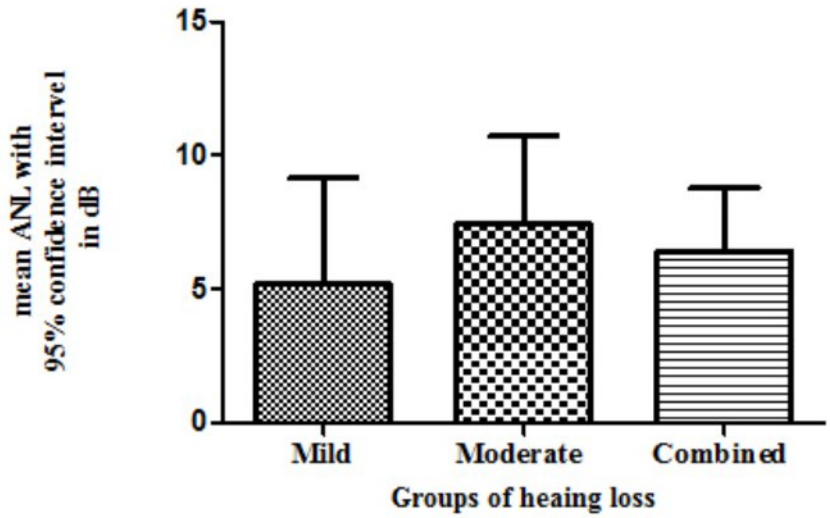

Figure 4.4. *Error bars showing the mean ANL and the 95% confidence level for different groups (mild, moderate and combined group)*

The Shapiro-Wilk's test ($p>0.05$) revealed that the data of mild and moderate SNHL groups were normally distributed. A Levene's test ($p>0.05$) and visual examination of Table 4.1 and Figure 4.1 showed that there is homogeneity in the variance between both the groups. Although the moderate SNHL group has higher mean value for ANL, the independent t-test revealed that there was no significant difference between both the groups ($p<0.05$). Hence, the combined group data were computed for gap detection threshold.

4.2.2. Hearing aid measure: SNR-50

The results of descriptive statistics showing mean, median, standard deviation, and the range (minimum & maximum) values of SNR-50 for both the groups are given in Table 4.5 and Figure 4.5.

Table 4.5. *Mean median, standard deviation and range of SNR-50 in dB HL*

Groups	*SNR-50*				
	Mean	*Median*	*Standard deviation*	*Minimum*	*Maximum*
Mild SNHL	5.20	4.50	3.55	1.00	11.00
Moderate SNHL	9.52	8.50	3.96	2.00	15.00
Combined group	7.55	4.50	4.30	1.00	15.00

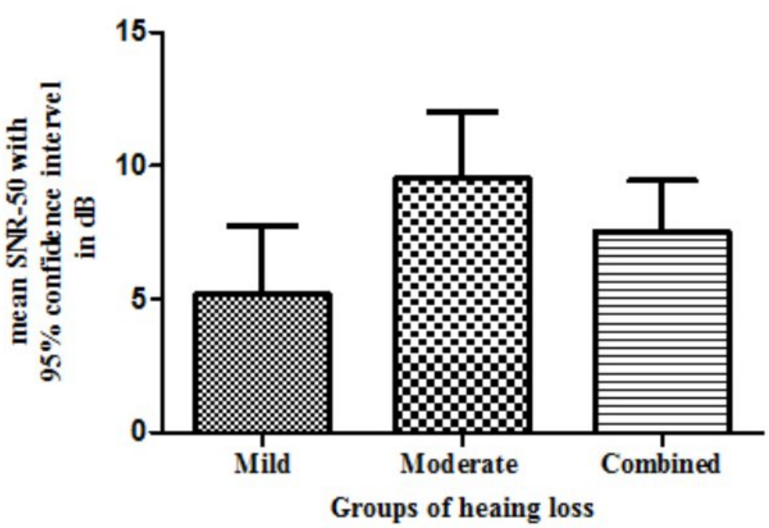

Figure 4.5. *The error bars showing the mean SNR-50 and the 95% confidence level for different groups (mild, moderate and combined group)*

The Shapiro-Wilk's test revealed that the data of mild and moderate SNHL groups were normally distributed ($p>0.05$). A Levene's test ($p>0.05$) and visual examination of Table 4.1 and Figure 4.1 showed that there was homogeneity in the variance between both the groups. Hence, the combined group data were computed for gap detection threshold. Comparison of SNR-50 between the mild and the moderate SNHL groups using independent t-test showed that the moderate SNHL group had significantly higher mean values of GDT than the mild SNHL group.

4.2.3. Hearing aid measure: Hearing aid benefit questionnaire

The questionnaire was administered only on moderate SNHL group as experienced hearing aid users were considered in this group. The mild SNHL group included naive hearing aid users and hence the questionnaire was not administered. The hearing aid benefit scores for the moderate SNHL group were obtained by subtracting the hearing difficulties in the aided condition from that of the unaided condition. The percentage of benefit from the hearing aid was obtained for different sub sections by dividing the mean benefit scores obtained from overall benefit of that section. The results are discussed under different sub-sections of the questionnaire. The mean, median, standard deviation and the range (minimum & maximum) scores for the benefit of hearing aid for different conditions such as, speech in quiet, speech in noise, psychological aspects and the environmental sound awareness are given in the Table 4.6.

Table 4.6. *Mean, median, standard deviation and range of scores on different sub-sections of hearing aid benefit questionnaire*

Sub-section of questionnaire	*Maximum scores*	*Raw mean scores*	*Benefit of hearing aid (in percentage)*				
			Mean	*Median*	*Standard Deviation*	*Minimum*	*Maximum*
Speech in quiet	55	17.00	22.40	23.12	9.80	7.50	36.25
Speech in noise	80	17.58	30.91	29.09	9.21	20.00	47.27
Environmental Sound awareness	65	8.50	28.46	23.85	13.70	12.31	53.85
Psychological aspects	40	18.50	21.25	20.00	18.60	0.00	60.00
Overall	240	61.58	25.66	24.58	6.74	18.33	40.00

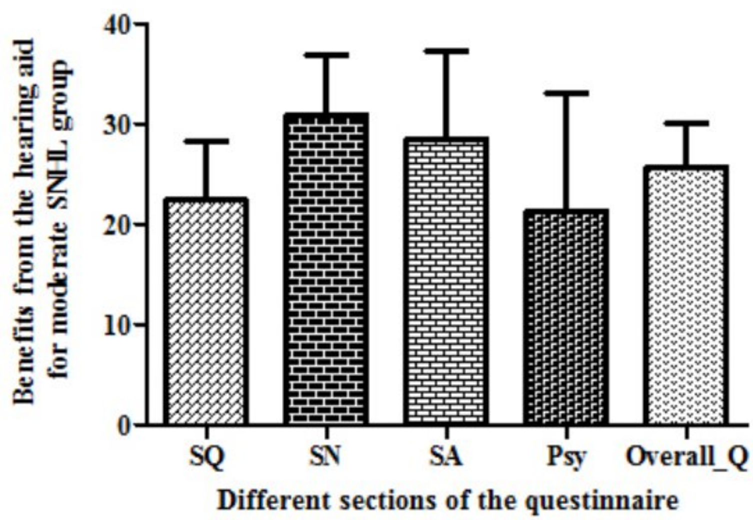

Figure 4.6. *The error bars showing the mean scores and the 95% confidence interval of of different sub-sections of the questionnaire showing benefit for speech in quiet (SQ), speech in noise (SN), sound awareness (SA), psychological aspects (Psy) and overall scores (overall_Q)*

The benefit scores shows that most of the individuals rated the benefit from hearing to be less (none of the sections showing scores of more than 50%). The scores show that hearing aids were most beneficial for speech in noise (29.09%), followed by environmental sound awareness (28.46%), speech in quiet (22.40%) and psychological aspects (21.25%). The variability was high for the psychological benefit rating. Overall benefit showed there was 25.66% of benefit from the hearing aid.

