Acoustic Analysis of the Speech Processed Through Three Amplification Strategies and Their Effect on Speech Recognition Scores of Individual with Severe Hearing Impairment

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Abstract

Individuals with severe hearing impairment exhibit reduced frequency resolution and temporal discrimination. Therefore the requirements of amplification for this group of population will be different from those with lesser degree of hearing loss. The aim of the present study was to investigate acoustic changes to the speech signal [in terms of Consonant Vowel Ratio (CVR) and Envelope Difference Index (EDI)] that occurred with different amplification strategies and to examine the relationship between such changes and speech perception in individuals with severe sensorineural impairment. A total of 10 subjects having moderately severe to severe hearing loss participated in the study. Speech Recognition Scores were calculated for CV nonsense syllable list at input level of 65 and 80 dBSPL for the three amplification strategies viz Peak Clipping, Compression Limiting, and Wide Dynamic Range Compression. Consonant Vowel Ratio was calculated for the unprocessed and processed stimuli for 5 subjects and Correlation Index for one subject at input level of 65 and 80 dBSPL for all the three strategies using Matlab software. The scores were better with Compression Limiting compared to Wide Dynamic Range Compression (WDRC) at both 65 and 80 dBSPL. The CVR values for the processed stimuli with vowel environment /u/ were higher for the Compression Limiting strategy as compared to WDRC and at 65 and 80 dBSPL for /a/ and /i/ at 80 dBSPL. The EDI value was greater at 65 dBSPL and as the level increased to 80 dBSPL there was a decrease in the EDI value for all the three strategies. The results of the present study indicate a relationship between acoustic changes to the hearing aid processed speech signal and speech perception performance of severely hearing impaired individuals.

Key words: Peak Clipping, Compression Limiting, Wide Dynamic Range Compression, Consonant Vowel Ratio, Envelope Difference Index.

Introduction

Sensorineural hearing loss is often associated with loudness recruitment, an abnormally rapid growth of loudness level with increasing sound level (Moore, 2004). Recruitment could be due to reduced compressive nonlinearity on the basilar membrane produced by loss of outer hair cell function (Moore, 1998). The effect of recruitment is represented on the audiogram by the reduced range between hearing thresholds and uncomfortable loudness levels. In some patients with large losses, and thus small dynamic range, even the dynamics of speech signal itself causes

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problem, amplifying the weak parts of the speech to audible level that causes the strong parts to be uncomfortably loud.

The feature of Multichannel wide dynamic range compression gives more gain for weak sounds than for intense sounds. WDRC compresses most of the speech spectrum into the residual range giving increased audibility and comfort and making loudness perception more similar to normal (Villchur, 1973). There have been various studies reported in literature that compared WDRC with Linear amplification and found greatest benefits for WDRC for low level speech in quiet and conversational level speech in quiet (Souza 2002) and some studies have even shown small benefits for speech in background noises (Moore, Peters & Stone 1999). However, most of these studies have dealt with listeners with mild to moderate hearing loss.

The audiological profile differs for different degrees of hearing loss and hence the choice of amplification also varies. Individuals with severe hearing loss are characterized by suprathreshold processing deficits primarily by dramatically reduced frequency selectivity (Faulkner, Rosen & Moore 1990) and in some circumstances by reduced temporal discrimination (Lamore, Verwiej & Brocaar 1990). It has long been accepted that listeners with a severe loss require different linear amplification characteristics than listeners with a mild to moderate loss (Byrne, 1978; Byrne et al., 1990; Schwartz et al., 1988; Van Tasell, 1993). Because of their broader auditory filters (Faulkner et al., 1990), listeners with a severe-to profound loss may not be able to take full advantage of spectral information (eg, Erber, 1972) and must rely to a greater extent on temporal cues which are altered by WDRC amplification (Moore 1996; Van Tasell et al., 1987). For WDRC amplification one effect is alteration of the natural time-intensity variations of the speech signal. For listeners with a mild-to-moderate loss who presumably depend to a greater extent on spectral cues, these changes in time-intensity variations do not significantly offset the benefits of improved speech audibility (Souza & Turner, 1996, 1998 and 1999).

