EFFECTS OF CV AMPLITUDE RATIO ON SPEECH PERCEPTION

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पिताहमस्य जगतो माता धाता पितामहः |
वेधं पवित्रमोङ्कार ऋक्साम यजुरेव च ||

Bhagavad Gita
Chapter - 9, Shloka -17

I am the Father of this world, the Mother, the Dispenser and the Grandfather; I am the Knowable, the Purifier, the syllable Om; I am the Rik, the Santa and the Yaju.

Parents were my first teachers
And teachers my second parents

Dedicated to:

My parents

My pillar of strength ....

&

My Guide

My inspiration. . . . .

CERTIFICATE

This is to certify that this dissertation entitled **"Effects of CV Amplitude Ratio on Speech Perception"** is bonafide work in part fulfillment for the degree of **Master of Science (Speech and Hearing)** of the student **(Register No. 02SH0010).**

Director
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May, 2004

CERTIFICATE

This is to certify that this dissertation entitled **"Effects of CV Amplitude Ratio on Speech Perception"** has been prepared under my supervision and guidance. It is also certified that this dissertation has not been submitted earlier in any other university for the award of any diploma or degree.

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May, 2004

DECLARATION

This is to certify that this dissertation entitled **"Effects of CV Amplitude Ratio on Speech Perception"** is the result of my own study under the guidance of **Dr. Asha Yathiraj,** Reader & H.O.D., Department of Audiology, All India Institute of Speech and Hearing, Mysore, and has not been submitted earlier in any other university for the award of any diploma or degree.

Register No. 02SH0010

Mysore
May, 2004

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I will rather lose in a cause that will someday win,
Than win in a cause that will someday loose.

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It is easy enough to Be pleasant
When life flows along like a song,
But the person worthwhile is the one, who will smile,
'When everything goes dead wrong.

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Dear ***Babu*** *and* ***Ma,***

It is a wise father who knows his own child.
What a mother sings to the cradle goes the way down to the coffin.

For hearing my thoughts, understanding my dreams, being my best friend and critic. . . . . . . For knowing when to hold me tight and when to let me go.....For filling my life with joy and loving me without end.. . . . . . . / Love 'You.

Dear Bappu,

'We may not have much, but we have each other.

Thanks for reacting as a younger brother occasionally and taking the role of an elder brother most of the time.

Dear Viji,

The worthiest season in our life is showered here,
By the great moments which is showed by hearts and thoughts.

It is not the presence of someone that brings meaning to life. It is the way that someone touches your heart which gives life a beautiful meaning. You are the easy solution for my endless problems.

Kote, Shailaja, Priya *and* ***Ridhhima,*** *thanks for the sweet gestures on your part. I will always remember you all.*

Dear Shrikant,

Like Birds, let us leave Behind what we don't need to carry,
Grudges, differences, sadness and regrets— Fly light.

I am thankful to God to give us the maturity to leave behind all our differences. Thanks for all your timely help. But I surely miss our "Dushmani".

Dear Classmates, (The Outstanding Batch), I am lucky enough to have joined the right "hut-ke" Batch, the memories of all the "record-Breaking" events will Be treasured forever.

The night has a thousand eyes, and the day But one,
Yet the light of the Bright world dies, with the dying sun.
The mind has a thousand eyes, and the heart But one,
Yet the light of a whole life dies, when friendship is done.

Dear Shivu, people might remember you for all your pranks (I was your main victim). But I will remember you for being on my side in the lowest phase of my life. Thank you for all the support and counseling. Dear Roomies - Gauri, Then, & Banu, you people really know how to make a room a home. Anitha, Purnima, Anjana, Richa, Tanuja, Vijay, Varghese,.,. I am richer By your friendship.

Dear Sami & Faiza,

Legendary is the friendship that withstands
Time, turbulence, and a million chances of doubts.

Your friendship is one of the Best things that I integrated into my life.

Dear Uncle, Aunty of Kittu,

The road traveled with you turned out to Be more Beautiful than the destination we reached. Some people are separated By time, some by differences, some By distances, some By pride. No matter whatever differences we have, you all will always remain very special to my heart. Your good wishes and prayers will always Be treasured.

Dear Garu,

Time might lead me to nowhere; fate might Break me into pieces,
But I am always thankful to God, that once in my lifetime....
We Became friends.

Thanks for guiding me in choosing the project, for helping me see things in a different aspect which was unknown to me, for showering alt the affections, for making me face all the hardships and come out a stronger person.

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If God be for us, who can be against us!

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INTRODUCTION

Speech perception is defined as the process by which sensory evidences are used to decide about the linguistic patterns of a speaker. These sensory evidences are generated by physical stimuli that originate from a talker's speech movements and these speech movements represent the linguistic patterns of the speaker (Boothroyd, 1993). This definition leads to a convenient method of quantifying speech perception performance as the probability that the language patterns generated by the perceiver correspond with those generated by the talker. Speech perception, as defined, occurs within the larger context of communication by spoken language. Evidence indicates that speech perception is a specialized aspect of a general human ability to seek and recognize acoustic patterns (Boothroyd, 1993).

