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

Padmashree, B.[1] & Manjula, P.[2]

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. The ANL and SNR-50 increased as the gap detection threshold increased; and that 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*

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.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).

From these studies it can be inferred that several factors contribute to the outcome from 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.

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 ratio (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 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). 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,

1. basavaraju.padmashree@gmail.com
2. manjulap21@hotmail.com

gap detection threshold correlated well with the speech perception in quiet and in noisy situations(Dreschler & Plomp, 1980). 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 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 the perception of speech in noise.

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) has also reported cases of elevated gap thresholds in subjects with high frequency hearing loss. 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 (APHAB) (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 questionnaire. 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.

The aim of the study was to investigate whether the temporal processing measure 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 hearing aid benefit.
4. To evaluate the relationship of ANL and SNR-50 with the hearing aid benefit.

Method

Participants selection criteria

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, Group I having 10 ears with mild sensorineural hearing loss (SNHL) and the Group II having 12 ears with moderate SNHL. 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.

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.

Instruments and material used

A calibrated 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 (Temporal Fine Structure 1, TFS1 software) (Moore & Sek, 2009; Sek & Moore, 2012) 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 (Shivaprakash & Manjula, 2003) was used to establish the gap detection threshold.

c) For measurement of ANL, a recorded Kannada passage and Kannada four-speaker multi talker babble (Kumar, 2012) were used.

d) For measurement of SNR-50, Phonemically Balanced (PB) test material in Kannada (Manjula, Geetha, Kumar, & 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, et al, 2012) was used to obtain the SNR-50.

e) The hearing handicap scale titled Self-Assessment of Hearing Handicap (SAHH), (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).

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.

Measurement of Temporal fine structure (TFS) sensitivity

The sensitivity to TFS was measured using TFS1 test (Moore & Sek, 2009; Sek & Moore, 2012). 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 a 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 temporal fine structure discrimination thresholds were obtained using adaptive and non- adaptive runs. 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).

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., 2003), 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.

Administration of Gap Detection Test

The Gap Detection Test (Shivaprakash & Manjula, 2003) was used to obtain the gap detection threshold. The participant was presented with a set of three bursts of noise, and they were asked to identify the burst of noise which had a gap in it. The gap was randomly inserted in one of the bursts and the duration of the gap kept on reducing with the presentation.

The minimum gap identified by the participant for each test ear was considered as the gap detection threshold (GDT).

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. The instructions used were same as that of Nabelek, Freyaldenhoven, Tampas, Burchfield, and Muenchen (2006) study. Though ANL is generally used as a predictive measure for hearing aid use, in the present study it was used to know its efficacy as a measure to predict hearing aid outcome.The ANL for each participant was calculated by subtracting the BNL from MCL.

$$ANL = MCL - BNL$$

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 at the MCL throughout the testing.

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 difference between the level of speech and the noise at this juncture was considered to be the SNR-50.

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.

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 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. Then the scoring was done 1 to 5, where1 indicating 100% difficulty and 5 indicating 0% difficulty.

The benefit from the hearing aid under each of the sub-sections and the overall benefit were calculated by subtracting the unaided scores from aided scores.

Since the number of questions varied under each sub-section, the scores were converted to percentage for comparison.

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

Statistical analyses

After obtaining the data on temporal processing (i.e., TFS sensitivity threshold and gap detection threshold) and hearing aid outcome measures (ANL, SNR-50 and benefit through questionnaire) 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.
4. The linear regression analysis was carried out on the measures which were related.

Results

Temporal processing measures

Descriptive statistics were used to get the mean, median, standard deviation (SD), and range (minimum and maximum) for the two groups of ears. The results of the gap detection test, temporal fine structure discriminability index (d') for F_0 of 100 Hz and for F_0 of 500 Hzare listed in the Table 1.