Souza and Jenstad (2005) attempted to compare speech recognition scores across different amplification strategies for listeners with severe hearing loss and found that the benefits of fast acting WDRC relative to more linear amplification may be reduced in listeners with severe loss. In contrast, Moore and Marriage (2005) studied the effect of three amplification strategies on speech perception by children with severe and profound hearing loss and found that speech scores on close set testing for the profound group showed significant benefit for WDRC over the other two algorithms. The contradictory results could probably be because the latter study was done on children with congenital hearing loss in whom the dynamic range is reduced as seen in adults with sensorineural hearing loss.

Review of hearing aids for hearing impairment has shown that signal processing techniques that take the acoustic- phonetic structure of speech into account promise to be more effective in improving intelligibility than non phonetically -based methods of signal processing, provided the relevant speech features are extracted reliably. A form of signal processing which is phonetically based and which holds some promise for improving intelligibility is that of adjusting the ratio of consonant intensity to vowel intensity (C-V ratio). So the consonant vowel ratio appears promising as a good measure for selection of suitable strategy for an individual. Acoustic analysis of single channel syllabic compression and linear amplification has revealed that compression may result in changes in the intensity relationships between parts of the speech signal (Hickson & Byrne, 1995). It is expected that increase in the CVR could be expected to improve consonant perception for people with hearing impairment. Even research in linguistics with normal hearing subjects reveal that CVR itself is an important cue for perception of certain sounds. Thus calculating the Consonant Vowel ratio of the speech signal after signal processing through a hearing aid might help in predicting the performance with that hearing aid. Hickson and Thyer (1999) reported that it is possible to predict speech perception performance with compression by examining the acoustic characteristics of the processeed speech signal.

The aim of the present study was to investigate the acoustic changes to the speech signal (interms of Consonant Vowel Ratio and Envelope Difference Index) that occurred with different amplification strategies and to examine the relationship between such changes and speech perception in individuals with severe sensorineural impairment.

Objectives:

1) To study the effects of different amplification strategies on speech recognition scores of severely Hearing Impaired listeners, 2) To objectively measure the acoustic effects of different amplification strategies on amplified speech (by calculating the consonant vowel ratio and Envelope difference index) and 3) To evaluate the relation between acoustic changes and speech recognition.

Method

Subjects: Ten (5 males and 5 females) hearing aid users between 20-55 years of age participated in the study. All subjects had bilateral moderately severe to severe sensorineural hearing loss (65-90 dBHL) with normal middle ear functioning.

Stimuli: CV items word list containing nonsense monosyllabic words were recorded with a unidirectional microphone fixed at a distance of 6 inches from the speaker. The recording was done by a native Kannada speaker seated in a sound treated room. The CV word list consisted of 16 consonants paired with three different vowels /a/, /i/ and /u/ such that most of the speech frequencies are covered. The word list consisted of 48 CV items shown in Table 1. The stimulus was recorded at the sampling rate of 44.1 KHz and 16 bit resolution and stored onto the computer memory. An inter-stimulus interval of 3 secs was introduced between stimuli using Wave pad Software.

The Speech stimuli and 1 KHz tone were delivered from the same loudspeaker at a distance of 1 meter from the clients head. Level in dBA was set using the calibration track on the computer output with the sound level meter (Larsen & Davis) placed in the position of the clients head without the client present.

Table 1- Consonants, Vowels and combination of CV stimuli used in the study

	Stop						Nasal		Affricate		Fricative			Liquid		Glide
Vowels	**p**	**b**	**T**	**d**	**k**	**g**	**m**	**n**	**tʃ**	**dz**	**s**	**ʃ**	**h**	**r**	**l**	**v**
a	pa	ba	Ta	da	ka	ga	ma	na	tʃa	dza	sa	ʃa	ha	ra	la	va
i	pi	bi	Ti	di	ki	gi	mi	ni	tʃi	dzi	si	ʃi	hi	ri	li	vi
u	pu	bu	Tu	du	ku	gu	mu	nu	tʃu	dzu	su	ʃu	hu	ru	lu	vu

Procedure

[A] Experiment-I: To measure the effect of different amplification strategies on speech recognition scores:

