Effects of Compression Release Time in Hearing Aid on Acoustic and Behavioural Measures of Speech

[1]Arpitha V. & [2]Manjula P.

Abstract

The present study investigated the effects of varying the release time (40 ms, 640 ms & 1280 ms) on acoustic and behavioural measures of speech. The acoustic measures included a temporal measure or Envelope Difference Index (EDI) and a spectral measure or Log Likelihood Ratio (LLR). These were computed for VCV tokens of six classes of speech sounds. The behavioural measures were Speech Identification scores (SIS) and quality ratings for loudness, clarity, naturalness and overall impression. The effect of the release time was investigated at three input levels (30, 45 & 65 dBHL). The behavioural measures were performed on Group A participants (N=10; with moderate to moderately severe HL) and Group B participants (N=10; with moderately severe to severe HL). The acoustic measures were performed on five individuals (hearing loss above moderately severe) using the mean audiometric data of Group A and Group B. The effect of release time on EDI and LLR varied at each input level. At low input level of 30 dBHL, the effect of release time was not significant on all speech sounds. At 45 and 65 dBHL, shorter release time (40 ms) showed significantly higher temporal and spectral distortions than longer release times (640 and 1280 ms) for majority of speech sounds. The amount of temporal and spectral distortions was found to be proportional to input level. SIS and quality ratings increased as the release time was made longer. Although not significant, Group B showed higher distortions and lesser SIS than Group A.

Keywords:*Release time, Input level, Envelope difference index (EDI), Log likelihood index (LLR), SIS and quality rating*

Introduction

A cochlear hearing loss implies a poorer functioning of the compressive non-linearity mechanism. Auditory dysfunction due to a loss in cochlear non-linearity can be described in several psycho-acoustical terms, such as a reduced spectral and temporal resolution, a disturbed loudness perception and an increased temporal and spectral masking (Oxenham & Bacon, 2003). Hence, to combat such problems, dynamic range compression has been introduced in hearing aids. As the level of the signal is enhanced, the spectral resolution becomes more impaired and this also leads to spread of masking. Hence, it can be inferred that individuals with hearing impairment rely more on temporal cues than spectral cues. Thus, it is necessary to maintain the temporal cues of the speech processed by hearing aid in order to compensate for their loss. In the WDRC compression system, the major factors influencing the temporal information of speech envelope include compression time constants i.e., attack and release time (Souza, 2002).

With respect to compression time constants, if the release time is too short, then the gain will vary during each voice pitch period, i.e., the compressor will distort the waveform. If the release time is made longer, rapid gain fluctuations will be reduced and thus the distortions would be minimal. However, for the intense signal which is of brief duration, short attack time causes rapid reduction in gain. But, long release time has its undesirable effect by having the gain to remain low for a longer time after a brief sound (Kuk, 1996). During compression activation or de-activation, due to the brief attack or release time intervals, the spread of energy and the distortions induced are inevitable, contributing to the temporal and spectral artifacts (Wang, 2001)

Research so far, however, is inconclusive in providing guidelines on the correct setting of release time. Literature reviews on compression provide no compelling answers with regard to release time (Dillon, 1996; Hickson, 1994). This is due to a number of variables compounding the findings in such studies. Two approaches have been used to study the release time in compression hearing aids. They are studying the effects of this parameter on speech intelligibility, and on quality or user preference. With regard to intelligibility, a few available studies conflict with each other showing either no difference among settings of different release times (Bentler & Nelson, 1997) or that moderate values (between 60 and 150 ms) provide better intelligibility than very short or very long release times (Walker & Dillon, 1982). Studies of user preference showed mixed results; some show no user preferences for any release time (Bentler & Nelson, 1997), while others rated longer release times to be more pleasant than shorter release times (Hansen, 2002)

To address the issue of an optimal release time for hearing aid fittings, it is necessary for a comprehensive analysis of the acoustic effects of compression on speech and the resulting effects on speech perception. The acoustic analysis must focus on the aspects of speech

[1]Email:Arpitha_v25@yahoo.com
[2]Professor in Audiology, Email: manjulap21@aiishmysore.in

that are mostly likely to be affected by varying the release time such as, temporal and spectral parameters.

Different acoustic measures are available to quantify the effect of changes in the acoustic properties of the signal. They include measures such as Envelope Difference Index (EDI), CVR (Consonant-to-Vowel Ratio), and Spectral Distance Measure (SDM). The EDI is an index of change in the temporal envelope between two signals. The value ranges from 0 to 1, where 1 represents completely dissimilar envelopes and 0 represents perfectly similar envelopes (Fortune, Woodruff, & Preves, 1994). This technique is based on envelope subtraction, and generates an Envelope Difference Index that may help to detect the alteration of the natural speech envelope due to amplification. The Log-Likelihood Ratio (LLR) is a spectral distance measure which mainly models the mismatch between the formants of the original and enhanced signals (Rao, Murthy, & Rao, 2011). Jeon and Lee (2008) have used LLR for objectively analyzing the spectral distortions caused due to spectral enhancement technique in hearing aids and found that the LLR values increased as the weightage of the enhancement increased.

Amongst the approaches used, there is a dearth of studies on acoustic effects of compression release time. Also a few studies on behavioural parameters have used different release times with a single input level (Neuman, Bakke, Mackersie, Hellman, & Levitt, 1995; Novick, Bentler, Dittberner, & Flamme, 2001). There is also a need for different settings in compression parameters which maintains the temporal cues for speech recognition, for individuals with different degrees of loss (Van Tasell, 1993).

The aim of the present study was to investigate the effect of compression release time (40 ms, 640 ms and 1280 ms) on temporal and spectral characteristics of the VCV tokens in the aided condition, at three different presentation levels (30, 45 and 65 dB HL). Also, to evaluate the effect of different compression release times (40 ms, 640 ms & 1280 ms) on the speech intelligibility and perceived quality judgments of speech through the hearing aid set at three different presentation levels (30, 45 and 65 dB HL), in individuals with hearing impairment.