The study of speech perception is, in larger part, an attempt to identify the acoustic cues that are used by a listener in reaching phonetic decisions. The understanding of speech perception has been advanced greatly by improvements in the acoustic analysis of speech and the synthesis of speech by machines. The ability to analyze the acoustic signal of speech and the ability to produce synthetic replicas of speech have been complimentary in the modern understanding of how humans perceive speech. The basic acoustic cues are sufficiently understood that speech syntheses are becoming highly intelligible and sometimes even quite natural (Kent & Read, 1992).

Boothroyd (1993) reported that the sound patterns of speech are the product of organized speech movements whose purpose is to convey information about the underlying language patterns. The details of the sound patterns are intimately related to the movements that produce them. The basic movements are organized into a set of movement patterns that can be thought of as building blocks for the creation of meaningful language patterns. Each basic movement pattern is referred to as a phoneme. Observation of their character and use reveals two main types: vowels and consonants. Vowels are produced with a fairly open oral cavity, relatively slow movements of the articulators and are louder. They serve as the nuclei for syllables. Consonants are produced with a relatively closed oral cavity and involve relatively rapid movements. The resulting sound patters tend to be weaker than those of vowels, and they do not last as long. Consonants occur with vowels to create the beginning and ends of syllables. Meaningful words contain one or more syllables.

Speech sounds are rarely produced in isolation; they overlap and influence one another as a result of their production. For perception this means that speech sounds often are not discrete and separable. The listener, therefore, must use context to decode the messages. A speech sound is often perceived by simultaneously perceiving neighbouring acoustic information. There are a number of context effects in speech perception in which the identification of one phoneme is changed due to the identity of neighbouring phonemes. It has been proposed that these identity shifts compensate for the spectral deformations caused by coarticulation (Revoille & Holden- Pitt, 1993).

When phonemes are combined in sequence to create words and sentences, the individual movement patterns flow into each other and often overlap. Thus, although the phonemes appear to be discretely sequenced, like beads on a string, their realization at the level of movement and sound patters is not. Boothroyd (1993) reported that the flow of movement and sound patterns could be divided to a certain extent into temporally discrete segments. Each temporal segment of the movements and sound patterns can reveal the influence of two or more phonemes. By the same token, each phoneme can influence two or more segments.

The acoustic cues to the perception of vowels lie in the patterns created by the vocal tract resonance (formants) of the speaker. The formant patterns by themselves, however, are not always sufficient for listener identification. Perception of vowel is easy because they are voiced and thus relatively high in intensity, the vocal tract is relatively open for them, producing prominent resonance, and the formant frequencies are often held steady for a hundred msec or so, allowing the listener to perceive the formant patterns (Revoille & Holden-Pitt, 1993).

Research on speech acoustics has shown that the intensity of most consonant sounds are substantially lower than that of vpwels, with the weakest consonants being as much as 30 dB lower than the strongest vowels (Dunn & White, 1940, cited in Balakrishnan, Freyman, Chiang, Nerbonne, & Shea, 1996). In difficult listening environment or when a listener's dynamic range is severely reduced, the relatively low level of consonants has been thought to degrade speech intelligibility. In running speech, where there are also unstressed syllables, this dynamic range increases to 40 dB (Dunn & White, 1940, cited in Boothroyd, 1993). Some of this range can be accounted for by the general decrease of intensity with rising frequency. In other words, the weaker speech sounds tend also to be those that contain only high-frequency-components. Even within a restricted range of frequencies, however, the level fluctuates by as much as 10 dB above the average and 20 dB below it.

Studies have attempted to investigate the acoustic correlates of variations in speech on intelligibility. Since significant differences in intelligibility have been observed even for simple monosyllabic words, it is likely that important variations exist at the segmental level (Freyman & Nerbonne, 1989). Variability in intelligibility is explained by various studies that focus on the consonant-vowel (CV) intensity ratio. CV ratio refers to the differences in decibels between either the power or the energy of a consonant and that of an adjacent vowel. CV ratio is known to be an important factor in speech intelligibility. There are several reasons for focusing on this variable as a possible explanation for differences in intelligibility among talkers and among different productions. First, it is already known that talkers and repeated productions by the same talker vary with respect to CV ratio (Fairbanks & Miron, 1957, cited in Freyman & Nerbonne, 1989; House, Williams, Hecker & Kryter, 1965, cited in Freyman & Nerbonne, 1989; Picheny, Durlach & Braida, 1986). Second, a significant percentage of the information contributing to the intelligibility of speech is conveyed by consonants, and this is particularly true for tests of monosyllabic words recognition. In most closed-response tests of speech recognition, for example, the Modified Rhyme Test (Kreul, Bell & Nixon, 1969), the California Consonant Test (Owens & Schubert, 1977), and the Nonsense Syllable Test (Resnick, Dubno, Hoffnung & Levitt, 1975), the major task for the listener is consonant identification. When these or other tests are presented to listeners, the level of each word is typically adjusted to yield equal VU readings at the syllabic peaks, which usually reflect vowel peak energy. With vowel level held constant in this way, the CV intensity ratio effectively determines the absolute level of consonants. Therefore, the suggestions that variations in CV ratio contribute to variations in intelligibility would seem logical.