A routine audiological evaluation that included pure tone audiometry using Carhart-Jerger Modified Hughson-Westlake (1959) procedure using a calibrated (ISO-389, 1994) dual channel diagnostic audiometer (MADSEN OB922) with TDH 39 headphone was done. Speech recognition scores and uncomfortable loudness level for speech was measured. Immitance measurements including tympanogram and acoustic reflex threshold were carried out using GSI-Tympstar immitance audiometer to rule out any middle ear pathology. The test was carried out in an acoustically treated room with noise level within the permissible limits (ANSI S3.1-1991 cited, Wilber 1994). After audiological evaluation subjects were fitted with Phonak Supero 412 Digital BTE Hearing aid having the option of different signal processing strategies: Wide Dynamic Range Compression, Peak clipping and Compression limiting. The hearing aid was programmed for all the three signal processing strategies using NAL-NL1 (Dillon et al., 1998) prescriptive formula using the NOAH Link Compass Version 4 programming software. CV items were presented from the computer sound card attached to the two channel diagnostic audiometer. The stimuli were presented via the loudspeaker at the distance of 1 m from the client at the level of 65 and 80 dBSPL. The responses of the client were noted and scored.

[B] Experiment II: To measure the effect of different amplification strategies on speech acoustics:

The acoustic measures used in the study were Consonant Vowel Ratio (CVR) and Envelope Difference Index (EDI) that quantifies the effect of amplification strategies on the temporal envelope of speech.

1) **CVR calculation:** The CV items were presented at the level of 65 and 80 dBSPL into an anechoic chamber through a PC soundcard. A microphone connected to the sound level meter was placed in the anechoic chamber to record the input stimuli. The stimuli picked up by the microphone was routed through the SLM and stored on to the computer memory. Using the same procedure all the CV items were recorded at 65 and 80 dBSPL. In the next step the programmed hearing aid for each of the different conditions was kept in the anechoic chamber with the receiver output coupled to a 2cc coupler. The stimuli presented at 65 and 80 dBSPL in the anechoic chamber were picked up by the hearing aid microphone and the output of hearing aid is

picked up by the microphone of SLM and stored onto the computer memory. The CVR was calculated using an algorithm in Matlab. From the acquired waveforms for the processed and unprocessed stimuli the consonant and vowel amplitudes are separated out through high pass and low pass Butterworth filter respectively.

2) Envelope Difference Index: This quantifies temporal changes caused by amplification and a measure is used for comparing the temporal contrasts of the two acoustic signals called EDI. Similar procedure was followed for recording the sound as for CVR calculation. The input waveform of the speech signal the waveform of the amplified signal after passing through the hearing aid was acquired and the absolute value of the waveforms were taken. The waveforms were scaled to a mean value of 1. Both the scaled waveforms were correlated using the cross correlation technique. The CI value was calculated using the formula:

NCI = (∑ ISAMPLE1n – SAMPLE2n1) / 2N

n=1

The procedure was repeated using each of the three amplification strategies.

Results

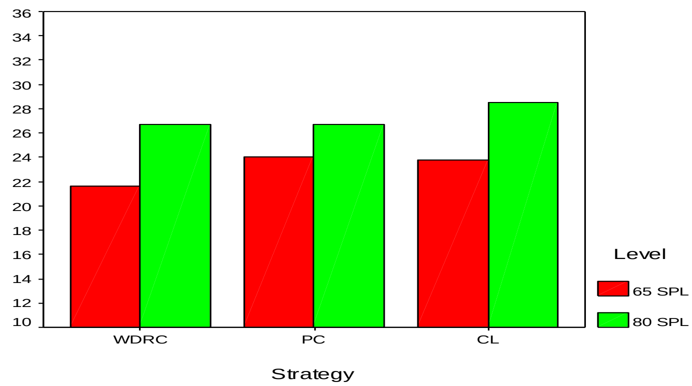
[A] Experiment-I: The speech recognition scores obtained for 10 subjects were analyzed to study the effect of amplification strategies and levels. SPSS, Statistical Package for Social Sciences (version 10) for windows was used to analyze the data. The following parameters were analyzed.