The Shapiro-Wilk's test revealed that the data on gap detection threshold of mild and moderate SNHL groups were normally distributed ($p<0.05$), whereas the temporal fine structure discriminability index (d') for F_0 of 100 Hz and 500 Hz were not normally distributed ($p>0.05$). The data on temporal fine structure discriminability index (d') were transformed into normal distribution. A parametric test, Levene's test ($p<0.05$), showed that there was homogeneity in the variance between both the groups for the gap detection threshold and temporal fine structure discriminability index (d') for F_0 of 100 Hz. The independent samples t-test showed that there was no significant difference between the groups ($p<0.05$) for gap detection threshold and temporal fine structure discriminability index (d') for F_0 of 100 Hz. Hence, data from both the groups were combined to form a single group. But temporal fine structure discriminability index (d') for F_0 of 500 Hence, the data from the two groups were not combined for this measure. The Mann-Whitney U test ($p<0.05$) showed that there was no difference between the mild (Group I) and moderate (Group II) groups.

Hearing aid measure

The Shapiro-Wilk's test revealed normal distribution of the data ($p<0.05$) for both ANL and SNR-50. On Levene's test ($p<0.05$), there was homogeneity in the variance between both the two groups in both the measures. Hence, the data from the two groups were combined for gap detection threshold. Independent samples t-test showed that the moderate SNHL group had significantly higher mean values of GDT than the mild SNHL group. On comparison of SNR-50 between the mild and the moderate SNHL groups, it was noted that the group with moderate SNHL had a significantly higher mean value of SNR-50 than the mild SNHL group.

Table 1: *Mean, median, standard deviation and range of gap detection threshold(in ms), Temporal fine structure discriminability index (d') for F_0 of 100 Hz (d' TFS_100) and Temporal fine structure discriminability index (d') for F_0 of 500 Hz (d' TFS_500)*

Measure	*Groups*	*Mean*	*Median*	*Standard Deviation*	*Range*	
					Minimum	*Maximum*
Gap detection threshold(in ms)	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
d' TFS-100	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
d' TFS-500	Mild SNHL	55.15	6.44	77.97	0.00	181.25
	Moderate SNHL	43.75	0.00	67.84	0.00	181.25

Hearing aid benefit questionnaire

The questionnaire was administered only on moderate SNHL group as experienced hearing aid users were considered in this group. The benefit scores revealed that most of the individuals rated the benefit from hearing aid to be relatively less (i.e., none of the sections showed 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 that there was 25.66% of benefit from the hearing aid.

Table 2. *Mean, median, standard deviation and range of ANL (in dB) and SNR-50*

Measure	*Groups*	*Mean*	*Median*	*Standard Deviation*	*Range*	
					Minimum	*Maximum*
ANL	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
SNR-50	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

Table 3. *Mean, median, standard deviation and range of scores on different sub-sections of hearing aid benefit questionnaire*

Sub-sections of questionnaire	*Maximum scores*	*Raw mean scores*	*Benefit from 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

The relationship between different outcome measures

The questionnaire was administered only on moderate SNHL group as it is difficult to obtain experienced hearing aid users

In mild SNHL group. Hence, the relationship between the hearing aid benefit questionnaire scores with the ANL and SNR-50 were assessed only 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.

Table 4.*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 increased, the benefit from the hearing aid obtained reduced for all the type of sound environments. But these relationships were not statistically significant.

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

The effect of temporal processing on hearing aid measures

In the following sections the influence of temporal processing on hearing aid benefit is being provided.

Influence of temporal processing on acceptable noise level (ANL)

The comparisons were made between the measures using Pearson's correlation coefficient. The temporal gap detection thresholds, discriminability index (d') of TFS were compared with aided ANL. The results are given in Table 5.

Table 5. *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.*

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: * C orrelation 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 F_0 at 500 Hz 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 then subjected to 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 benefit measures.

To measure whether the ANL is dependent on gap detection threshold, a simple linear regression was carried out based on the scatter plot. The regression equation was computed.

$$ANL = A + b\,(GDT),$$

Where 'A' is the intercept, 'b' is the slope of the line which is a constant.