Data from acoustic measurements (Halle, Hughes & Radley. 1957, cited in Ohde & Stevens, 1983; Stevens, House & Paul, 1966, cited in Ohde & Stevens, 1983; Lehiste & Peterson, 1961, cited in Ohde & Stevens, 1983; Searle, Jakobson & Rayment, 1979; Blumstein & Stevens, 1979; Kewley-Port, 1981; 1982) and from speech perception experiments (Cooper, Delattre, Liberman, Borst & Gerstman, 1952, cited in Ohde & Stevens, 1983; Delattre, Liberman & Cooper, 1955, cited in Ohde & Stevens, 1983; Hoffman, 1958, cited in Ohde & Stevens, 1983; Blumstein & Stevens, 1980) led to several hypotheses concerning the way in which these acoustic patterns are processed by a listener in order to identify the place of articulation for the consonant in a consonant-vowel syllable. One hypothesis given by Dorman, Studdert-Kennedy, and Raphael, (1977, cited in Ohde & Stevens, 1983) has been that several acoustic cues are used by listener but that these cues are dependent on the vowel context in which the consonant appears. The listener must take the phonetic environment into account in identifying the place of articulation features. Another hypothesis given by Blumstein & Stevens (1979) is that for each place of articulation there are invariant acoustic properties that are independent of the vowel context. Current speech algorithms, which selectively enhance high intensity, voiced segments, will improve the representation of the transitions between the vowels and consonants by decreasing the noise in the vowel segments. Therefore, even if a consonant is masked by noise, the transition information in the enhanced vowels might be expected to contain sufficient information to allow the consonant to be identified.

Individuals with hearing impairment due to cochlear pathology frequently experience a deficit in speech understanding. The mechanisms that underlie the deficit are not well understood. The most obvious consequence of sensorineural hearing loss is that the sense organ is no longer able to provide the expected amount of sensory evidences about the details of acoustic speech patterns. The result is that the probability of recognition of the underlying language pattern is reduced. There is a rich psychoacoustic literature describing aberrations in frequency resolution, temporal resolution, and loudness growth in individuals with hearing impairment. A survey of literature revealed that cochlear pathology could alter peripheral processing in each of the physical domains of the speech signal i.e. time, frequency and intensity. Many persons with cochlear hearing impairment have difficulty in understanding speech in background noise, even with properly fitted amplification. With sloping audiograms, a primary goal of amplification is to ensure the audibility of higher frequency consonant energy, which caries the most weight in speech intelligibility. Once audibility is ensured, however, there may be other factors in amplified speech that, if intentionally manipulated, might improve speech recognition performance in some listeners.

Individuals with a cochlear hearing impairment are known to have problems in the perception of specific psychoacoustic characteristics (Moore, 1983). Knowing their problems in perception, it is necessary to know to what extent is it possible to process sounds so as to compensate for the impairments. Signal processing has been studied for many years for improving the recognition of speech by the hearing impaired. Many of these studies have been directed at traditional audiological problems associated with hearing aid use: loudness tolerance and optimal use of dynamic range (Braida, Durlach, DeGennaro, Peterson, & Bustamante, 1982; cited in Montgomery & Edge, 1988), and loss of high frequency sensitivity (Allen, Strong, & Palmer, 1981). Another technique to improve their perception is through speech enhancement. Speech enhancement may be defined narrowly as processing performed to increase speech intelligibility beyond that present in the original signal. It implies that complex digital operation can be performed on speech to make it "superintelligible" to compensate in advance for the degradation imposed by the sensorineural loss.

Studies on speech enhancement for the hearing impaired have generally explored three classes of speech alterations: changes to phoneme durations; modifications to spectral characteristics of the speech signal; and consonant amplification or vowel reduction to increase the overall energy of consonant segments. The last of these alterations has been reported to have the maximum effect in enhancing speech intelligibility.