1) **Effect of strategy on Speech recognition Scores:** Table 2 shows the overall mean Speech recognition scores, Standard deviation for different amplification strategies at 65 and 80 dBSPL. The mean scores were better for the Peak clipping (PC) at 65 dBSPL and for Compression Limiting (CL) strategy at 80 dBSPL.

Table 2- Mean and SD of speech recognition scores across conditions

Level dBspl	Strategies	Mean	SD
65	Compression Limiting	23.8	2.49
	Peak Clipping	24.0	3.83
	Wide Dynamic Range Compression	21.6	2.72
80	Compression Limiting	28.5	2.01
	Peak Clipping	26.7	4.11
	Wide Dynamic Range Compression	26.7	4.00

a) At 65 dBSPL input: One-way repeated measure ANOVA was performed for comparison across strategies within 65 dBSPL. The effect of amplification strategy was significant, $F (2, 18) = 3.661$; $p < 0.05$. Since there was a significant difference across strategies, pair-wise differences among them was tested with Bonferroni’s multiple comparison. There was a significant difference between WDRC and CL at 0.05 level of significance. The mean scores were better for Compression Limiting than WDRC. The remaining pairs were not significant at 0.05 level**.**



Graph 1: Mean Percentage Speech recognition scores across strategies

b) At 80 dBSPL input: One-way repeated measure ANOVA was performed for comparison across strategy for 80 dBSPL input. The effect of amplification strategy was not significant, $F(2, 18) = 1.254$; $p > 0.05$.

2) Effect of presentation level on speech recognition Scores

Paired t- test was done for comparison across level within each strategy. The effect of presentation level was significant for all the strategies, WDRC [$t(9) = 4.680$, $p < 0.05$], PC [$t(9) = 6.384$, $p < 0.05$], CL [$t(9) = 6.567$; $p < 0.05$]. The scores were higher at 80 dBSPL than at 65 dBSPL.

[B] Experiment II

1. Effect of strategy on consonant vowel ratio: The consonant vowel ratio values were calculated for 5 subjects. They were analyzed to study the effect of amplification strategy.

a) Peak clipping condition: The CVR values were calculated for the stimuli with vowel environment /a/, /i/, /u/. Table 3 shows the mean CVR values and Standard Deviation of the input (unprocessed) stimuli and the output (processed) stimuli in 3 different vowel environments for 5 subjects.

Paired t test was done to compare the CVR values of the unprocessed and processed stimuli.

i) **Stimuli with vowel environment /a/:** There was significant difference between the CVR values of the unprocessed and processed stimuli at 65 dBSPL [$t(15) = 3.451$, $p<0.01$] and 80 dBSPL [$t(15) =4.351$, $p<0.01$]. The CVR values were higher for the processed stimuli as compared to the unprocessed stimuli both for 65 and 80 dBSPL

Table 3: Mean and SD of CVR values for the processed and unprocessed stimuli

Stimuli		Mean	SD
/a/ 65	Input	0.68	0.14
	Output	0.80	0.04
/a/ 80	Input	0.60	0.17
	Output	0.77	0.04
/i/ 65	Input	0.39	0.22
	Output	0.37	0.10
/i/ 80	Input	0.21	0.18
	Output	0.35	0.09
/u/ 65	Input	0.66	0.23
	Output	0.67	0.08
/u/ 80	Input	0.58	0.19
	Output	0.69	0.08

ii) **Stimuli with vowel environment /i/:** There was no significant difference between the CVR values of the unprocessed and processed stimuli at 65 dBSPL [t (15)= 0.736, p>0.01] whereas difference was seen at 80 dBSPL input [t (15) = 2.899, p<0.01]. The CVR was enhanced significantly after processing at 80 but not at 65 dBSPL.

iii) **Stimuli with vowel environment /u/:** There was no significant difference between the CVR values of the unprocessed and processed stimuli at 65 dBSPL [t (15)= 0.259, p>0.01] whereas difference was seen at 80 dBSPL input [t (15) = 2.940, p<0.01]. The CVR was enhanced significantly after processing at 80 dBSPL but not at 65 dBSPL.

b) **Compression Limiting:** The CVR values were calculated for stimuli with vowel environment /a/, /i/, /u/. Table 4 shows the mean CVR values and SD of the input unprocessed stimuli and the output processed stimuli in 3 different vowel environments.