Method

The aim of the study was to evaluate the acoustic and behavioural effects of different release times of compression in a hearing aid. The following procedure was used.

Participants for Behavioural Measures

Thirteen male and seven female participants were considered in the study. Their age range was from 20 years to 55 years (mean: 42.9 years, SD8.76). All the 20 participants were diagnosed to have flat or gradually sloping sensorineural hearing loss (SNHL) ranging from moderate to severe degree. The participants were divided into two groups based on the degree of hearing loss. Group A consisted of ten participants having moderate to moderately severe SNHL. Their Pure Tone Average (PTA) ranged from 41 dB HL to 70 dB HL (mean: 60.9, SD: 7.89). Group B consisted of ten participants having moderately severe to severe SNHL. Their PTA ranged from 71 dB HL to 90 dB HL (mean: 75.4, SD: 4.57). Their speech recognition thresholds and Speech Identification Scores were proportionate to their hearing thresholds. All the participants had normal middle ear status. The participants had post-lingually acquired hearing loss with age adequate speech and language. They did not have any previous history of neurological and cognitive dysfunction. Out of twenty participants, twelve participants had more than three months of experience with the hearing aid usage; the other eight participants were naive hearing aid users.

Participants for Acoustic Measurement

Five participants having moderately-severe to severe hearing loss were considered. Their age ranged from 20 to 30 years (Mean: 24.2 years, SD: 2.48). Acoustic measures were performed on these five participants with the hearing aid programmed for the mean audiometric data of Group A (mean PTA 60.9) and Group B (mean PTA of 75.3 dB HL).

Preparation of VCV Tokens and Kannada Story Passage

Three female speakers whose mother tongue was Kannada were chosen to utter the Vowel-Consonant-Vowel (VCV) tokens. The phonemes in Kannada with greater than 0.5% of frequency of occurrence (Ramkrishna, Nair, Chiplunkar, Atal, Ramachandran, & Subramanian, 1962) were selected and paired with a combination of vowel /i/. Table 1 gives the seven speech sounds used in the study, classified based on manner of articulation. The VCV tokens uttered by the three speakers were recorded on to a computer, using the Adobe Audition software, via the recording microphone (Ahuja, AUD-101XLR) placed at a distance of 10 cm from the lips of the speaker (Winholtz & Titze, 1997). The recorded stimulus was digitized using a 32-bit processor at 44,100 Hz sampling frequency. The recorded 21 syllables were subjected to goodness test in order to select one set of test stimuli. These test stimuli were then concatenated with an inter-stimulus interval of 3 sec. These stimuli were preceded by a 1 kHz calibration tone and were written on to a compact disc. Similarly, one of the speakers read out the Kannada passage and this was recorded using the above mentioned procedure. The stimulus was recorded in an air conditioned sound treated room.

Table 1: Classification of consonants based on manner of articulation

Stops	/ipi/, /iti/, /iki/, /ibi/, /idi/, /igi/, /iti/, /idi/
Nasals	/ini/, /imi/, /ini/
Fricatives	/isi/, /ishi/, /ihi/
Affricates	/ichi/, /idzi/
Liquids	/iri/, /ili/, /illi/
Glides	/ivi/, /iyi/

Hearing Aid Programming

For the purpose of the study, a digital behind the ear hearing aid with an option for varying its compression release time, attack time, phase cancellation feedback reduction technique, two listening programmes, two channels and seven bands was used. This hearing aid was programmed using the NAL-NL1 prescriptive formula, with acclimatization level of 2 via NOAH software and was optimized for each individual. WDRC with compression threshold of 50 dB SPL was selected. Other than release time, all other parameters were kept constant across conditions. Electroacoustical measurements were performed to verify the parameters set in the hearing aid.

Acoustic and Behavioural Measurements

Acoustic (unaided and aided) and behavioural (aided) measurements were carried out with the release time set to 40 ms, 640 ms and 1280 ms at three different input levels. The data were collected in two phases; Phase I, Measurement of acoustic parameters - temporal (EDI) and spectral (LLR) parameters and Phase II, Measurement of behavioural parameters - speech identification scores (SIS) and speech quality ratings.

Phase I: Measurement of acoustic parameters - temporal and spectral

The acoustic measures used in the study were Envelope Difference Index (EDI) and a Spectral Distance / Distortion Measure (SDM) called Log-Likelihood Ratio (LLR). The following steps were involved in measuring these two parameters.

Step A: Set-up for acoustic measurement: A personal computer containing the VCV tokens was connected to the auxiliary input of the portable diagnostic audiometer. The output of the audiometer was routed to the loudspeaker of the real ear measurement system, Fonix 7000. The input from the Fonix 7000 was disabled and the input from the audiometer was routed to the loud speaker. The probe tube microphone was inserted into the unoccluded ear canal of the participant. The output from the Fonix 7000 system was routed to the microphone inlet of the PC containing Praat software. The participants were seated comfortably on a chair at a distance of 12 inches away and at 45^0 Azimuth from the loudspeaker of the real ear measurement system. Figure 1 shows the set-up of the equipment used for recording.

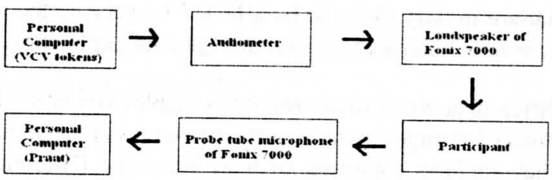

Figure 1: Block diagram depicting the set-up of equipment for acoustic data collection.