4.3. The relationship between the different outcome measures

The questionnaire was administered only on moderate SNHL group as experienced hearing aid users were considered in this group. The mild SNHL group included naive hearing aid users. Hence, the relationship between the hearing aid benefit questionnaire scores with the ANL and SNR-50 were assessed in the moderate hearing loss group. The relationship was measured with the assumption that if the relationship is present in the moderate SNHL group, it will be present in the mild SNHL group also. The results are presented in the Table 4.7.

Table 4.7. *Pearson's correlation coefficient (r) for different sub-sections of questionnaires with ANL and SNR-50*

Benefit in Sub-sections of questionnaire	*ANL*	*SNR-50*
Speech in quiet	-0.04	0.28
Speech in noise	-0.11	-0.15
Psychological aspects	-0.09	0.33
Environmental sound awareness	-0.06	0.27
Overall	-0.14	0.32

The results depict that the relationship between the benefit scores and the ANL had low negative correlation. This shows that as the ANL increases the benefit from the hearing aid obtained reduces for all the type of sound environments. But these relationships were not statistically significant.

The correlation assessment of SNR-50 with speech in quite, environmental awareness, psychological aspects and overall measure showed that they were positively related. This revealed that the benefit increased with the increase in SNR-50 for these environments. Speech in noise benefits had negative low correlation with SNR-50. This shows that as the SNR-50 increases the benefit from the hearing aid in noisy situation reduces. None of the sub-sections of the questionnaire or the overall scores had any significant relationship with SNR-50.

4.4. The effect of temporal processing on hearing aid measures

4.4.1 Influence of temporal processing on acceptable noise level (ANL)

To see if the temporal processing affects the hearing aid outcomes, the gap detection thresholds were compared with the ANL. The comparisons were made between the measures using Pearson's correlation coefficient. The temporal gap detection thresholds, discriminability index (d') of TFS was compared with aiding ANL. The comparison was made between mild, moderate and combined data with the ANL. The results are presented in Table 4.8.

Table 4.8. *Pearson's correlation coefficient (r) between the ANL and the temporal processing measures (gap detection threshold, TFS discriminability index (d') for F_0 of 100 Hz and for F_0 500 Hz.*

Different Groups	Gap detection threshold	d' TFS_100	d' TFS_500
Mild SNHL	0.77**	-0.30	-0.26
Moderate SNHL	0.67*	-0.42	-0.26
Combined group	0.70**	-0.33	#

Note: * Correlation is significant at the 0.05 level (2-tailed)
** Correlation is significant at the 0.01 level (2-tailed)
# not measured as the d' of TFS for 500 Hz F_0 had heterogeneous variance between the groups

The results showed that the gap detection thresholds were related to the ANL in both mild, moderate and in the combined group. The combined group data revealed that there was a significant positive correlation between gap detection threshold and ANL ($p<0.01$). This denotes that as the gap detection threshold increases the ANL increases. There was no correlation between the temporal fine structure processing and the ANL, for both low and high frequencies.

The related variables were them using linear regression analysis. The analysis was carried out on combined group data as the objective was to assess relationship between temporal processing and the hearing aid measures.

To measure whether the ANL is dependent on gap detection threshold a simple linear regression was carried out based on the scatter plot. A linear regression measure established that the gap detection threshold could predict the ANL, [$F (1, 20) = 19.41$, $p < 0.00$] with an R^2 of 0.49. The predicted ANL is -10.55+2.87 of gap detection threshold when it is measured in ms and the ANL is measured in dB HL. The ANL increased by

2.87 for each ms increase in the gap detection threshold. The linearity of the data is presented in the Figure 4.7.

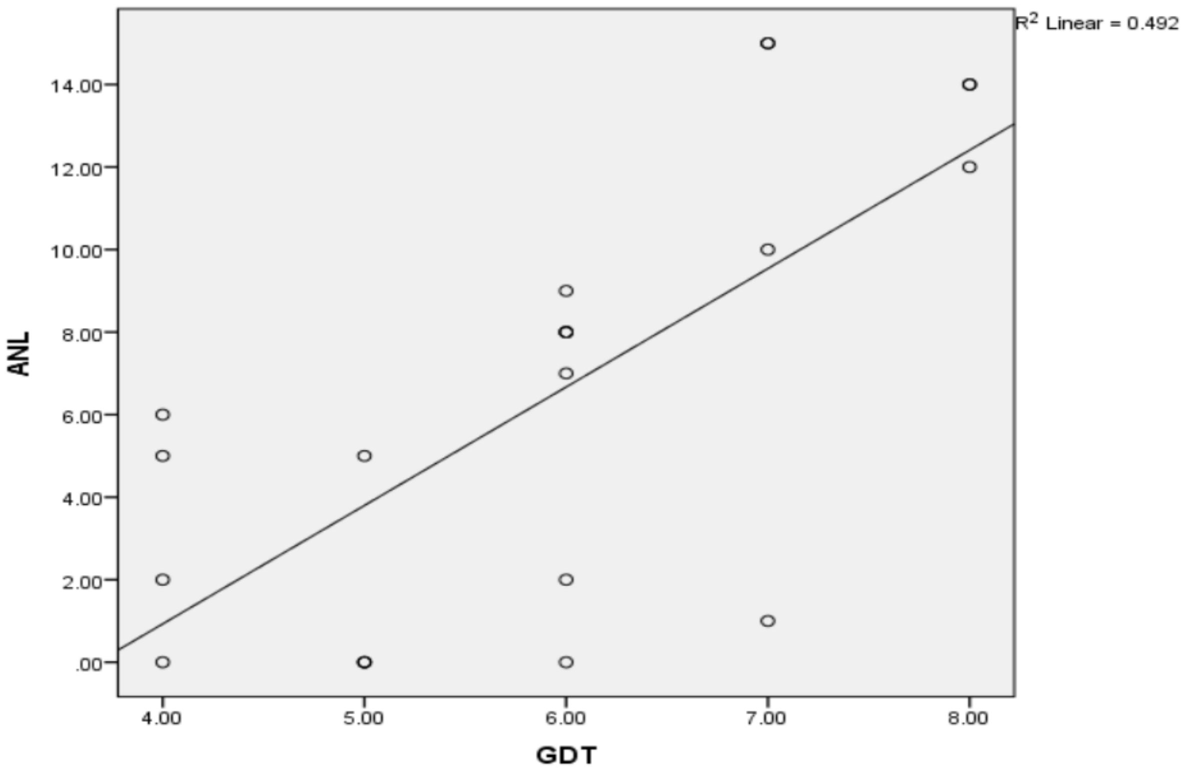

Figure 4.7. *Scatter plot showing the statistical relationship between the gad detection threshold and the acceptable noise level*

4.4.2 Influence of temporal processing on SNR-50

To assess the influence of temporal processing on SNR-50, the relationship of the gap detection threshold and d' of TFS with SNR-50 measured using the Pearson's correlation co-efficient (r). The bivariate analysis of relation was measured between these measures. The results are depicted in Table 4.9.