Therefore the predicted ANL is,

$$ANL = -10.55 + 2.87(GDT)$$

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 ANL is increased by 2.87 for each ms increase in the gap detection threshold. The linearity of the data is presented in Figure 1.

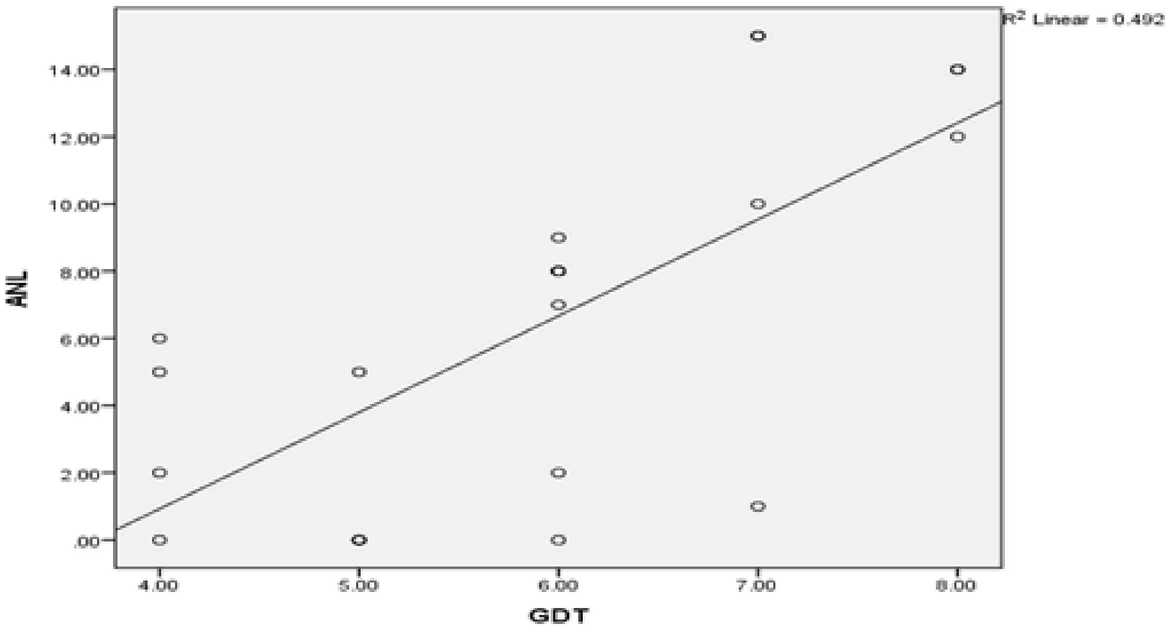

Figure 1. *Scatter plot showing the statistical relationship between the gap detection threshold (GDT) and the acceptable noise level (ANL).*

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 6.

Table 6. *Pearson's correlation coefficient (r) between SNR-50 and the temporal processing measures i.e., 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 F_0 at 500 Hz had heterogeneous variance between the groups

The results show that the SNR-50 is 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 too. The TFS processing at $F_0$of 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.

The regression equation was computed.

$$SNR\text{-}50 = A + b\,(GDT),$$

Where 'A' is the intercept, 'b' is the slope of the line which is a constant.

Therefore the predicted SNR-50 is,

$$SNR\text{-}50 = -3.36 + 1.85(GDT)$$

A linear regression established that the gap detection threshold could significantly predict the SNR-50[F (1, 20) = 9.19, p= 0.07) with an R^2 of 3.15]. 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 2.