Step B: Unaided measurement for acoustic analysis: The probe tube microphone of the real ear measurement system was inserted in the ear canal. The length of the probe tube inserted in the ear canal was 3-5 mm beyond the length of the ear mould of the participant. The VCV tokens were presented to the participant. This was picked up from the ear canal of the participant and recorded on to the PC using Praat software, for further analysis. This procedure was repeated at three presentation levels, i.e., 30, 45 and 65 dB HL.

Step C: Aided measurement for acoustic analysis: Hearing aid was set to one of the three release times and was fitted using custom ear mould. The probe tube microphone was inserted such that the tube was 3 to 5 mm beyond the ear mould. The VCV tokens were presented from the loudspeaker and were picked up by the hearing aid; the output of the hearing aid in the ear canal was in turn picked up by the probe tube microphone of the real ear measurement system. The signal from the probe tube microphone was recorded in Praat software in the computer for further analysis. This procedure was performed for three release times (40 ms, 640 ms & 1280 ms) and at three input levels (30, 45 & 65 dB HL). The aided probe tube microphone measurements were done on five participants for the mean audiological data of two groups of participants (Group A and Group B of behavioural measurement).

Step D: Calculation of EDI and LLR: Using the MATLAB functions, different algorithms or codes were generated to calculate the EDI and LLR values. To calculate EDI and LLR, the speech VCV tokens (unaided and aided) which have to be compared were edited with respect to the common reference point shared by them. The edited aided and unaided VCV tokens were then fed into the MATLAB software containing particular algorithm for the calculation of EDI and LLR values.

Phase II: Measurement of behavioural parameters - Speech Identification Scores and speech quality rating

Behavioural measures used in the study were speech identification scores (SIS) and speech quality judgment. For both the measurements in aided condition, the hearing aid was programmed as mentioned earlier.

Step A: Measurement of aided SIS: The participants were seated comfortably on a chair, one meter away from the loudspeaker of the audiometer, at 45^0 Azimuth. They were tested for speech identification using bi-syllabic words (Yathiraj & Vijayalakshmi, 2005). This word-list included five lists and each list comprising of 20 words, which are phonemically balanced. The words were presented in monitored live mode through the loud speaker of the sound field diagnostic audiometer. This was carried out for different release time (40 ms, 640 ms & 1280 ms) at three input levels (30, 45 & 65 dB HL) on two groups of participants. The participants were instructed to repeat the words. In each condition, the number of words correctly identified was noted.

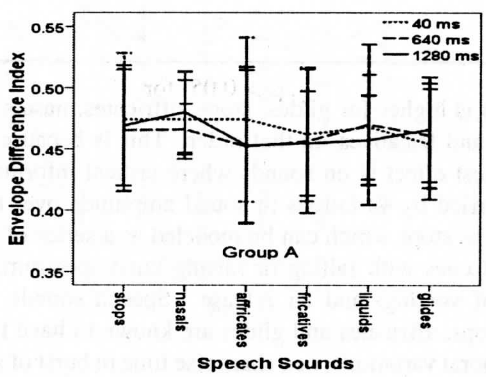

Figure 2

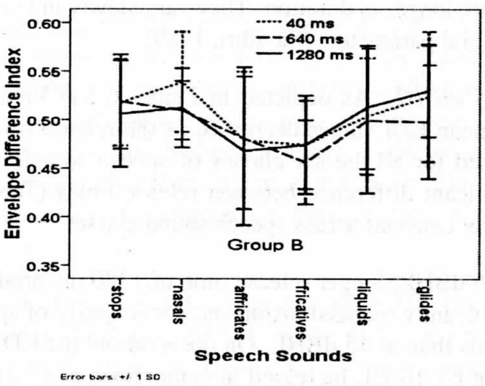

Figure 3

Figures 2 and 3: Effect of three release times at 30 dB HL input level on EDI of six classes of speech sounds for mean audiometric data of Group A and Group B, respectively.

Step B: Measurement of aided speech quality judgment: To assess the speech quality, a recorded Kannada story passage was presented via recorded mode through the loud speaker of the sound field diagnostic audiometer. The participants were instructed to rate the story for its quality on a 10-point rating scale for the parameters of loudness, clarity, naturalness and overall impression. The rating scale ranges from 0 to 10 wherein, 0 indicates 'very poor' 2 indicates 'poor' 4 indicates 'fair' 6 indicates 'good', 8 indicates 'very good' and 10 indicates 'excellent'. The participants were instructed to use odd numbers for rating when the perception was between any the two points. This rating procedure was carried out for different release time (40 ms, 640 ms & 1280 ms) at three input levels (30, 45 & 65 dB HL) on two groups of participants.

For the computation of EDI, the method used by Fortune, Woodruff, and Preves (1994) was used. For computation of LLR, COLEA, a software tool for speech analysis developed by Loizou (1998) was used. The procedure adopted to compute LLR was the same as the one used by Jeon and Lee (2008); Cote, Turbin, and Moller (2008).

Results and Discussion

Appropriate statistical analysis was carried out to analyze the data. The results of the study are discussed for acoustic (EDI & LLR) and behavioural measures (SIS & quality rating) of speech.

Acoustic Measures

Non-parametric statistics was used for the analysis as the measurement was done on five participants, to evaluate the effect of release time on EDI and LLR.

Envelope Difference Index (EDI)

Descriptive statistics was performed to compute the mean and standard deviation (SD) of EDI values for six classes of speech sounds viz., stops, nasals, affricates, fricatives, liquids, and glides, at three release times and at three input levels (Figure2, 3, 4, 5, 6 & 7) on the data of two groups. A test of two independent samples i.e., Man Whitney U test, was performed in order to compare between groups. Two related samples test, i.e., Wilcoxon Signed rank test was performed in order to compare across conditions (Table 2).