NEED OF THE STUDY:

The most popular technique to enhance speech for the hearing impaired is by providing amplification. Further enhancement of speech intelligibility may be made possible by using signal processing techniques that enhance a consonant vowel ratio (CVR). Signal processing techniques that enhance CVR may be useful even if the sole outcome of that processing is to achieve greater audibility of high frequency energy. It needs to be studied as to which parameters can be manipulated independently in the time domain to improve intelligibility of speech. Such manipulation of parameters should not pose a theoretical limitation on near real time processing if implemented in a wearable device at some time in the future. Hearing aids of the future might operate by extracting speech parameters such as formant frequencies, presence and absence of voicing, and fundamental frequency. In addition, it would be possible to transform the output in various ways to enhance the discriminability of speech features.

Identification of the acoustic characteristics associated with the most intelligible speech could be of considerable value for hearing aid research (Picheny, Durlach & Braida, 1986). Once these acoustic characteristics are identified, it may be possible to enhance those characteristics through signal processing to improve speech recognition by hearing impaired individual. Information about ways in which speech perception can be enhanced can also be used during auditory training / auditory learning activities.

Increasing CVR via signal processing in amplification might result in improved speech recognition in noise. Burst or other consonant energy can also be enhanced by using either analog or digital signal processing Guelke (1987, cited in Sammeth, Dorman, & Stearns, 1999); Kates (1984, cited in Sammeth et al., 1999). Studies by House, Williams, Hecker and Kryter (1965, cited in Freyman &Nerbonne, 1989), Williams, Hecker, Stevens, and Woods (1966), Salmon (1970, cited in Freyman & Nerbonne, 1996), Hecker (1974, cited in Freyman & Nerbonne, 1989), Ono, Okasaki, Nakai, and Harasaki (1982), Ohde and Stevens (1983), Gordon-Salant (1986), Freyman and Nerbonne (1989), Gordon-Salant (1987), Montgomery and Edge (1988), Preves, Fortune, Woodruff, and Newton, (1991), Hedrick Schulte and Jesteadt (1995), Balakrishnan, Freyman, Chiang, Nerbonne, and Shea (1996), Revoille, Holden-Pitt, Pickett, and Brandt (1986), and Revoille, Holden-Pitt, Edward, and Pickett (1987) have reported an enhancement in speech perception by amplifying the consonant, in comparison to the vowel in languages spoken in other parts of the world. There is a need to study whether manipulation of the CVR would produce similar effects in hearing-impaired individuals exposed to Indian languages as reported in studies done abroad.

AIM OF THE STUDY:

The purpose of this study is to find out the effects on intelligibility of a set of speech enhancement algorithms that decreased vowel intensity while keeping the consonant energy constant. The study aims to evaluate the extent to which variation in the CV intensity ratio could account for variation in speech intelligibility in adults with hearing impairment, and also check whether it would have any effect on the perception of normal hearing adults.

REVIEW

Speech has highly redundant information, which is utilized by normal hearing individuals for speech perception. For normally hearing persons speech is a highly redundant stimulus. However, in impaired listeners, this redundancy is considerably reduced, since the full range of acoustic cues available to the normal listeners may not be usable by the impaired listener.

Factors contributing to the difficulty in speech perception in hearing-impaired listener are:

- Reduced sensitivity of hearing
- Recruitment, i.e. growth of loudness with intensity is more rapid than in a normal ear
- Reduced frequency discrimination which leads to difficulty to resolve fine detail in the spectrum of speech
- Reduced frequency selectivity
- Poor temporal resolution, and
- A loss of binaural processing

Listeners with mild to moderate sensorineural hearing loss can perform quite well in identifying place of articulation for voiced stop consonants, once the stimuli are at a comfortably high sensation level and all normal acoustic information is present (Van Tasell, Hagen, Koblas & Penner, 1982; Van Tasell, 1993). However, if a portion of the stimulus duration is shortened, some of these listeners have substantially more difficulty in making place of articulation judgments (Hannley & Dorman, 1983; Dubno, Dirks & Schaefer, 1987; Schum & Collins, 1990). The amount of difficulty experienced both in speech perception can reasonably be expected to increase with the severity of the hearing impairment. Ahlstrom (1970) reported a high correlation between hearing impairment and speech recognition and speech indelibility scores obtained by deaf school children. Boothroyd (1974) and Levitt (1974) found that speech perception skills correlate highly with the average pure tone thresholds in the speech range, particularly with those at 1000 and 2000 Hz. This correlation also holds true for phoneme and word recognition tests. There is also a correlation exists between the severity of the hearing impairment and speech recognition performance. Because the initial cues to the message content can seldom be predicted, they must be derived from an analysis of the acoustic signal. Any reduction in the acoustic signal received will result in a reduction of potential information. A hearing deficit always reduces the overall loudness of the speech signal; frequently, as we have seen, it also distorts the frequency spectrum by removing more energy at some frequency than others. Clinical experience with adults who have peripheral (cochlear) sensory hearing impairment reveals that the correlation between the degree of impairment and discrimination ability is not absolute. In many instances the discrimination performance of an individual with less residual hearing may be better than that of another person who has 10 to 20 dB more hearing. In summary, the data from a variety of tasks indicate that hearing-impaired listeners as a group generally show poorer than normal temporal resolution. The magnitude of the disability is related in only a moderate degree to the magnitude of the loss in sensitivity.