Table 4: Mean CVR values and Standard Deviation for unprocessed and processed stimuli

Stimuli	Input/Output	Mean	SD
/a/ 65	Input	0.68	0.14
	Output	0.79	0.04
/a/ 80	Input	0.60	0.17
	Output	0.80	0.02
/i/ 65	Input	0.39	0.22
	Output	0.41	0.11
/i/ 80	Input	0.20	0.18
	Output	0.40	0.08
/u/ 65	Input	0.66	0.23
	Output	0.75	0.07
/u/ 80	Input	0.58	0.19
	Output	0.71	0.05

Paired t test was done to compare the CVR values of the unprocessed input and processed output stimuli.

i) **Stimuli with vowel environment /a/:** There was significant difference between the CVR values of the unprocessed and processed stimuli at 65 dBSPL [$t\ (15) = 2.840$, $p<0.01$] and 80 dBSPL [$t\ (15) = 5.035$, $p<0.01$].

ii) **Stimuli with vowel environment /i/:** There was no significant difference between the CVR values of the unprocessed and processed stimuli at 65 dBSPL [$t\ (15) = 0.194$, $p>0.01$] whereas difference was seen at 80 dBSPL input [$t\ (15) = 4.454$, $p<0.01$].

iii) **Stimuli with vowel environment /u/:** There was no significant difference between the CVR values of the unprocessed and processed stimuli at 65 dBSPL [$t\ (15) = 1.389$, $p>0.01$] whereas difference was seen at 80 dBSPL input [$t\ (15) = 2.720$, $p<0.01$].

c) Wide dynamic range compression: The CVR values were calculated for the stimuli with vowel environment /a/, /i/ and /u/ divided into 6 consonants groups (stops, nasals, affricates, fricatives, liquids and glides respectively). Table 5 shows the mean CVR values and Standard Deviation of the input unprocessed stimuli and the output processed stimuli in 3 different vowel environments.

Table 5: Mean CVR values and Standard Deviation for unprocessed and processed stimuli

Stimuli	Input/Output	Mean	SD
/a/ 65	Input	0.68	0.14
	Output	0.70	0.50
/a/ 80	Input	0.60	0.17
	Output	0.74	0.05
/i/ 65	Input	0.40	0.22
	Output	0.49	0.10
/i/ 80	Input	0.21	0.18
	Output	0.35	0.08
/u/ 65	Input	0.66	0.23
	Output	0.56	0.06
/u/ 80	Input	0.58	0.19
	Output	0.66	0.07

Paired t test was done to compare the CVR values of the unprocessed input and processed output stimuli.

i) Stimuli with vowel environment /a/: There was no significant difference between the CVR values of the unprocessed and processed stimuli at 65 dBSPL [$t\ (15) = 0.520$, $p>0.01$] whereas there was significant difference at 80 dBSPL [$t\ (15) = 3.152$, $p<0.01$].

ii) **Stimuli with vowel environment /i/:** There was no significant difference between the CVR values of the unprocessed and processed stimuli at 65 dBSPL [t (15) = 1.431, p>0.01] whereas difference was seen at 80 dBSPL input [t (15) = 3.118, p<0.01].

iii) **Stimuli with vowel environment /u/:** There was no significant difference between the CVR values of the unprocessed and processed stimuli at 65 dBSPL [t (15) = 1.488, p>0.01] at 80 dBSPL input [t (15) = 1.790, p>0.01].

2) Comparison of CVR values across different amplification strategies

i) Stimuli with vowel environment /a/

a) At 65 dBSPL: The mean CVR values and Standard Deviation for the processed stimuli for all the 3 conditions are shown in Table 6. The mean CVR values were higher for peak clipping.