Effect of release times on six groups of speech sounds: The results of comparison across three release time conditions are discussed below separately at each input level.

At 30 dBHL: As depicted in Figures 2 and 3, there is no systematic trend seen for the mean EDI values, as the release time increased. As in Table 3, Wilcoxon Signed Rank test revealed no significant difference between release times ($p>0.05$). This trend was noticed for all the six groups of speech sounds and for both the groups.

The results are in consonance with that reported by Jenstad and Souza (2005). According to their study, at lower input levels of 50 dB SPL, the EDI values underwent minimal changes across release times used (12 ms,

Table 2: Significance of effect of release time on EDI for six classes of speech sounds at three input levels for group A and Group B mean audiometric data

Pair wise comparison of EDI for Group A									
Input level	***30 dB HL***			***45 dB HL***			***65 dB HL***		
Release time	40 & 640	40 & 1280	640 & 1280	40 & 640	40 & 1280	640 & 1280	40 & 640	40 & 1280	640 & 1280
Stops					*		*	*	
Nasals				*	*		*	*	*
Affricates							*	*	*
Fricatives								*	
Liquids								*	
Glides				*	*	*		*	*
Pair wise comparison of EDI for Group B									
Input level	***30 dB HL***			***45 dB HL***			***65 dB HL***		
Stops							*	*	
Nasals					*		*	*	*
Affricates				*	*	*	*	*	*
Fricatives							*	*	*
Liquids							*	*	
Glides							*	*	*

*Note: *significant difference at p<0.05 At 30 dB HL*

100 ms & 800 ms). This can be explained by the fact that at lowest input level of 30 dB HL used in the study, the signal would be below the compression threshold. If the signal falls below the compression threshold, that particular signal would be amplified linearly rather than non-linearly. Hence, the effect of release times at this low input level is not significant and also shows larger variability.

At 45 dB HL: As depicted in Figure 4 and Figure 5, the mean EDI values decreased as the release time increased for all six classes of speech sounds. The significant difference between release times (Table 2) are not constant across speech sound classes. On observation, the EDI values at 45 dB HL increased in comparison to 30 dB HL for all the conditions. The similar trend is seen for both groups.

The results of the present study are in agreement with that carried out by Jenstad and Souza (2005). Longer release time had significantly reduced temporal envelope distortions compared to short release time. This can be due to the fact explained by Kuk (1996) that at short release time (40 ms used in the current study), the gain will vary during each voice pitch period, and hence the compressor will distort the waveform. If the release time is made longer, rapid gain fluctuations will be reduced and thus the distortions would be minimal.

The results also revealed variable effects of release time on different consonants. A few consonants had significantly reduced EDI and other consonants did not vary significantly. Although not significant for few of the speech sounds, the mean EDI values for all sounds decreased as the release time increased from 40 ms to 640 ms and to 1280 ms.

The mean EDI values in most of the test conditions revealed that the temporal envelope distortion of consonants is higher for glides, stops, affricates, nasals, liquids and fricatives, in that order. This is because, the greatest effect is on sounds where critical information is carried by variations in sound amplitude over time, such as stops which can be modeled as a series of temporal cues with falling or raising burst spectrum, onset of voicing, and air release. Speech sounds such as stops, affricates and glides are known to have faster temporal variations, i.e., sharp rise time in burst of stops and affricates, faster transition in glides in contrast to semivowels, as compared to other classes of speech sounds such as fricatives which are high frequency hiss and are longer in duration. They vary slowly in terms of temporal parameters (Savithri, 1989).

At 65 dB HL: As depicted in Figure 6 and Figure 7, the mean EDI values decreased as the release time increased for all the six classes of speech sounds. The significant difference between release times (Table 2) are not constant across speech sound classes.

At 65 dBHL, longer release time of 1280 ms produced significantly reduced distortions for majority of speech sounds than at 45 dBHL. On observation, the EDI values at 65 dB HL increased in comparison to 45 dB HL for all the conditions. The similar trend is seen for both the groups.

As depicted in Table 2, at 65 dBHL, the effects of release time on temporal envelopes are significant for most of the speech sounds compared to 45 dBHL. This implies that, at higher input levels, the compression is more effective (Henning & Bentler, 2008), i.e., the more the input intensity, more is the reduction in gain provided. As described by Neuman et al. (1996), longer release time play a major role to offset the effects of increased compression, as the compression increases.

Hence, it can be inferred from the findings that the sig-

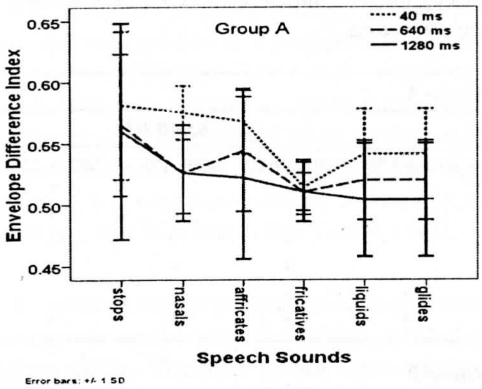

Figure 4

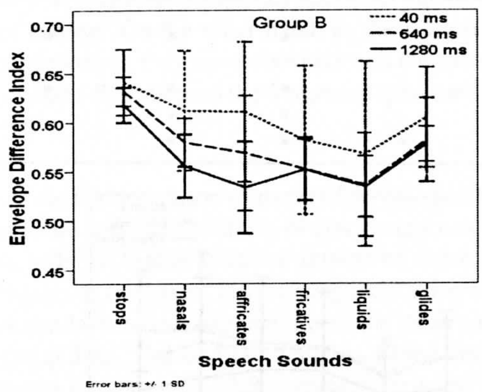

Figure 5

Figures 4 and 5: Effects of three release times at 45 dB HL input level on EDI of six classes of speech sounds for mean audiometric data of Group A and Group B.