The area of speech analysis techniques has been very active over the past twenty years. As techniques are developed to improve the identification of specific aspects of speech, recognition devices can be modified to change or to disregard selected components of the speech signal. By the same token, synthesis techniques can be custom-tailored to employ such information in order to enhance speech in a particular fashion. These concepts can be exploited for improving the naturalness of speech synthesis devices.

A number of new speech analysis techniques have tried to augment recognition capacities in continuous and noisy speech by identifying related parameters against the usual background of irrelevant information. The basic process of signal analysis proceeds by a series of transformations, each of which prepares the signal in some way to highlight specific speech related features. Analyses are typically performed either in the temporal or the frequency domain.

Temporal domain:

The major time-domain parameters of interest are duration and amplitude. Duration of pauses, syllables or segments are typically measured directly in the new signal, or are calculated on the basis of an amplitude envelope. The amplitude is obtained by averaging signal values over a moving time window. Values are squared so that positive and negative values contribute equally to the amplitude. The mean is taken and optionally the square root is extracted. The final value plotted over time provides the amplitude curve (Keller, 1994).

Frequency Domain:

Features in the frequency domain are identified by spectral analysis. There are a number of techniques that calculate the spectrum from a signal, such as Fast Fourier Transformation (FFT), Linear Predictive Coding (LPC), Wigner-Wille and Cone-Kernal techniques. Of these, the FFT is the most common. It provides a measure of the frequency found in a given segment of a signal by decomposing it into its sine components. Another common tertiary technique is the LPC. This algorithm helps in removing a person's individual speech characteristics from the signal and thus facilitates the identification of fundamental frequency and formants.

Using the above methods, speech transformation techniques to enhance speech intelligibility have been developed to enhance speech intelligibility in normal hearing as well as hearing impaired individuals.

Speech Enhancement techniques:

A variety of techniques has been described in which the speech signal is transformed acoustically to improve speech intelligibility. Comparatively few studies have attempted to investigate the acoustic correlates of variation in speech intelligibility.

Picheny, Durlach and Braida (1985) reported that identification of the acoustic characteristics associated with the most intelligible speech could be of considerable value for hearing aid research, because once they are identified, it may be possible to enhance those characteristics through signal processing to improve speech recognition by hearing impaired individual.

Picheny et al. (1985) asked three talkers to read some speech material normally and then again as if talking to a hearing impaired listener. Recordings of the normal and the clear speech were then presented to a group of adult hearing-impaired subjects and the intelligibility of the clear speech was found to be an average of 17% higher. Further, they analyzed the two types of speech to determine what characteristics had been changed in the clear speech. It was found, generally, that three changes took place: -

a) The duration of consonants and vowels increased;

b) The phonemes were articulated more as if the words were in isolation, not in sentences, i.e. less vowel reduction, more consistent release of final stops; and

c) The consonant/vowel intensity ratio increased, especially for stops.

Another promising scheme for enhancing the speech signal to improve intelligibility is based on studies of speaking clearly for the hearing impaired, conducted at MIT by Chen (1980). The underlying assumption of this work was that speakers naturally revise their speech when speaking to impaired listeners; this "clear" speech is more intelligible than "conversational" speech to the impaired listeners; clear speech incorporates certain consistent acoustic modifications of the speech signals, and preprocessing speech with these acoustic modifications might be expected to improve speech intelligibility for impaired listeners. In "clear" speech, the speaking rate decreased, all final consonants were released, and intensities, particularly of the stop consonant bursts, were greater resulting in as much as a 10 dB increase in the consonant-to-vowel ratio (CVR). Because "clear" speech is usually more understandable to the person with hearing impaired, a number of authors have explored the use of intentional CVR enhancement to improve speech recognition of listeners with hearing impairment.

Studies on speech enhancement have generally explored three classes of speech alterations. These enhancements include:

- Changes of phonemic duration;
- Modification to spectral characteristics of the speech signal; and
- Consonant amplification to increase the overall energy of consonant segment or vowel reduction to reduce the vowel to consonant intensity ratio;

The rationales behind these alterations are based on a mix theory and empirical evidence about the auditory deficits of the hearing impaired, as well as knowledge of speech characteristics and their importance for normal speech perception.

Phoneme Duration Alteration:

Interest in lengthening phoneme duration to facilitate speech recognition arises largely from the finding that speech sounds are typically longer in duration in carefully produced speech (Picheny et al., 1986). Lengthening consonant duration has yielded equivocal effects on speech recognition by hearing impaired listeners. Some evidence suggested that such alterations might degrade intelligibility.