Table 6: Mean CVR values across strategies for stimuli with vowel /a/ at 65 dBSPL

Strategies	Mean	SD
Peak Clipping	0.81	0.04
Compression Limiting	0.79	0.03
Wide Dynamic Range Compression	0.70	0.05

One-way repeated measure ANOVA was done to see the effect of amplification condition. There was a significant effect of amplification condition on the CVR values [F (2, 30) = 4.946, p< 0.05]. Since there was a significant difference across strategies, pair-wise differences among them was tested with Bonferroni's multiple comparison. There was significant difference between Peak Clipping and WDRC, WDRC and Compression Limiting at 0.05 level of significance. There was no significant difference between Peak Clipping and Compression Limiting at 0.05 level.

b) At 80 dBSPL: The mean CVR values and Standard Deviation for the processed stimuli for all the 3 conditions are shown in Table 7. The mean CVR values were higher for compression limiting.

Table 7: Mean CVR values across strategies for stimuli with vowel /a/ at 80 dBSPL

Strategies	Mean	SD
Peak Clipping	0.77	0.39
Compression Limiting	0.80	0.02
Wide Dynamic Range Compression	0.74	0.05

One-way repeated measure ANOVA was done to see the effect of amplification condition. There was a significant effect of amplification condition on the CVR values. [F (2, 30) = 10.659, p< .05]. Since there was a significant difference across strategies, pair-wise differences among them was tested with Bonferroni's multiple comparison. There was significant difference between Peak Clipping and Compression Limiting, WDRC and Compression Limiting at 0.05 level of significance. There was no significant difference between Peak Clipping and WDRC.

ii) Stimuli with vowel environment /i/

a) **At 65 dBSPL:** The mean CVR values and Standard Deviation for the processed stimuli for all the 3 conditions are shown in Table 8. The mean CVR values were higher for Wide Dynamic range Compression.

Table 8: Mean CVR values across strategies for stimuli with vowel /i/ at 65 dBSPL

Strategies	Mean	SD
Peak Clipping	0.37	0.99
Compression Limiting	0.41	0.10
Wide Dynamic Range Compression	0.49	0.09

One-way repeated measure ANOVA was done to see the effect of amplification condition. There was a significant effect of amplification condition on the CVR values [$F(2, 30) = 12.961$, $p < 0.05$]. Since there was a significant difference across strategies, pair-wise differences among them was tested with Bonferroni's multiple comparison. There was significant difference between Peak Clipping and WDRC, WDRC and Compression Limiting at 0.05 level of significance. There was no significant difference between Peak Clipping and Compression Limiting.

b) **At 80 dBSPL:** The mean CVR values and Standard Deviation for the processed stimuli for all the 3 conditions are shown in Table 9. The mean CVR values were higher for compression limiting.

Table 9: Mean CVR values across strategies for stimuli with vowel /i/ at 80 dBSPL

Strategies	Mean	SD
Peak Clipping	0.35	0.95
Compression Limiting	0.40	0.08
Wide Dynamic Range Compression	0.35	0.07

One-way repeated measure ANOVA was done to see the effect of amplification condition. There was a significant effect of amplification condition on the CVR values [$F(2, 30) = 5.533$, $p < 0.05$]. Since there was a significant difference across strategies, pair-wise differences among them was tested with Bonferroni's multiple comparison. There was significant difference between Peak Clipping and Compression Limiting, WDRC and Compression Limiting at 0.05 level of significance. There was no significant difference between Peak Clipping and WDRC.

iii) Stimuli with vowel environment /u/

a) **At 65 dBSPL:** The mean CVR values and Standard Deviation for the processed stimuli for all the 3 conditions are shown in Table 10. The mean CVR scores were higher for compression limiting.

Table 10: Mean CVR values across strategies for stimuli with vowel /u/ at 65 dBSPL

Strategies	Mean	SD
Peak Clipping	0.67	0.07
Compression Limiting	0.75	0.07
Wide Dynamic Range Compression	0.56	0.06