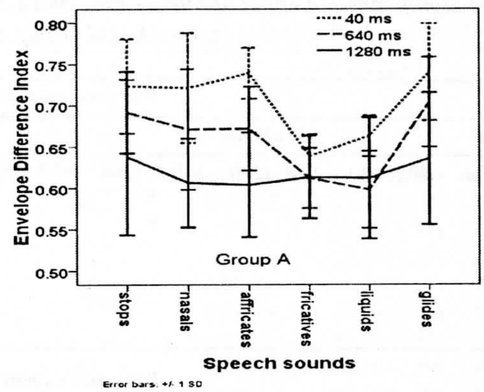

Figure 6

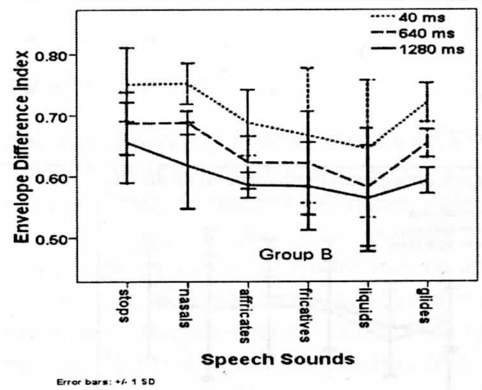

Figure 7

Figures 6 and 7: Effect of three release times at 65 dB HL input level on EDI of six classes of speech sounds for mean audiometric data of Group A and Group B.

nificant effect of short and long release times on temporal envelope distortion is more evident at higher input levels. As discussed earlier, on general observation of the mean EDI values, the temporal envelope distortion of consonants are higher for glides, stops, nasals, affricates, liquids and fricatives, in that order. This is due to the same fact as explained earlier for effect of release time at 45 dB HL.

Effect of degree of hearing loss on EDI: On observation of the mean EDI values, the difference between the two groups across the conditions may be attributed to the fact that, the dynamic range into which the signals have to be compressed was less for Group B than for Group A. Hence, the compression ratio to fit the entire intensity range within the dynamic range was set to be higher. At higher compression ratio almost all sounds will undergo effective compression and the role of shorter and longer release times are more evident under this condition (Henning & Bentler, 2008; Neuman et al 1996). The two groups are not statistically different as the mean audiometric thresholds of Group A and Group B differs only by 10 to 15 dB HL.

Log-Likelihood Ratio

Descriptive statistics was performed to compute the mean and standard deviation (SD) of LLR values for six classes of speech sounds viz., stops, nasals, affricates, fricatives, liquids, and glides, at three release times and at three input levels (Figure, 8, 9, 10, 11, 12, 13) on the data of two groups. Man Whitney U test, a test of two independent samples, was performed in order to compare between groups. In order to compare across conditions two related samples test i.e., Wilcoxon Signed rank test, was performed (Table 3).

Effect of release time on Log-Likelihood Ratio: The results of comparison across three release time conditions are discussed below, at each input level separately.

The results of LLR on six classes of speech sounds at each of the level across three release times follow the same trend as seen in the effects of release times on EDI. The mean LLR values at 30 dBHL do not vary systematically with the release time. As depicted in the Table 3, and Figures 8 and 9, at 30 dBHL, there was no significant effect of release time. As depicted in the respective figures, the mean LLR values decreased as the release time increased, at 45 dBHL and 65 dBHL. At 45 dBHL and 65 dBHL, the spectral distortion was significantly higher at 40 ms release time condition and as the release time increases from 640 to 1280, the spectral distortions tend to decrease (Table 3, Figure 10, Figure

Table 3: Significance of effect of release time on LLR for six classes of speech sounds at three input levels for group A and Group B mean audiometric data

Pair wise comparison of EDI for Group A

Input level	*30 dB HL*			*45 dB HL*			*65 dB HL*		
Release time	40 & 640	40 & 1280	640 & 1280	40 & 640	40 & 1280	640 & 1280	40 & 640	40 & 1280	640 & 1280
Stops		*	*						*
Nasals			*					*	*
Affricates					*		*	*	
Fricatives							*	*	*
Liquids					*	*	*	*	
Glides					*	*	*	*	*

Pair wise comparison of EDI for Group B

	30 dB HL			*45 dB HL*			*65 dB HL*		
Stops		*			*	*			
Nasals			*	*	*		*	*	*
Affricates									
Fricatives		*		*			*	*	*
Liquids							*	*	
Glides				*	*	*	*	*	