Gordon-Salant (1987) reported no performance improvement with elderly listener with mild-to-moderate sloping losses for consonants doubled in duration relative to their natural length. Moreover, when the duration length was combined with amplification of consonants, significantly more consonant confusions occurred than for consonant amplification alone. These effects were found for stimulation presentation at both 75 and 95 dBSPL.

Other hearing impaired listeners have shown small (about 5%) but significant gains in recognition of consonant lengthened by 30 msec and consonant with and without accompanying consonant amplification (Montgomery & Edge, 1988). These subjects heard the test stimuli at a higher level (95 dBSPL) than a second group of subjects in the same study listening at 65 dBSPL who demonstrated no benefits from lengthened consonants.

The different types of alterations made in the stimulus, such as amount of consonant lengthening, signal analysis and processing effects, stimuli subject variables might explain the indeterminable effect of consonant lengthening for consonant recognition by the hearing impaired listeners.

A question, which arises at this point, is that whether universal consonant lengthening can be expected spontaneously to facilitate the overall consonant recognition for the hearing impaired. Relevant to this question is consideration of the acoustic cues critical to certain consonant distinctions. E.g. burst duration can be the dominant cue for voicing distinctions of word initial and inter-vocalic stops. The bursts of /b, d, g/ are about 2 to 3 times shorter than /p, t, k/ bursts (Stevens & Klatt, 1974). Stevens and Klatt (1974) reported that when the release bursts of voiced stops contain no periodicity, lengthening these bursts could elicit a voiceless stop perception. Other predictable phoneme errors from expanded consonant duration could occur between voiceless stops and frication. Lengthened voiceless stop bursts might be confused with fricatives due to expansion of the bursts.

It may prove more effective to apply temporal enhancement only to consonant distinctions that are cued by speech sound duration differences. Revoille, Holden-Pitt, Pickett and Brandt (1986) adopted this strategy of voicing distinctions for word final fricatives by severely and profoundly hearing impaired listeners. This, consonant distinctions can be cued by duration differences in the vowel preceding voiced versus voiceless word final consonant. For vowels that were similar in duration in spoken CVCs, those preceding voiced fricative were lengthened and those preceding voiceless fricatives were shortened. Significantly better perception of fricative voicing was shown by the listener who relied on the vowel duration cue for consonant voicing distinctions. However, the enhancement of the vowel duration cue had no effect on distinctions among the fricatives according to place of articulation; generally fricative place distinctions are cued by spectral differences associated with the consonant and for voiced fricatives with adjacent vowels.

Hedrick and Jesteadt (1996) studied two different aspects of CV perception. The first was a comparison of relative amplitude manipulation in the presence of natural formant transitions versus manipulation of both formant transition and relative amplitude. Amplitude parameters were manipulated in the burst to arrive at the desired relative amplitude value. The second aspect evaluated was the additional variable of vowel duration in synthetic CV stimuli. The consonant contrast examined were voiceless stop labial-alveolar contrast /p/-/t/ in the /a/ vowel context. They used neutral formant transition values, manipulated relative amplitude and vowel duration ranged from 14 to 200 msec. Results from the first experiment showed no significant difference between listener groups when only relative amplitude information was manipulated, but significant differences when both relative amplitude and formant transition information was present. These results suggest that the listeners with normal hearing, weighted the two acoustic cues differently from listeners with sensorineural hearing loss. Results from the second experiment indicated that increasing vowel duration generally increased the number of labial responses from listeners with normal hearing, but did not always increase the number of labial responses from listeners with sensorineural hearing loss.

Thus, it is seen that duration alteration shows mixed results in perception of speech in hearing impaired population. While some studies (Stevens & Klatt, 1974; Gordon-Salant, 1987; Hedrick & Jesteadt, 1996) reported no performance improvement when phoneme duration was lengthened, other studies (Revoille et al., 1986; Montgomery & Edge, 1988) showed better consonant distinction and better speech perception. However, the studies on duration alteration varied in method and procedure, and also in subjects who participated in the study. Subjects performed poorly when consonants were lengthened along with amplification due to consonant confusion.

Spectral Alterations:

The concept of enhancing given spectral properties in speech is grounded partly in the importance of such characteristics in normal speech perception for distinctions among consonants, especially according to place of articulation. Moreover, compelling evidence of degraded frequency resolution among the hearing impaired (Dreschler & Plomp, 1985) contributes to the notion that enhanced speech spectral characteristics might mitigate the effects of such deficits on speech perception by this population.

Modifications to formants, either in bandwidth or transition frequency extent, have been a major acoustic variable in much of the work on complex spectral alterations to facilitate consonant recognition by the hearing impaired. The benefits seemed modest, at best, and then only in given phonemic contexts and selected hearing impaired listeners.

Some explorating work on enhancement of formant transitions involved exaggeration of the associated dynamic characteristics (Bunnell & Martin, 1986). An effect of the algorithm under study was to increase the extent over which rapid frequency change occurred between consonant and adjacent vowels in speech. Thus, formant transitions are expanded in frequency extent and consequently, rate of change.