Table 4.9. *Pearson's correlation coefficient (r) between SNR-50 and the temporal processing measures [gap detection threshold, d' of TFS for F_0 of 100 Hz and F_0 of 500 Hz]*

Different Groups	*GDT*	*TFS_100*	*TFS_500*
Mild SNHL	0.85**	-0.14	-0.87
Moderate SNHL	0.49	-0.82**	-0.53
Combined group	0.56**	-0.41	#

Note: ** Correlation is significant at the 0.01 level (2-tailed)
not measured as the d' of TFS for 500 Hz F_0 had heterogeneous variance between the groups

The results show that the SNR-50 in positively related with the gap detection thresholds in the mild hearing loss group and in the combined data. This showed that as there was an increase in the gap detection threshold there was an increase in the SNR-50. The TFS processing at F_0 100 Hz showed a significant negative correlation with the SNR-50 in moderate hearing loss group. Since higher d' values represent better TFS processing, the negative correlation shows that better the TFS processing abilities better will be the SNR-50. There was no relationship between other the TFS measures and the SNR-50 in any of the groups.

A simple linear regression was carried out based on the scatter plot to measure relationship between the SNR-50 and gap detection threshold in the combined data. A linear regression established that the gap detection threshold could statistically significantly predict the SNR-50, $F(1, 20) = 9.19$, $p= 0.07$) with an R^2 of 3.15. The predicted SNR-50 is (-3.36+1.85) of gap detection threshold when it is measured in ms and the SNR-50 is measured in dB HL. The SNR-50 increased by 1.85 for each ms increase in the gap detection threshold. The linearity of the data is presented in the Figure 4.8.

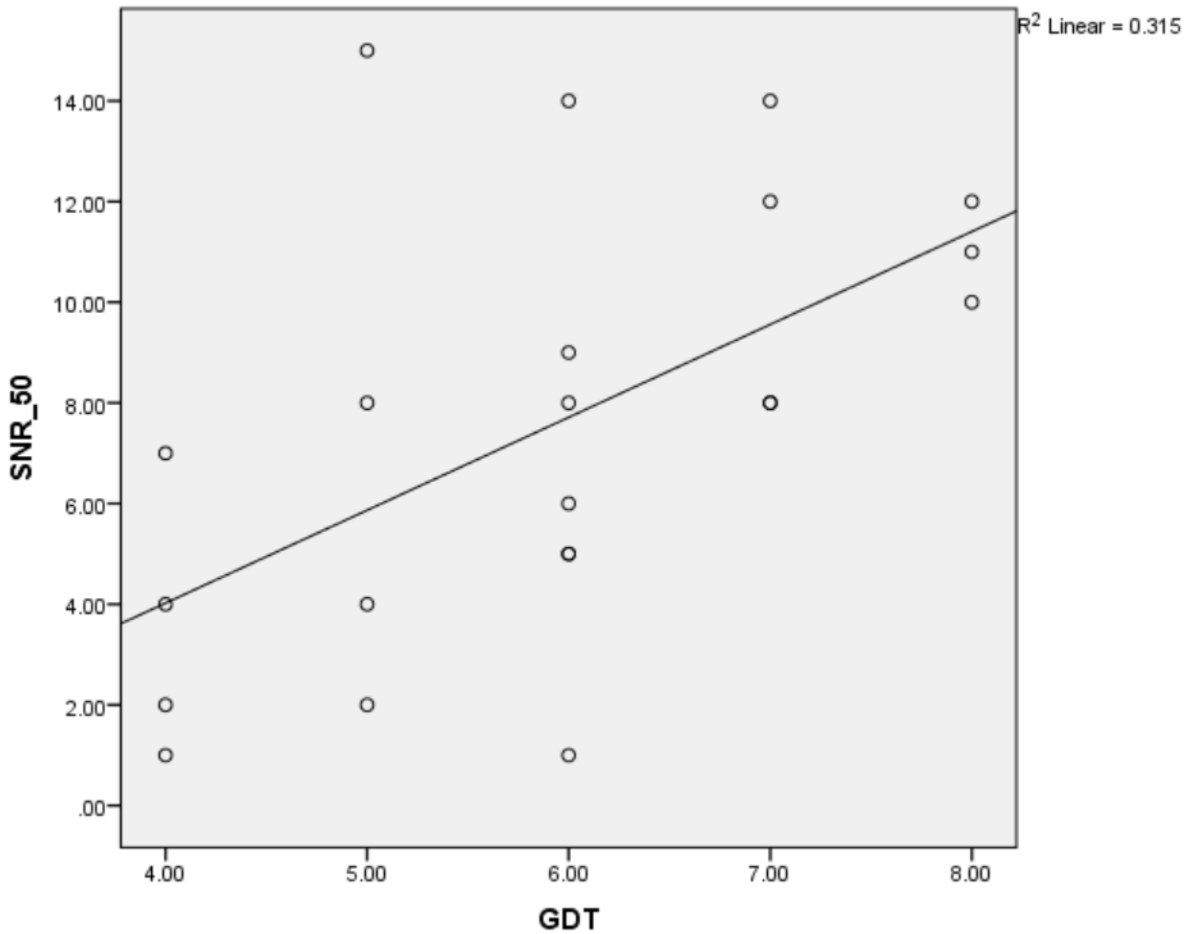

Figure 4.8. *Scatter plot of the relationship between the gap detection threshold (GDT) and SNR-50 (SNR_50)*

4.4.3 Temporal processing and its relation to the benefit of hearing aid through self-assessment hearing aid benefit scales

The influence of temporal processing on hearing aid outcomes were measured for 12 moderate SNHL group only. The relationship between the various measures of temporal processing and the questionnaire scores were assessed using Pearson's correlation co-efficient. The results are displayed in Table 4.10.

Table 4.10. *Pearson's correlation coefficient (r) between different sub-sections of the questionnaires and the temporal processing measures (gap detection threshold, d' of TFS for F_0 of 100 Hz and for F_0 500 Hz.*

Sub-section of questionnaire	*Gap detection threshold*	*d' TFS_100*	*d' TFS_500*
Speech in quiet	-0.26	-0.17	-0.13
Speech in noise	-0.10	-0.02	0.04
Psychological aspects	-0.24	-0.08	-0.09
Environmental awareness	-0.14	-0.18	0.27
Overall	-0.32	-0.18	0.12

The correlation coefficients were very small, indicating lack of relationship between the measures. And none of the sub-sections of the questionnaire or the overall rating had any significant relationship with the temporal processing measures.