*Note: *significant difference at p<0.05 At 30 dB HL*

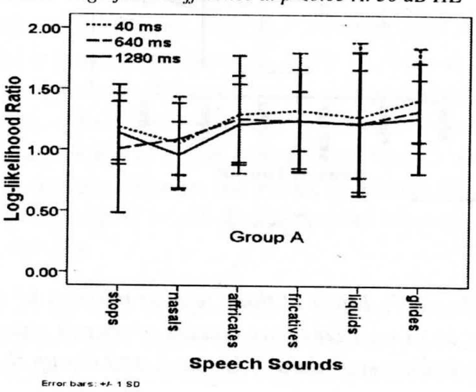

Figure 8

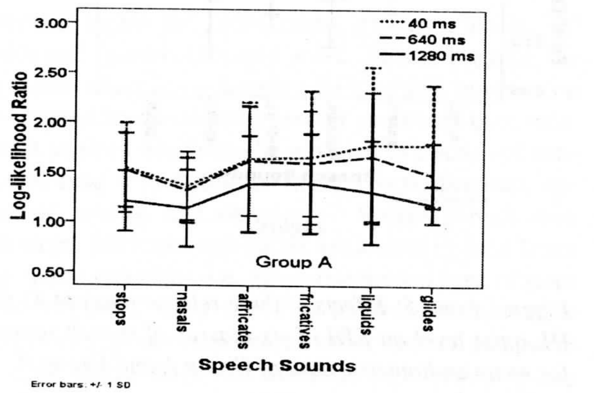

Figure 10

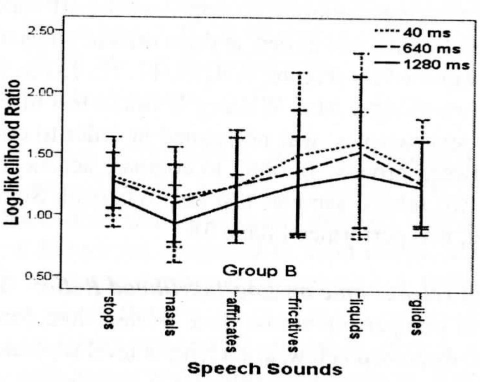

Figure 9

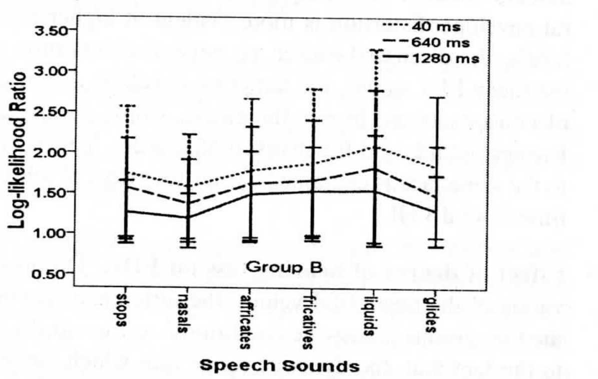

Figure 11

Figures 8 and 9: Effect of three release times at 30 dB HL input level on LLR of six classes of speech sounds for mean audiometric data of Group A and Group B.

Figures 10 and 11: Effect of three release times at 45 dB HL input level on LLR of six classes of speech sounds for mean audiometric data of Group A and Group B.

11, Figure 12 & Figure 13). This is true for both 45 and 65 dBHL input levels. But, as depicted in the Table 3, the effect of release time on LLR was significantly greater at 65 dB HL than at 45 dB HL condition. Also, the majority of speech sounds shows significant effect of release times at 65 dB HL, compared to 45 dB HL input level. As it was seen for EDI, irrespective of the input level and RT, not all speech sounds are affected to the same extent. There exists a lot of variability.

In general, the overall results of LLR are similar to that of EDI, i.e., there are higher spectral distortions at short

(40 ms) release time. In addition, a spectral distortion significantly reduces as the release time increases from 640 ms to 1280 ms. This can be explained based on the fact that, alterations in one of the domains (temporal/spectral) nearly always have corresponding effects in the other one. That is, changes to the temporal waveform of the envelope produce corresponding spectral changes, and vice versa (Van Tassel, 1993).

The result of shorter release time having greater spectral distortions can be attributed to the reason described by Wang (2001). When the release times are made shorter, they are associated with the broadest and strongest distortion across the frequency spectrum due to the spread of energy. On the other hand, as the release times are made longer, they are associated with the narrowest and weakest distortion on the frequency spectrum of the signal.

On close observation of mean LLR values, it was noted that the spectral distortion of consonants can be placed in order of higher to lower amount of distortions as in liquids & fricatives, affricates, glides, stops and nasals. A similar trend was noted for both the mean audiometric group data. Unlike EDI, which is a time and intensity based measure, the LLR compares formants of speech tokens at every fixed time frame and displays one single value. Hence, both the measures tap different aspects in a particular signal. The speech sounds which are confounded majorly by temporal variations tend to be more vulnerable to changes detected in the EDI than in LLR and vice versa.

The order in which the consonants have more spectral distortion can be due to the fact that, the formant frequencies of consonants range from low to high frequencies. For example, in Kannada language, formant frequencies of velar stops range from 400 Hz to 1.9 kHz, liquids have their formants from 450 Hz to 2.9 kHz, nasals have their formants from 300Hz to 1.5 kHz, formants of fricatives ranges from 500 Hz to 4.9 kHz etc. The compression amplification used in the study is a two channel device and each of the channel vary in terms of compression ratios. Hence, each portion of the speech signal might have undergone varied degrees of compression resulting in diffused effects of spectral distortion among the six classes of speech sounds (Savithri, 1989).

The magnitude of the temporal/spectral artifacts during compression activation/deactivation is not constant, but constantly changing. Specifically, broader and stronger distortion across frequency spectrum occurs within the shorter attack/release times whenever the input signal level rises to or falls from slightly above the compression threshold (Wang, 2001). In simpler words, at higher levels of input in contrast to low levels, maximum compression takes place and hence more spectral distortions are noted.

Table 4: Mean and SD of SIS across three input levels and across three release times for Group A and Group B

Input Level (in dB HL)	*Release time (ms)*	*Group A*	*Group B*
		Mean (SD)	*Mean (SD)*
30	40 ms	14.70 (0.68)	11.90 (0.88)
	640 ms	15.70 (0.82)	11.60 (1.08)
	1280 ms	15.50 (1.08)	12.50 (0.71)
45	40 ms	17.50 (0.53)	15.00 (0.82)
	640 ms	18.00 (0.67)	15.00 (0.82)
	1280 ms	18.10 (0.74)	15.70 (0.68)
65	40 ms	19.10 (0.32)	16.80 (0.92)
	640 ms	19.10 (1.10)	16.90 (1.40)
	1280 ms	19.10 (1.19)	17.20 (0.92)

Effect of degrees of hearing loss on LLR: On observation of the mean LLR values in Table 4, although not significant, the mean LLR values were higher for Group B audiometric data. The difference between the two groups across the conditions may be attributed to the fact that, group B had lesser dynamic range and hence more compression ratio caused more spectral distortions. Hence at higher compression ratio, almost all sounds will undergo effective compression and the role of shorter and longer release times are more evident under this condition (Henning & Bentler, 2008; Neuman et al. 1996). The fact that the two groups are not statistically significant is because the mean audiometric thresholds of Group A and Group B differ only by 10 to 15 dB HL.