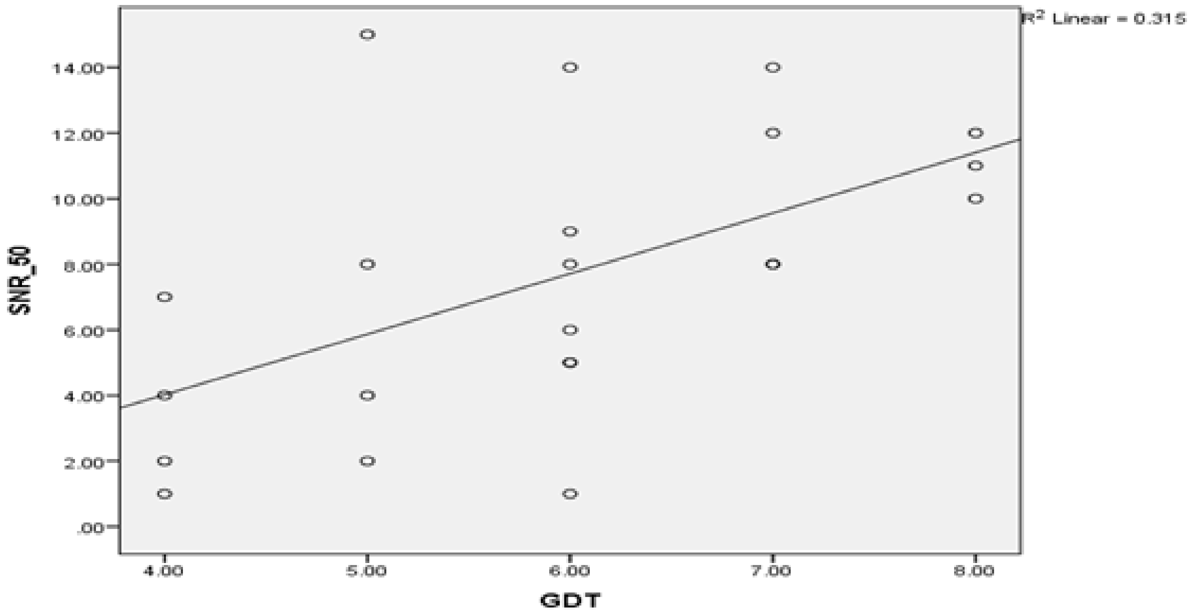

Figure 2.*Scatter plot of the relationship between the gap detection threshold (GDT) and SNR-50.*

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 moderate SNHL group only. The relationship between the various measures of temporal processing and the questionnaire scores were assessed using

Table 7. *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.

Discussion

Temporal processing measures

The two temporal processing measures (GDT and TFS) are discussed in the following sections.

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 1). Both the groups had a gap detection threshold ranging from 4 to 8 ms. Florentine and Buus (1984) have 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 7000Hz) 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 (F_0 of 100 Hz) and high frequency (F_0 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

The two hearing aid measures (ANL and SNR-50) are discussed in the following sections.

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 groups. There was no significant difference between mean ANL 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 have affected the results. Recker and Edwards (2003) also found that the ANL did not differ between groups 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 that in 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 correlation 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) among others.

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. 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 due to individual difference in measuring the difficulties in different listening conditions and 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 multi-talker babble was used. This may have led to the differences. When speech perception was measured in the presence of multi-talker babble, the scores might have reduced for SNR-50 due to difficulty in the task.

The effect of temporal processing on hearing aid measures

The effect of TFS and GDT on ANL, SNR-50, and questionnaire measure was evaluated.

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 involve central processing. 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) have 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. The ANL reduced as the TFS sensitivity increased. 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. Glasberg, Moore, and Bacon (1987) explained that the poorer gap detection led to slower recovery from the background noise. Hence, theeffect of noise will be more in individuals with poor gap detection threshold, as they will not be able to separate speech from noise during fluctuations due to forward masking. In addition, the studies reveal that 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.

Many studies suggest that the temporal fine structure cues are important for speech performance in noise (Shannon et al., 1995; Dorman et al., 1998; Stone, Moore & Fullgrabe, 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 due to sample size.

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

The 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. Non audiological attributes may have influenced the results (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 influence of TFS sensitivity on hearing aid outcome are inconclusive because of larger variability in the results.

Conclusions

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. This would help in counseling the patients about the real-life benefits from the hearing aids and realistic expectations. 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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