To summarize the results,

- The gap detection thresholds were similar in both mild and moderate hearing loss group, whereas there was a lot of variability in the TFS sensitivity (d' of TFS) results in both the groups.
- Among the outcome measures the aided ANL, SNR-50 and hearing aid benefit questionnaires were measured. The ANL was not significantly different and SNR-50 was sigificantly higher for moderate SNHL group than mild SNHL group.

- Since the hearing aid benefit questionnaire was not administered on the mild SNHL group the relationship of ANL, SNR-50 with hearing aid benefit questionnaire was assessed in moderate SNHL group with the assumption that if there is any relationship was present it will be present in mild SNHL group also. But there was no relation between these parameters as measured by Pearson's correlation co-efficient.
- The relationship between the temporal processing and the ANL showed that,
  - There was a significant positive correlation between the ANL and gap detection threshold. As the gap detection thresholds increased the ANL increased.
  - But there was no relationship between the temporal fine structure processing and ANL.
- The relationship between the temporal processing and SNR-50 revealed that
  - The gap detection thresholds had a significant positive correlation with SNR-50. As the gap detection thresholds increase the SNR-50 increases.
  - Among the temporal fine structure processing measures the temporal fine structure processing at low frequency had a significant negative correlation with the SNR-50 in the moderate SNHL group. Hence, in the moderate hearing loss group as the sensitivity to TFS (d' of TFS) increases in lower frequency the SNR-50 improves. Whereas, there was no relationship in other groups in both low and high frequencies.

- The relationship between the temporal processing and the hearing aid benefit questionnaire were assessed. There was no significant correlations present between these measures.

To conclude the gap detection threshold influences most of the hearing aid measures such as the ANL, SNR-50. Whenever the gap detection threshold increased the ANL and SNR-50 increases. The results on the TFS sensitivity influence on the hearing aid outcome are inconclusive because of larger variability in the results.

Chapter 5

Discussion

The present study was carried out to assess the effect of temporal processing on the hearing aid outcomes. In the study, the temporal processing parameters measured were gap detection threshold and the temporal fine structure processing. Their relation to the acceptable noise level (ANL), SNR-50 and the hearing aid benefit questionnaire rating scores were measured. The results showed that the gap detection thresholds significantly affected the ANL and SNR-50; where as low frequency temporal fine structure processing affected the SNR-50 only in the moderate hearing loss group. There were no relationships of the hearing aid benefit questionnaire with either of the temporal processing measures.

The results will be discussed under the following headings,

- 4.1. Temporal processing measures
  - 4.1.1. Gap detection threshold
  - 4.1.2. Temporal fine structure sensitivity
- 4.2. Hearing aid outcome measures
  - 4.2.1. Acceptable noise level
  - 4.2.2. SNR-50
  - 4.2.3. Self-assessed hearing aid benefit
- 4.3. The relationship between the hearing aid outcome measures, i.e., self-assessed hearing aid benefit with the aided ANL and aided SNR-50.
- 4.4. The effect of temporal processing on hearing aid outcome measures

4.4.1. The relationship of temporal processing with the acceptable noise levels

4.4.2. The relationship between temporal processing and SNR-50 measures

4.4.3. Temporal processing and its relation to the benefit of hearing aid through self-assessment hearing aid benefit scales.

Temporal processing measures

Gap detection threshold

The results showed that the mean and range of the gap detection threshold did not vary with the degree of hearing loss (mild and moderate SNHL). The mean value of gap detection thresholds of mild and moderate groups were 5.90 and 5.92 respectively (table 4.1). And both the groups had a gap detection threshold ranging from 4 to 8 ms. Florentine and Buus (1984) also suggested that age rather than the degree of hearing loss had an impact on gap detection threshold. They showed that the gap detection threshold ranged from near normal to 8 ms with the low pass noise (having low cut 7 kHz) which is in agreement with the present study.

Temporal fine structure processing

The temporal fine structure ability showed a lot of variability in the results in both mild and moderate sensorineural hearing loss. There was no difference between the mild and moderate hearing loss group for TFS processing abilities. The comparison was made between the discriminability index (d') of TFS of low frequency (F0 of 100 Hz) and high frequency (F0 of 500 Hz). It showed that high frequency had significantly poorer TFS sensitivity than low frequency. In similar studies assessing the TFS processing in mild and moderate degree of hearing loss, they have found variability in the processing abilities in them (Ardoint, Sheft, Fleuriot, Garnier, & Lorenzi, 2010; Hopkins & Moore, 2010b; Lorenzi, Debruille, Garnier, Fleuriot, & Moore, 2009). Hence, mild and moderate hearing loss reduces the ability to utilize temporal fine structure cues.

To summarize, there was no difference in the gap detection threshold between the temporal processing in individuals with mild and moderate degree of hearing loss. The TFS sensitivity had variable results.

Hearing aid outcome measures

Acceptable noise level

The ANL of mild and moderate hearing loss group showed mean of 5.20 and 7.41 dB respectively. The range was 0-14 dB for mild and 0-15 dB for moderate hearing loss. There was no significant difference between mean ANL and variance of both the groups. The possible reason could be because the ANL involves central processing (Harkrider & Tampas, 2006; Harkrider & Smith, 2005; Shetty, Mahadev, & Veeresh, 2014) and hearing loss being sensory / peripheral may not affected the results. Recker and Edwards (2003) also found that the ANL did not differ between group of individuals with normal hearing and hearing loss. Hence, it can be concluded that the ANL is not affected by the hearing loss.

SNR-50

The SNR-50 values for mild and moderate hearing loss individuals showed mean of 5.20 dB and 9.52 dB respectively. The range was 1 to 11 dB for mild and 2 to 15 dB for moderate hearing loss. Both the groups showed equal variance. When SNR-50 of mild and moderate SNHL groups was compared, the moderate group had significantly higher SNR-50. Yip (2010) also reported similar results in the unaided condition. The moderate to severe SNHL group had higher SNR-50 than the mild to moderate group. This can be attributed to the reduced frequency selectivity of listeners having severe degree of sensorineural hearing loss. This might lead to difficulties in separating signals in the presence of background noise ((Moore, Vickers, Glasberg, & Baer, 1997; Rosen, Faulkner, & Moore, 1990).

Self-assessed hearing aid benefit

The results of different sub-sections of the questionnaire showed that the maximum benefit from the hearing aid was noticed for speech in noise and for environmental sound awareness. It was followed by benefit for speech in quiet. Least benefit was noted for the psychological aspects. Since the individuals considered for the study had lesser severity of hearing loss, they had fewer difficulties in quiet. Therefore, the benefits noticed in quiet were lesser compared to noise.