A few of the varied results noted with respect to speech sounds of a particular category across release times may be because of the reason that, within each class, the speech sounds constituted of both voiced and voiceless consonants. These effects of release time for voiced sounds might be different from that of a voiceless speech sound. Hence, it would be important to study the effect of release time on speech sounds categorized based on place of articulation, manner of articulation and based on voicing characteristics. However, due to time constraints, the study was carried out only based on categorization of manner of articulation.

Behavioural Measures

The behavioural measures, SIS and quality ratings, across conditions are discussed for Group A and Group B.

Speech Identification Scores

Descriptive statistics was performed to compute the mean and standard deviation (SD) of SIS. Table 4 depicts the mean and SD of SIS, across three release times and across three input levels, for Group A and Group B. Two way repeated measure ANOVA revealed that the

Table 5: Effect of three release times across three input levels on perceptual ratings of quality for Group B

Release time (ms)	Input Level (dBHL)	Group A - Quality ratings			
		Loudness	Clarity	Naturalness	Overall Impression
		Mean (S.D)	Mean (S.D)	Mean (S.D)	Mean (S.D)
40	30	5.20(1.31)	5.00(1.33)	4.60(1.21)	5.20(1.13)
	45	6.90(1.28)	6.50(1.26)	6.00(1.41)	6.90(1.37)
	65	8.50(1.08)	7.60(1.50)	6.30(1.41)	8.30(0.91)
640	30	4.90(1.30)	5.50(1.17)	5.20(0.63)	5.50(1.64)
	45	6.60(1.56)	6.90(1.10)	7.20(1.03)	7.40(0.96)
	65	8.15(2.10)	8.20(1.31)	7.40(1.07)	8.60(1.42)
1280	30	5.10(1.10)	5.80(1.22)	5.90(0.99)	6.00(0.94)
	45	6.40(1.26)	7.80(1.39)	7.40(0.96)	8.10(0.96)
	65	8.60(1.76)	8.80(1.31)	8.20(0.91)	9.20(1.00)

interaction between group and conditions are statistically significant [$F(1, 64.14) = 3.283$, $p<0.05$]. In addition, significant main effect of conditions [$F(8, 144) = 119.56$, $p<0.05$] was also present. Bonferroni's multiple comparison test results are discussed for Group A and B.

Effects of Release Time on SIS: Table 4 depicts the mean and SD of SIS across release times and across three input levels for both Group A and Group B.

Group A: As depicted in Table 4, the mean scores are higher for longer release times, at both 30 dB HL and 45 dB HL. At 30 dBHL, repeated measure ANOVA revealed that the release times were significantly different [$F(2, 18)$ 7.132: $p<0.05$]. Pair-wise differences with Bonferroni's multiple comparison showed a significant difference between 40 and 640 ms, at 0.05 level of significance.

At 45 dBHL, repeated measure ANOVA revealed that the release times were significantly different [$F(2, 18)$ 7.154: $p<0.05$]. Bonferroni's multiple comparison results showed a significant difference between 40 and 640 ms and also between 40 and 1280 ms, at 0.05 level of significance.

The high speech intelligibility scores obtained at longer release times and significantly low SIS at short (40 ms) release time is because, short release time causes unnatural alteration of vowel and consonant ratio (Freyman, Nerbonne, & Cote, 1991). At higher levels of 65 dBHL, there was no improvement in SIS as the release time increased. A study by Vanaja and Jayaram (2006) reported the mean SIS for different degrees of hearing. According to their study, listeners with moderate hearing loss would have mean SIS of around 85 % (12.47 SD) and listeners with moderately severe hearing loss would have mean SIS of around 77.5 % (13.89 SD). For listeners in the current study, the audibility was compensated through hearing aid, and additional audibility was provided at the higher input level of 65 dB HL. The SIS at this level in the current study reached its maximum performance, and the effect reached plateau across release time. This could be attributed to the reason of ceiling effect of SIS at 65 dB HL.

Group B: As depicted in the Table 4, the mean SIS slightly increased as the release time increased at each input level. Repeated measures ANOVA revealed no significant difference across RT conditions in any of the input levels. Although not significant, the mean SIS increased for longer release times (1280 ms) at 45 and 65 dB HL. This could be attributed to the fact that Group B listeners had very narrow dynamic range and hence the signal had to be compressed to a larger extent. When there is more compression due to high gain, high compression ratio or higher input level, longer release time can offset the possible temporal distortions to some extent compared to shorter release times (Henning & Bentler, 2008). The finding of difference not being significant can be due to the reason that listeners used other cues like contextual cues, rather than depending upon only temporal ones (Jenstad & Souza, 2005).

Perceptual Quality Ratings

Descriptive statistics was done to compute the mean and standard deviation of quality ratings for four parameters. Repeated measures ANOVA was administered to find out the overall interaction of the conditions and groups. Bonferroni's multiple comparison test was done to determine the significantly different pairs. Multivariate Analysis of Variance (MANOVA) was carried out to compare between the two groups. As depicted in Table 5 and Table 6, the mean and SD for loudness, clarity, naturalness and overall impression parameters, across three release times and across three input levels, for Group A and Group B. The results are described below for each of the parameter, at each input level, for the two groups separately.