The intention was to simulate some of the characteristics of clearly articulated speech, which contains more definitive phonemic acoustic markers than speech spoken conversationally. Normal hearing listeners who were tested in noise showed improved recognition of bilabial stops, no effect for alveolar stops, and a decline in performance for velar stops.

Another type of formant alteration that has been studied with hearing impaired listeners is formant sharpening, i.e., heightening the spectral distinctiveness of formants in speech. An effect of such alteration is expansion of the differences in amplitude between peaks and valleys and the speech spectrum. As with modification to formant transition dynamics, the benefits from formant sharpening for the hearing impaired have been mixed.

Summerfield, Foster, Tyler, and Bailey (1985) reported that narrowing formant bandwidth did not significantly improve identification of /b,d,g/ for the hearing impaired listeners. F_1, F_2, F_3 bandwidths were reduced by 50% and 75% in synthetic whispered syllables with stops as the test consonants. In unaltered test tokens, formant bandwidths approximated those measured from whispered speech. Both impaired and normal hearing listener groups showed performance declined for tokens with formants broadened 2.0, 4.0, and 8.0 times the bandwidths of the unaltered tokens. However, stimuli with narrowed formant bandwidth yielded significant improvements in stop identification only for the normal hearing listeners.

In other research with spoken syllables, application of an algorithm to sharpen format has shown some benefit for consonant recognition by hearing impaired listeners (Bunnell, 1990). Bilabials and velar stops showed improvements of about 10% or more with expansion of the amplitude differences between spectral peaks and valleys, depending on the adjacent vowels. Such improvements were not seen for enhanced alveolar stops. These effects occurred for stop token that previously were determined to be moderately intelligible for normal hearing listeners tested in noise. Other stop tokens of originally poor or good clarity that were subsequently processed for expansion of spectral peak and valleys did not yield improved performance for hearing impaired listeners.

Formant manipulation of frequency shaping has been studied for glide versus stop manner distinction by moderately and severely hearing impaired listeners (Revoille, Holden-Pitt, Bunnell, & Pickett, 1992). Revoille et al. (1992) compared spectral characteristics of the onset of a test syllable, /waek/, unmodified and with two types of spectral enhancement- a) formants reduced in bandwidth and b) increased in transition frequency. Compared to the unmodified onset sequence the high frequency emphasis showed greater energy above 1000 Hz. In another sequence, formants were reduced in bandwidth as well as increased in transition frequency extent. Preliminary analysis showed no performance differences among these three combinations for the hearing impaired listeners as a group, although some listener appeared to distinguish glides versus stop manner best for the stimulus with high frequency emphasis.

In summary, hearing impaired subjects showed varied results in speech performance when spectral characteristics were altered in speech. Among the hearing impaired listeners tested todate with speech processed using spectral changes, rather large individual differences have been observed. Listener's performances have ranged from improved identification for all enhanced stops tested (Dreschler & Plomp, 1985; Bunnel, 1990; Revoille et al., 1992; Bunnel & Martin, 1986), to no difference in identification (Summerfield et al., 1985; Bunnell & Martin, 1986; Bunnell, 1990; Revoille et al, 1992). Thus, spectral alteration may or may not enhance speech perception. This probably depends on the subjects auditory capabilities.

Consonant versus Vowel Amplitude:

Studies have been carried out where either the consonant has been amplified relative to the adjacent vowel or the vowel amplitude has been reduced relative to the consonant. This has been done to enhance speech perception in hearing impaired individuals who show reduced speech identification. Consonant amplification attempts to overcome the reduced capacity to understand speech, that is implicit for a hearing impaired person. Acoustic measurements of speech reveal that for weak consonants such as voiceless fricatives, the overall acoustic energy associated with the consonant can be as much as 20 to 25 dB lower than that in adjacent vowels (Revoille, Holden-Pitt, Edward, & Pickett, 1987). Revoille et al. (1987) reported that raising the energy of the consonant relative to vowel, i.e. reducing the vowel-to-consonant intensity ratio, could increase the audibility of a consonant for a hearing impaired person. Most of the relatively limited number of attempts to explain variability in intelligibility through acoustic studies has focused on the consonant-vowel (CV) intensity ratio. CV ratio has been defined and measured differently by different investigators, but in general it refers to the differences in decibels between either the power or the energy of a consonant and that of an adjacent vowel.

Among the three categories of spectral enhancement i.e. duration alteration, spectral alteration and amplitude alteration, increasing the acoustic energy of consonant segments relative to vowel has yielded the largest gains in consonant recognition by hearing impaired subjects. Several studies that have included descriptions of differences in intelligibility among talkers seem to support the suggestion that CV ratio is important.