Relationship between the hearing aid outcome measures, i.e., self-assessed hearing aid benefit with the aided ANL and aided SNR-50:

The results showed that there was no correlation of self-assessed hearing aid benefit to ANL or SNR-50. The relationship between the benefit scores and the ANL revealed a low negative correlation and the relationship was not significant. The negative correlation indicates that the benefit obtained from the hearing aid increased as the ANL reduced in all the sections of the questionnaire (speech in quiet, speech in noise, environmental sound awareness, & psychological aspects). Freyaldenhoven, Nabelek, and Tampas (2008) also revealed similar results showing lack of correlation between ANL and APHAB.

This lack of correlations can be attributed to individual difference in measuring the difficulties in different listening conditions. The lack of relationships can be also because of the influence of the non-audiological variables such as desire to hide the degree of handicap (Tyler & Smith, 1983).

The relationship between the SNR-50 and self-assessed hearing aid benefits revealed that the four out of five sections had positive and one section had a negative correlation with SNR-50. The correlation was not significant, showing there was no relationship between SNR-50 and self-assessment of hearing aid benefit. The benefit of speech in quiet, environmental awareness, psychological aspects and overall measure increased with the increase in SNR-50. The speech in noise benefits had negative low correlation with SNR-50. Similar findings have been reported from Rowland, Dirks, Dubno, and Bell (1985) who showed poorer correlation between the SNR-50 measure and the self-assessment of handicap scale.

This lack of correlations can be attributed to individual difference in measuring the difficulties in different listening conditions. The lack of relationships can be also because of the influence of the non-audiological variables such as desire to hide the degree of handicap (Tyler & Smith, 1983).

Whereas, this finding is in contrast to the findings of Manjula and Megha (2012) who showed that there was a significant correlation between the SNR-50 and the rating on the speech in noise handicap scores. The possible differences in the studies can be due to the procedural variations. In that study speech noise was used to find SNR-50 whereas in the current study a multitalker babble was used. This may have led to the differences.

The effect of temporal processing on hearing aid measures

The relationship of temporal processing with the acceptable noise levels

The results showed that the gap detection thresholds had a significant positive correlation with the ANL measure. As the gap detection thresholds became better the ANL reduced. Since there was a positive correlation, the predictability value of GDT on hearing aid outcome measures was analyzed. The results show that the GDT could be used to predict the ANL successfully. Further, studying in order to find out the validity of predictive ability of the regression equation would throw more light on the reliability on using the temporal processing for prediction of hearing aid outcomes in a separate group of participants.

Although no studies have been done assessing the relation between the gap detection threshold and ANL, the relationship can be attributed to the fact that both the measures are central processing measures. Syka, Rybalko, Mazelová, and Druga (2002) have shown that the gap detection thresholds increase in rats after the cortical ablations which did not recover after one month of surgery. Musiek et al. (2005) also reported that the gap detection thresholds were significantly higher for the confirmed cortical lesion patients. As discussed earlier, the ANL is a central measure (Harkrider & Tampas, 2006; Harkrider & Smith, 2005; Shetty, Mahadev, & Veeresh, 2014). Hence, both the measures may be related.

The results comparing the TFS sensitivity with the ANL showed that there was a negative correlation between the d' of TFS and ANL but the relationship was not significant. As the TFS sensitivity increases the ANL reduces. The lack of relationship can be attributed to temporal fine structure sensitivity being a peripheral measure and ANL is a central processing measure. The TFS identification requires the individuals to separate the TFS components at the cochlea level and phase locking to individual components at the auditory nerve (Moore, 1983, 2003). Hence, these abilities may not truly affect the ANL. This cannot be concluded as the variability was high for d' of TFS.

The relationship between temporal processing and SNR-50 measures

The gap detection threshold had significant positive correlation with the SNR-50 in mild and overall hearing loss group. This showed that as the gap detection threshold increased, the SNR-50 also increased. The regression analysis showed that SNR-50 could be predicted from the gap detection threshold.

The studies show that the temporal gap detection thresholds have good correlation with the speech perception in quiet and noise (Dreschler & Plomp, 1985; Snell, Mapes, Hickman, & Frisina, 2002). Dreschler and Plomp (1985) revealed that there is a trade-off between the frequency selectivity and the temporal resolution. Hence, the poorer speech in noise performance in poor temproal resolution may be due to inability to separate the speech from the background noise. The gap detection thresholds. Glasberg, Moore, and Bacon (1987) explained that the poorer gap detection led to slower recovery from the background noise. Hence, noise effect will be more in individuals with poor gap dection threshold as they will not be able to separate the speech from the noise during fluctuations due to forward masking. Also the studies reveal the deterioration in speech perception abilities in older adults is due to poorer temporal gap detection threshold leading to poor temporal coding (Lutman, 1990). This suggests that the temporal resolution is important for speech perception in noise and they are related. Since the SNR-50 is a measure of speech in noise performance, both the parameters were related.

The assessment of relationship between the d’ of TFS and SNR-50 for mild hearing loss group showed there was no significant relationship between them. For moderate hearing loss it was noticed that the SNR-50 and d’ of TFS at 100 had significant negative correlation. There was no correlation in moderate hearing loss group for d' of TFS at 500 F_0 and SNR-50. Overall there is variability in the results and remains inconclusive.

Many studies suggest that the temporal fine structure cues are important for speech performance in noise (Shannon et al., 1995; Dorman et al., 1998; Fu et al., 1998; Qin & Oxenham, 2003; Stone & Moore, 2003). Since the overall envelop cues are masked in the presence of noise, the TFS cues help in recovering the speech information. That is, whenever there is any reduction in the energy of the masker/ noise (dip) the listener would use the cues available in those dips to understand the speech information. The cues available in those dips would be the fine structure cues. Studies have shown that the TFS cues are important for accurate place of articulation recognition (Sheft, Ardoint, & Lorenzi, 2008).

Hence, TFS resolution abilities play a critical role in speech perception in quiet and noise. Although these cues are important, lack of correaltion between the SNR-50 and TFS can be attributed to the variability in the data of TFS.

Temporal processing and its relationship to the benefit of hearing aid through self-assessment hearing aid benefit scale:

To results showed that the temporal processing measured using gap detection threshold and d' of TFS sensitivity had no significant correlation with the self-assessment of hearing aid benefit. No sub-sections of the questionnaire or the overall rating had any significant relationship with the temporal processing measures. The lack of relationships can be because of the influence of the non-audiological variables such as desire to hide the degree of handicap (Tyler & Smith, 1983).

To conclude, the gap detection threshold influences most of the hearing aid measures such as the ANL and SNR-50. Whenever, the gap detection threshold increased, the ANL and SNR-50 also increased. The results on TFS sensitivity influence on hearing aid outcome are inconclusive because of larger variability in the results.

Chapter 6

Summery and Conclusion

The aim of the present study was to evaluate the influence of temporal processing on hearing aid outcomes. To assess this, two temporal measures were considered [gap detection threshold and temporal fine structure (TFS) sensitivity] and their correlation with hearing aid measures such as acceptable noise level (ANL), SNR-50 and self-assessment of hearing aid benefit questionnaires. The specific objectives of the study were,

5. To assess the relationship of temporal processing with the acceptable noise levels. In case if there is correlation, to analyze the ability of temporal processing to predict ANL.
6. To assess the relationship between temporal processing and SNR-50 measures. In case if there is correlation, to analyze the ability of temporal processing to predict SNR-50.
7. To evaluate the temporal processing and its relation to the benefit of hearing aid through self-assessment hearing aid benefit scales.
8. To evaluate the relationship of ANL and SNR-50 with the self-assessment hearing aid benefit scale.