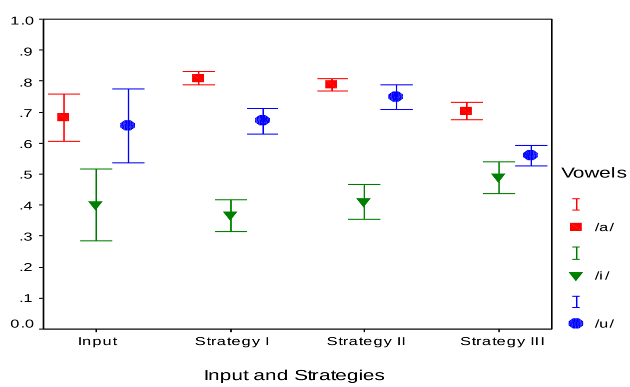
One-way repeated measure ANOVA was done to see the effect of amplification condition. There was a significant effect of amplification condition on the CVR values [F (2, 30) = 42.301, p<0.05]. Since there was a significant difference across strategies pair-wise differences among them was tested with Bonferroni's multiple comparison. There was significant difference between Peak Clipping and Compression Limiting, WDRC and Compression Limiting, Peak Clipping and WDRC at 0.05 level of significance.

b) At 80 dBSPL: The mean CVR values and Standard Deviation for the processed stimuli for all the 3 conditions are shown in Table 11. The mean CVR were higher for compression limiting.

Table 11: Mean CVR values across strategies for stimuli with vowel /u/ at 80 dBSPL

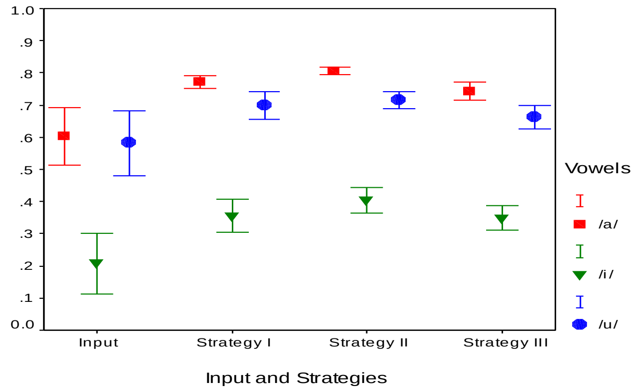
Strategies	Mean	SD
Peak Clipping	0.70	0.08
Compression Limiting	0.71	0.05
Wide Dynamic Range Compression	0.66	0.06

One-way repeated measure ANOVA was done to see the effect of amplification condition. There was a significant effect of amplification condition on the CVR values [F (2, 30) = 4.194, p< 0.05]. Since there was a significant difference across strategies, pair-wise differences among them was tested with Bonferroni's multiple comparison. There was significant difference between Compression Limiting and WDRC at 0.05 level significance. There was no significant difference found between Peak Clipping and WDRC and Compression Limiting and Peak Clipping.



Graph 2: Error graph showing 95% confidence interval for Consonant vowel ratio at 65 dBSPL for input and output processed stimuli across strategies.

Strategy I- peak clipping, strategy II- compression limiting, strategy III- wide dynamic range compression



Graph 3: Error graph showing 95% confidence interval for Consonant vowel ratio at 80 dBSPL for input and output processed stimuli across strategies. Strategy I- peak clipping, strategy II- compression limiting, strategy III- wide dynamic range compression.

The range of CVR values was greater for the input stimuli as compared to the output stimuli at 65 and 80 dBSPL. The CVR values were higher for the stimuli with /a/ and /u/ vowel environment than for /i/ both for the input and output stimuli as seen in the graph 2 and 3.

2) Effect of strategies on Envelope Difference Index: Table 12 shows the mean Correlation index values and standard deviation for the stimuli with vowel environment /a/, /i/, /u/ at input 65 and 80 dBSPL for one subject across three strategies. The EDI values were highest for Peak clipping and lowest for compression limiting at 65 dBSPL whereas at 80 dBSPL it was just the opposite, highest for WDRC and lowest for Peak Clipping.