Table 6: Effect of three release times across three input levels on perceptual ratings of quality for Group B

Release time	Input Level(dBHL)	Group B - Quality ratings			
		Loudness	Clarity	Naturalness	Overall Impression
		Mean (S.D)	Mean (S.D)	Mean (S.D)	Mean (S.D)
40	30	4.20(0.76)	4.50(1.08)	4.65(0.88)	4.60(0.69)
	45	6.30(1.39)	5.80(1.54)	5.65(1.29)	6.50(1.17)
	65	8.70(0.94)	7.20(1.39)	6.65(1.29)	8.00(0.47)
640	30	4.00(0.91)	4.70(0.63)	5.10(0.56)	5.25(0.97)
	45	6.65(0.88)	6.50(1.08)	6.90(0.73)	7.30(0.91)
	65	8.80(0.78)	7.55(1.77)	7.15(1.41)	8.35(1.20)
280	30	4.00(0.93)	4.85(0.66)	5.45(0.72)	5.75(0.85)
	45	6.30(0.94)	7.20(0.42)	7.25(0.54)	7.45(0.76)
	65	8.40(0.69)	7.65(1.70)	7.60(1.17)	8.40(0.93)

Table 7: Summary of results of perceptual quality ratings on four parameters, for Group A and Group B

Parameters	Group A		
	30 dB HL	45 dB HL	65 dB HL
Loudness	40	40	1280
Clarity	1280	1280 *	1280
Naturalness	1280 *	1280 *	1280 *
Overall Impression	1280 *	1280	1280
Parameters	**Group B**		
	30 dB HL	45 dB HL	65 dB HL
Loudness	40	40	640
Clarity	1280 *	1280 *	1280 *
Naturalness	1280 *	1280 *	1280 *
Overall Impression	1280 *	1280 *	1280

Table 7 summarizes the effect of three release time on SIS for Group A and Group B. As described in the above Table 7, at each input level, the release time which provides better ratings compared to other two release times are mentioned. Asterisks mark indicates that the particular release time is significantly better than the rest of the release times.

Loudness: Two-way repeated measures ANOVA did not reveal a significant interaction between the conditions and groups. The results did not reveal difference across nine conditions for both Group A and Group B (Table 7). As depicted in Table 5 and Table 6, the mean ratings are slightly higher at shorter (40 ms) release time. Although the effect is not seen at all conditions, this is in consonance with study by Neuman, Bakke, Hellman, and Levitt (1998). At shorter release times, the audibility will be maintained as the speech signal will be released from compression very quickly and the gain is applied for weaker part of the signal. Hence, the perceived loudness at short release times is due to the factor of audibility. This explanation is in agreement with that given by Moore (1996).

Clarity: Two-way repeated measure ANOVA did not reveal significant interaction between the conditions and groups. The results revealed a significant main effect across nine conditions [$F(8, 144) = 44.30$: $p<0.05$]. The effect is not significant in most of the conditions. But the mean ratings of clarity (Table 5 & Table 6)increased as the release time increased at all input levels, for both Group A and B. This is in agreement with the study by Neuman et al. (1998). At shorter release times, the gain fluctuates very rapidly giving the sensation of pumping of sounds (Wang, 2001; Moore, 1996). Hence, at longer release times the clarity of the speech sounds will be preserved to some extent in comparison with short release times.

Naturalness: The mean ratings of naturalness (Tables 5 & 6) increased as the release time increased at all input levels, for both Group A and B. Two-way repeated measure ANOVA did not reveal significant interaction between group and conditions. The results revealed significant difference across nine conditions [$F (8, 144) = 41.09$: $p<0.05$]. Bonferroni's multiple comparison (Table 9) revealed significant difference between 40 and 1280 ms, at 30 dBHL and 45dBHL; This was also seen between 40 and 640 ms, 40 and 1280 release time conditions, at 65 dBHL. The effect of release times on naturalness is the same as that of the effects of clarity. The results are in agreement with the study by Neuman et al. (1998). Since the distortions are controlled to some extent by using longer release times, the speech might sound pleasant and more natural.

Overall impression: As depicted in Tables 5, the mean ratings of overall impression increased as the release time was made longer, across the nine conditions, for both Group A and Group B. Two-way repeated measure ANOVA did not reveal significant interaction between groups and conditions. The results revealed significant difference across nine conditions [$F(8, 144) = 68.4$, $p<0.05$]. Bonferroni's multiple comparison (Table 9) revealed significantly higher scores at 1280 ms compared to 40 and 640 ms for most of the conditions. The results are in agreement with the study by Neuman et al. (1998). Due to the positive effects revealed by the longer release times on clarity, naturalness and other parameters, the overall impression will also be maintained at a higher rating for longer release times.

Effect of degree of hearing loss on quality rating: The Tables 5 and 6 depict the mean and SD of perceptual quality ratings of four parameters, across three release times and across three input levels, for Group A and B. In general, the perceptual ratings of quality are lower for Group B, though not significant, due to reduced dynamic range. The amount of compression taking place will be high and hence more temporal and spectral distortion in Group B. Hence, the quality ratings of the parameters are lesser for Group B.

Conclusions

From the present study it can be inferred that, 40 ms short release time induces significantly more temporal and spectral distortions when compared to 640 ms and 1280 ms release times. With respect to SIS and perceptual quality ratings, the performance was poorer with 40 ms short release time than when compared with 640 ms and 1280 ms release times. For both the acoustic and behavioural measures, as the input level increases or as the dynamic range reduces, the temporal envelope and spectral distortions also increases; and longer release times are required to offset the effects of reduced temporal envelope and spectral distortions.

The information from the present study helps the audiologists to gain knowledge as to how the compression release time can have various effects on temporal and spectral distortions. The current study helps to choose appropriate release time depending on the knowledge on dynamic range of the individuals with hearing impairment. The present study also helps to set appropriate release time when there is interaction between input level and compression ratio. Since the current study was carried out using hearing aid on real ear, it throws light on the realistic amount of distortions.

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