The data were collected from 10 mild naive hearing aid users and 12 moderate experienced hearing aid users (having experience of minimum 6 months with the device) having sensorineural hearing loss (SNHL) were considered. The data were collected to measure gap detection threshold, discriminability index of TFS, ANL, SNR-50 and self-assessment of hearing aid benefits using questionnaire. All the parameters were measured for moderate SNHL group whereas for mild SNHL the hearing aid benefit scale was not administered.

The data were tabulated and assessed using Statistical Package for Social Science (SPSS 20.0 for windows version). The descriptive statistics was carried out to obtain mean, median, standard deviation and range for all the parameters. To assess the influence of temporal processing on hearing aid otcome, the relationship of temporal processing measures (temporal gap detection threshold and TFS sensitivity measured using d') with hearing aid measures (ANL, SNR-50 and self-assessment of hearing aid benefit) was checked using Pearson's coefficient of correlation and linear regression analysis for related variables. The relationship between the outcome measures were also assessed by checking the Pearson's coefficient of correlation of ANL and SNR-50 with self-assessment of hearing aid questionnaire. The results are as follows,

The relationship of ANL, SNR-50 with self-assessment of hearing aid benefit questionnaire

The results showed that there was no correlation between the ANL, SNR-50 and the self-assessment of hearing aid benefit scale. The possible reason behind this lack of relationship can be because of the influence of the non-audiological variables such as desire to hide the degree of handicap.

The relationship of temporal processing with the acceptable noise levels

The results showed that the gap detection thresholds were related to acceptable noise level. With the increase in gap detection the ANLs also increased. The temporal fine structure processing was not related to ANL. The possible reason maybe because both ANL and gap detection threshold are central measures. Whereas, TFS processing and gap detection threshold were not related as TFS processing is a peripheral measure and ANL is a central measure. Studies show that ANL is not affected by hearing loss.

The relationship between temporal processing and SNR-50 measures

The results showed that the gap detection threshold and SNR-50 had a significant positive correlation. The possible reason being the importance of temporal resolution in reducing the effect of forward masking and helping to extract the information from the gaps of the noise. The TFS sensitivity and SNR-50 were related only in moderate hearing loss. The temporal fine structure processing is important to resolve the speech perception in noise. The lack of correlation could also be due to the individual in the TFS sensitivity and the procedural variability in assessing the SNR-50.

Temporal processing and its relation to the benefit of hearing aid through self-assessment hearing aid benefit scales

There was no correlation of the gap detection threshold and TFS sensitivity to self-assessment of hearing aid benefit scale. The reason might be because of the individual variability in the rating the questionnaire.

Clinical implications

1. The study establishes that the gap detection thresholds could be clinically used to predict the hearing aid outcome of an individual prior to hearing aid prescription. This will be a quick ‘objective’ method to predict hearing aid outcome.
2. This would help in counseling the patients about the real-life benefits from the hearing aids and realistic expectations.
3. Gap detection threshold will serve as a good hearing aid benefit predictor as the test has no language barrier.

Future directions

1. To study the effect of temporal fine structure processing on hearing aid outcome with larger number of samples.
2. To study the effect of temporal fine structure processing on the hearing aid selection options. Example: varying the attack time and release time based on TFS processing abilities.
3. To study the other temporal and spectral parameters affecting the hearing aid outcomes.

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Appendix A: Self assessment of Hearing Handicap

Vanaja (2000)

Rating scale: Most of the time-2; sometimes-1 andseldom-0

	Questions
1.	Do you have difficulty in understanding speech in the following situations?
a.	While conversing with a family members seated next to you, if you cannot see his/her face
b.	While conversing with a familiar male from a distance of 6-8 feet, if you cannot see his face.
c.	While conversing with a familiar female from a distance of 6-8 feet, if you cannot see her Face
d.	While listening to a family member (without visual cues) who is speaking in a normal tone of voice from a distance of 10-12 feet
e.	While conversing with a familiar person over telephone
f.	While watching a TV program, If the TV is turned on at a normal volume, at a distance of 6-8 feet, in a quiet room
g.	While watching a TV News, If the TV is turned on at a normal volume, at a distance of 6-8 feet, in a quiet room
h.	While listening to a radio turned on at normal volume, from a distance of 3 feet in a quiet room
i.	While watching a TV program, If the TV is turned on at a normal volume, at a distance of 6-8 feet and there is other noise in the room (e.g.- others talking)
j.	While conversing with a bus conductor in a crowded bus
k.	While conversing with a friend standing beside you on a crowded railway platform

l.	While conversing with a salesman in a busy shop
m.	While listening to a speech at a public gathering when you are at a distance of 6-8 feet from the loudspeaker
n.	While carrying out conversation with a friend sitting opposite you at a restaurant
o.	While conversing with a familiar person seated next to you at a wedding hall, if you cannot see his/her face
p.	While conversing with a familiar person who is beside you when you are walking in a busy Street
q.	While conversing with another person seated next to you, if there is a TV/radio playing at normal volume in the same room
r.	While watching a movie in theatre
s.	While listening to somebody whispering at a distance of 6 inches from your ear
t.	While carrying out conversation with an unfamiliar person standing beside you, when you are outdoors and it is reasonably quiet
u.	While conversing with a small group of people at home
v.	While conversing with a person seated in front of you at a distance of 3 feet and you are able to watch his face (with adequate light on his face)
2	Do you turn down the volume of TV/radio before you try to carry on a conversation?
3	Do you find it hard to understand when several people are talking at the same time?
4	Can you carry out a conversation when several people are talking in a large room?
5	Do you feel that you understand better when you talk slowly?
6	Do you ask for repetitions when people speak to you?
7	Do you have difficulty in recognizing familiar voice when your back is turned

	speaker?
8	Can you identify the direction from which you heard the automobile horn while you are walking on a street?
9	When you are conversing with a group of people, can you identify the location of the speaker?
10	Do you avoid talking to people because you have a hearing problem?
11	Do you hesitate to meet strangers because you have a hearing problem?
12	Does your hearing problem make you to feel left out when you are with a group of people?
13	Do you listen to TV/radio less often because you have a hearing problem?
14	Do you get frustrated when you cannot understand what others say?
15	Do you feel that your family members get annoyed when you do not understand what they say?
16	Do you feel that people leave you out of conversation because you have a hearing problem?
17	Does your family member get annoyed because you raise the volume?
18	Can you hear the following from a distance of 6-8 feet, in a quiet room?
a	A telephone ringing
b	A knock on the door
c	A dog barking
d	Sound of footsteps
e	A tap running
f	Hiss of a pressure cooker
19	Can you hear the following from a distance of 18-20 feet in a quiet room?

a	A bus horn
b	A telephone ringing
c	Hiss of a pressure cooker
20	In a quiet situation, can you hear somebody calling you from a distance of 6-8 feet?
21	In a quiet situation, can you hear somebody calling you from a distance of 18-20 feet?
22	Can you hear somebody calling you from behind (from a distance of 6-8 feet), if the TV is turned on at a normal volume?
23	Mention any other situation you have difficulty in hearing (please specify)

Appendix 2: Translated questionnaire in Kannada

Rating used

ಇ? ?ಕೆಲವು ಸಂದಭ? ಗಳನು? ಕೊಡಲಾ? ದೆ. **ಈ** ಕೆಳಗೆ ಕೊ? ?ರುವ ಸಂಧಭ? ಗಳ? ?? ಮಗೆ ಕೆ? ? ಕೊಳ?ಲು ಎಷು? ಕಷ?ವಾಗುತದೆ ? ? ? ?