Table 12: Mean Correlation index values and standard deviation for the stimuli with Vowel environment /a/, /i/, /u/ at input 65 and 80 dBSPL

stimuli	strategies					
	Peak Clipping		Compression Limiting		Wide Dynamic Range Compression	
	Mean	SD	Mean	SD	Mean	SD
/a/ 65	0.29	0.17	0.22	0.18	0.12	0.09
/a/ 80	0.04	0.02	0.74	0.07	0.11	0.10
/i/ 65/	0.23	0.13	0.20	0.14	0.19	0.15
/i/ 80	0.05	0.05	0.08	0.13	0.12	0.14
/u/ 65	0.13	0.10	0.09	0.06	0.06	0.06
/u/ 80	0.02	0.06	0.05	0.07	0.14	0.15

Discussion

1. Speech recognition scores: Results of the study demonstrated significant difference in speech recognition scores across strategies at 65 dBSPL but no significant difference between strategies at 80 dBSPL. The scores were better with Compression Limiting at 65 and 80 dBSPL compared to WDRC. The study is in agreement with previous study by Souza and Jenstad (2005). Even

Hickson and Thyer (2003) found that at higher input levels there was no difference between linear and compression amplification. We know that variation in amplitude over time provides critical speech information. Some authors have suggested that severely hearing impaired listeners depend more heavily on these cues because their broadened auditory filters prevent full access to spectral detail. In this study data was collected on specific groups of stimuli from a small number of subjects. To assess the efficacy of the approach it would be desirable to obtain similar measures from a large number of subjects across a relatively small number of phonetic contrasts.

2. Consonant vowel ratio: The results of the study showed that the Consonant vowel ratio was better for Compression limiting condition compared to Wide dynamic range compression for the stimuli with vowel environment /a/ and /i/ at 80 dBSPL and /u/ at 65 and 80 dBSPL. One of the reasons attributed is that the benefits of recruitment compensation may be nullified in effect by temporal distortions from the compressor attack and recovery times and their alterations of the normal intensity cues of speech. As compression limiting is only active at high signal levels it may provide better CVR without significantly altering the dynamics of conversational speech signals compared to the effect of a syllabic compressor as speculated by Walker and Dillon (1982) and Dreschler (1988). The finding of the study suggests that substantial changes in a speech signal can occur as a result of signal processing by hearing aids. In addition to simple changes due to frequency shaping, temporal changes such as loss or reduction in the periodicity associated with voicing and as obscuring of the boundary between aperiodic consonant noise and the onset of voicing can occur. In this study marked changes in Consonant vowel ratio occurred with processing. The magnitude of these changes for a given syllable however appears to be influenced by many factors including system release time, compression parameters, amplitude and duration of preceding speech sounds, the time delay between the vowel and consonant and the amplitude of the unprocessed consonant. As such, the changes in the speech signal observed after processing may not be easily predicted from traditional electroacoustic measures of hearing aid performance. There is likely to be a complex interaction between the dynamic characteristics of hearing aid processing and the dynamic characteristics of the speech signal. The result of the present study indicate a relationship between acoustic changes to the hearing aid processed speech signal and speech perception performance of severely hearing impaired individuals. The consonant vowel ratio was higher for the Compression Limiting compared to WDRC strategy and also the speech recognition scores were better with Compression Limiting compared to WDRC. So it is clear that the acoustic analysis of the aided speech signal does provide indicators about the perceptual measures and thus has clinical applications.

3. Envelope difference index: The EDI value was greater at 65 dBSPL and as the level increased to 80 dBSPL there was a decrease in the EDI value for all the strategies. The change is more significant for Peak clipping and Compression limiting and not for Wide dynamic range compression. Since the results were only for one subject one cannot generalize the results.

Conclusion

The study represents a step at resolving the clinical issue of how audiologists may choose the right amplification strategy while prescribing hearing aids for the severely hearing impaired individuals. The acoustic analysis is an initial step in describing and quantifying the effects of amplification strategies on phonemes and thus quantifying the benefits of amplification. In the present study speech recognition scores were calculated in quiet condition which does not depict real life situations. So, further study may be done to see the effect of amplification strategies on speech perception in noise. Since the study had certain time restrictions it was done on a small group of subjects so the results cannot be generalized. Replicated study on a larger number of subjects may be carried out to validate the results. Hence, studies on acclimatization effects in long term use of hearing aids and their effect on speech perception can be carried out. The present study addressed to only the effect of different amplification strategies on speech perception and speech acoustics. However, there are other compression parameters such as compression threshold, attack time/release time and compression bands that affect speech perception. Further studies need to be done to see the effect of these parameters on speech perception and speech acoustics.

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