೦% ಯಷು? **ಸಲ** ಕಷ?ವಾಗುತದೆ

೨೫% ರಷು? **ಸಲ** ಕಷ?ವಾಗುತದೆ

೫೦% ರಷು? **ಸಲ** ಕಷ?ವಾಗುತದೆ

೭೫% ರಷು? **ಸಲ** ಕಷ?ವಾಗುತದೆ

೧೦೦% ರಷು? **ಸಲ** ಕಷ?ವಾಗುತದೆ

	ಹಲವು ಸಂದಭ? ಗಳು	ಶ?ವಣ ಯಂತ? ಹಾ? ಕೊಳ?ದೆ	ಶ?ವಣ ಯಂತ? ಹಾ? ರುವಾಗ
1.	ಈ ಕೆಳಗೆ ಕೊ? ?ರುವ ಸಂಧಭ?ಗಳ? ?? ಮಗೆ ಕೆ? ? ಕೊಳ?ಲು ಎಷು?ಕಷ?ವಾಗುತದೆ ? ವ? ?		
a.	? ಮ? ಪಕ?? ? ? ಕು? ? ರುವ ? ಮ? ಮನೆಯ ಸದಸ?ರ ಜೊತೆ ಮುಖ ನೋ? ಕೊಂಡು ಮಾತನಾಡುವಾಗ		
b.	೬ ? ಂದ ೮ ಅ? ದೂರ? ಂದ ? ಮಗೆ ಪ? ಚಯ? ರುವ ವ??ಯು (ಪುರುಷ/ ಗಂಡಸು) ಜೊತೆ ಮಾತನಾಡುವಾಗ		
c.	೬ ? ಂದ ೮ ಅ? ದೂರ? ಂದ ? ಮಗೆ ಪ? ಚಯ? ರುವ ವ??ಯು (ಮ? ಳೆ/ ಹೆಂಗಸು) ಜೊತೆ ಮಾತನಾಡುವಾಗ		
d.	೧೦ ? ಂದ ೧೨ ಅ? ದೂರ? ಂದ ಯಾವುದಾದರು ಒಬ?ರು ಮನೆಯ ಸದಸ?ರೊಂ? ಗೆ ಮಾತನಾಡುವಾಗ		
e.	? ಮಗೆ ಪ? ಚಯ? ರುವ ವ?? ? ಂ? ಗೆ ? ೬? ನ? ?ಮಾತನಾಡುವಾಗ		
f.	? ಷಬ?ಾದ ಕೋಣೆ/ ರೂ? ನ? ?ಸುಮಾರು ? -೮ ಅ? ದೂರ? ಂದ ? ೬? ನೋಡುವಾಗ (ಬೇರೆಯವರು ಇಟ?ಥಹ ವಾಲೂ?ಿನ?)?		
g.	? ಷಬ?ಾದ ಕೋಣೆ/ ರೂ? ನ? ?ಸುಮಾರು ? -೮ ಅ? ದೂರ? ಂದ ? ೬? ಯ? ? ನೂ?? ನೋಡುವಾಗ (ಬೇರೆಯವರು ಇಟ?ತಹ ವಾಲೂ?ಿನ?)?		
h.	೬ ? ಂದ ೮ ಅ? ದೂರ? ಂದ ಗದ?? ರುವ ರೂ? ನ? ? ಕೋಣೆಯ? ?? ೬? ನೊಡುವಾಗ		
i.	ಜನ? ಂದ ತುಂ? ರುವ ಬ? ?? ?ಂಡಕ?? ನೊಂ? ಗೆ ಮಾತನಾಡುವಾಗ		

j.	ತುಂಬಾ ಜನ?ರುವ ರೈಲೆ?ನೆ?ಷ? ಸ? ?? ಮ? ಪಕ?? ಂ? ರುವವರ ಜೊತೆ ಮಾತನಾಡುವಾಗ ? ಡು? ಲಡಿ/ತುಂಬಾ ಜನ?ರುವ ಅಂಗ? ಯ? ?ಮಾ? ಕನ ಜೊತೆ ಮಾತನಾಡುವಾಗ		
k.	ಸಮಾರಂಭಗಳ? ?ಸುಮಾರು ೬ ?ಂದ ೮ ಅ? ದೂರದ? ಊವ ? ?ಕ? ?ಂದ ಬರು? ಊವ ಶಬ?ೇ?? ಕೊಳುಬಿಾಗ		
l.	ಹೋಟೆ? ನ? ?ಐದು?ನ? ?ಕು?? ರುವ ಪ?ಚಯ? ರುವ ವ??ಯು ಜೊತೆ ಮಾತನಾಡುವಾಗ		
m.	ಮದುವೆ ಮನೆಯ? ?? ಮ? ಪಕ?ದ? ?ಕು?? ರುವ ವ??ಯು ಜೊತೆ ಮುಖ ನೋಡದೆ ಮಾತನಾಡುವಾಗ		
n.	ಗದಲಿವುಳ?ರಸೆಯು? ?? ಮಗೆ ಪ?ಚಯ? ರುವವರ ಜೊತೆ ಮತನಾ? ಕೊಂಡು ಹೋಗು? ಊವಾಗ		
o.	? ೀ? ಅಥವ ರೇ?? ನಡೆಯು? ಊವಾಗ ? ಮ? ಪಕ?ದ? ಊವವರು ?? ?ಿ? ಗೆ ಮಾತನಾ? ದರೆ		
p.	? ತ?ಮಂ? ರದ? ? ?? ಟ? ನ? ?? ಮ? ಪಕ?ಕು?? ರುವ ವ??ಯು? ? ಂ? ಗೆ ಮುಖ ನೊಡದೆ ಮಾತನಡುವಗ		
q.	ಸುಮಾರು ೬ ಇಂಚು ದೂರ? ಂದ ಯಾರದರು ? ಸು ಮಾ? ನ? ?? ?ಿ? ಗೆ ಮಾತನಾ? ದರೆ		
r.	? ಶಬಿಾದ ವಾತವರಣದ? ?? ಮ? ಪಕ?ದ? ಊವ ಅಪ?? ತ ವ?? ಂ? ಗೆ ಮಾತನಾಡುವಾಗ		
s.	ಮನೆಯ? ?ಒಂದು ಸಣ?ಗುಂ? ನ? ?ಮಾತನಾಡುವಾಗ		
t.	? ಮ? ಮುಂದೆ ೩ ಅ? ದೂರದ? ?ಕು?? ರುವ ವ??ಯು ಜೊತೆ ಅವರ ಮುಖ ನೋ? ಕೊಂಡು ಮಾಥನಾಡುವಾಗ (ಕೋಣೆಯ? ?ಚೆನಾ? ಬೆಳ?ರುವಾಗ)		
2.	? ೀವು ಮಾತನಾಡುವ ? ದಲು ? ೀ? ಅಥವ ರೇ?? ವಾಲೂ? / ಶಬ? ಕ?? ಮಾಡು? ೀರ?		
3.	? ಮ? ಸುತಾಮುತ?ಇರುವ ಜನರು ಒ? ?ೆ ಮಾಥನಾ? ದರೆ ? ಮಗೆ ಅಥ?ಮಾ? ಕೊಳಬು ಕಷಬಿಾಗುತಡೆ? ?		
4.	ದೊಡ?ೂ? ನ? ?ಹೆಚು?ಜನರು ಮಾತನಾ? ದಾಗ ಅಥ?ಮಾ? ಕೊಳಬು ಕಷಬಿಾಗುತಡೆ? ?		
5.	? ಮ? ಜೊತೆ ? ದಾನವಾ? ಮಾತನಾ? ದಾಗ ಅಥ ಮಾ? ಕೊಳಬು ಸುಲಭವಾಗುತಡೆ? ?		
6.	? ಮ? ಜೊತೆ ಮಾಥನಾಡುವವರನು?ಪದೆ ಪದೆ ಹೇ? ಎಂದು ಕೇಳು? ೀರೆ?		
7.	? ಮ?? ಂದೆ? ಂದ ಮಾತನಾಡು? ಊವ ಪ?ಚಯ? ರುವ ವ??ಯು ಧ**?** ಯನು?		

	ಗುರು? ಸಲು ಕಷಬಿಾಗುತಡೆ? ?		
8.	? ೀವು ರಸೆಉು? ?ಹೊಗುವಾಗ ವಾಹನದ ಹ? ? ಯಾವ ಕಡೆ? ಂದ ಬರು? ಡೆ? ಂದು ಗುರು? ಸಬ? ಶೆ?		
9.	ಒಂದು ಗುಂ? ನ? ?ಮತನಾಡುವಾಗ, ಯಾರು ಎ? ಠಿದ ಮಾಥನಾ? ದರು ಎಂದು ? ? ಯುತಡೆ? ?		
10.	? ಮಗೆ ಶಬಿಣ ತೊಂದರೆ ಇರುವುದ? ಂದ, ಜನರ ಜೊತೆ ಮಾತನಾಡದೆ ದೂರ ಉ? ಯು? ೀರೆ?		
11.	? ಮಗೆ ಶಬಿಣ ತೊಂದರೆ ಇರುವುದ? ಂದ, ಹೊಸಬರ ಜೊತೆ ಮಾತನಾಡಲು ? ಂಜ? ಯು? ೀರೆ?		
12.	? ಮಗೆ ಶಬಿಣ ತೊಂದರೆ ಇರುವುದ? ಂದ, ಗುಂ? ನ? ?ಮಾತನಾಡುವಾಗ ಹೆಚು? ಭಾಗವ? ಸುವು? ಲಜೆ?		
13.	? ಮಗೆ ಶಬಿಣ ತೊಂದರೆ ಇರುವುದ? ಂದ, ? ೀವು ? ೀ? ಯನು?ಹೆಚು? ನೋದುವು? ಲಜೆ?		
14.	ಬೇರೆಯವರು ಮಾಥನಾಡುವುದು ಅಥ?ವಾಗದೆ ಇದಾಗ ಹತಾಷೆಯಾಗು? ೀರೆ?		
15.	? ಮ? ಕುಟುಂಬ ಸದಸ?ರು ಹೇ? ದು?? ಮಗೆ ಅಥ?ವಾಗದೆ ಇದಾಗ ಅವ? ಗೆ ?? ?? ಯಾಗುತಡೆ? ?		
16.	? ಮಗೆ ಶಬಿಣ ತೊಂದರೆ ಇರುವುದ? ಂದ, ಜನರು ? ? ?ೂ? ಗೆ ಹೆಚು? ಮಾತನಾಡುವು? ಲಜೆ?		
17.	? ೀವು ಜೋರಾ? ಮಾತನಾಡು? ೀರೆಂದು ? ಮ? ಮನೆಯವರು ?? ?? ಗೊಳುತಿಾಶೆ? ?		
18.	? ಶಬಪಿಾದ ಕೋಣೆಯ? ?ಸುಮಾರು ೬ ? ಂದ ೮ ಅ? ದೂರ? ಂದ ಈ ಕೆಳ? ನ ಶಬಗಳನು?ಕೇ? ? ಕೊಳಬ? ಶೆ?		
	೧. ? ೀ? ? ೦? ಆದ ಶಬ?		
	೨. ಬಾ? ಲು ಬ? ದ ಶಬ?		
	೩. ನಾ? ಬೊಗುಳುವ ಶಬ?		
	೪. ಕಾಲ?? ಗೆಯ ಶಬ?		
	೫. ನ? ಡು? ?? ೀರು ಬರು? ಡುವ ಶಬ?		
	೬. ಕುಕ?? ಕೂಗು/ ? ೀ? ಶಬ?		
19.	? ಶಬಪಿಾದ ಕೋಣೆಯ? ?ಸುಮಾರು ೧೮ ? ಂದ ೨೦ ಅ? ದೂರ? ಂದ ಈ ಕೆಳ? ನ ಶಬಗಳನು?ಕೇ? ? ಕೊಳಬ? ಶೆ?		
	೧. ? ೀ? ? ೦? ಆದ ಶಬ?		
	೨. ಕುಕ?? ಕೂಗು/ ? ೀ? ಶಬ?		
	೩. ಬ? ಹಾ? ?		
20.	? ಶಬಪಿಾದ ವಾತವರಣದ? ?ಸುಮಾರು ೬ ? ಂದ ೮ ಅ? ದೂರ? ಂದ ? ಮ?ಸು? ಕರೆದರೆ ? ಮಗೆ ಕೇ? ಸುತಡೆ? ?		

21.	? ಶಬಪಿಾದ ವಾತವರಣದ? ?ಸುಮಾರು ೧೮ ?ಂದ ೨೦ ಅ? ದೂರ? ಂದ ? ಮ?ನು?ಕರೆದರೆ ? ಮಗೆ ಕೇ? ಸುತಡೆ? ?		
22.	? ೯? ಯನು?ಸಾಧಾರಣ ವಾಲು?? ನ? ?ಹಾ?ದಾಗಿ ಸುಮಾರು ೬ ?ಂದ ೮ ಅ? ದೂರ? ಂದ ? ಮ?ನು?ಕರೆದರೆ ? ಮಗೆ ಕೇ? ಸುತಡೆ? ?		