Consonant Enhancement:

House, Williams, Hecker and Kryter (1965, cited in Freyman &Nerbonne, 1989) measured CV ratios of the recorded Modified Rhyme Test words in an attempt to explain differences in word recognition scores for two different talkers. Subjects were normal hearing individuals listening in noise. The average root mean square (RMS) power of the consonants in relation to that of the vowels was lower for the less intelligible talker. Williams, Hecker, Stevens, and Woods (1966) and Salmon (1970, cited in Freyman & Nerbonne, 1996) also measured the highest CV ratios for talkers who produced the highest listener scores on multiple-choice tests of word recognition.

Hecker (1974, cited in Freyman & Nerbonne, 1996) demonstrated that intelligibility of monosyllabic words could be improved by increasing CV ratio and could be made poorer by decreasing CV ratio. Ono, Okasaki, Nakai, and Harasaki

(1982) also reported improvement in intelligibility for monosyllables as a result of increases in CV ratio. Ohde and Stevens (1983) examined the effects of the relative amplitude of the release burst on perception of the place of articulation of voiceless and voiced stop consonants which occur in initial position of utterances. The amplitude of the burst, which occurs within the first 10-15 msec following consonant release, was systematically varied in 5 dB steps from -10 to +10 dB relative to a "normal" burst amplitude for two labial to alveolar synthetic speech continua, one comprising voiceless stops and the other voiced stops. The results of identification tests with these stimuli showed that the relative amplitude of the burst significantly improves the perception of the place of articulation of both voiceless and voiced stops, but the effect was greater for the for voiceless than voiced.

Gordon-Salant (1986) evaluated the effectiveness of computer-generated increments of consonant vowel ratio CVR on speech intelligibility for young and elderly normal hearing subjects. The stimuli were syllables of the form of CV, where the consonant was one of the 19 consonants studied and the vowel was one of the three vowels studied. They were presented in an unmodified form, with the CVR increased by 10 dB, and with combinations of both the CVR increments and duration increased by 100%. The results showed that the CVR increment and combined increment improved consonant recognition in noise. Further, the CVR modification (but not the combined increase modification) improved recognition of most consonant place, manner, and voicing classes, without a substantial increase in consonant confusions. Results showed that young listeners outperformed the elderly listeners in each condition. Scores of elderly listeners in CVR and combined modification was approximately same as those of young listener in the unmodified condition and the authors concluded that elderly listeners with normal hearing appear to benefit from enhancements of CVR for consonant recognition in noise.

Freyman and Nerbonne (1989) took 50 normal hearing college going students in the age range of 19—35 years and the results reported by them for CV syllables with eight voiceless consonants also suggested that the major benefits of CV ratio enhancement relate to audibility; i.e. listener's performance was determined more by absolute levels of consonant segments than by CV ratio per se, and that CV ratio would therefore be more important at lower signal levels. They noted that CV ratio modification influenced recognition cues for fricatives but not stops. They hypothesized that these variations across consonants may also be related to the audibility of the different consonants.

In another study, Gordon-Salant (1987) evaluated the effect of a 10 dB increase in the CVR of nonsense syllables presented at 75 and 90 dB SPL in 12-talker babble at a +6 dB signal-to-noise ratio (SNR). The listeners were elderly persons with hearing impairment, with one group showing gradually sloping audiograms and the other showing steeply sloping audiograms. The result of the CVR increase was a mean 14% improvement in speech recognition scores, averaged across all listeners and the two presentation levels. Listeners with gradually sloping audiograms showed better results with CVR enhancement at the higher rather than the lower listening level, whereas listeners with sharply sloping audiograms showed similar scores across both levels.

Montgomery and Edge (1988) evaluated the effects of manipulating CVR on the speech recognition of 20 adults with hearing impairment. Stimuli from the California Consonant Test were presented at 65 dBSPL both unprocessed (at the normal CVR) and processed by increasing the consonant amplitude (up to a maximum of 21.5 dB) so that its root-mean-squared (RMS) level was equivalent to the adjacent vowel. The investigators found a modest but statistically significant improvement of 10% in mean speech recognition with amplitude enhancement. However, for another group of 10 listeners with hearing impairment who were listening at a 95 dB SPL level, there was no significant difference.

Using consonant-vowel syllables, Behrens and Blumstein (1988) studied the effect of altering the relative amplitudes of voiceless fricatives; /f/ and / / were amplified so that the intensity relative to the following vowel was more like that of /s/ and /ʃ//s/ and /ʃ/ were processed in the reverse manner. These modifications in relative consonant amplitude produced some /f, / for /s, / errors, but very few /s, / for /f, / errors. In general, a difference in the natural CV intensity ratio among the fricatives was not a stronger cue than the spectral differences among these sounds.

Kennedy and Levitt (1990) evaluated nine adults with moderate to moderately-severe hearing impairment who listened to nonsense vowel-consonant syllables from the Nonsense Syllable Test (NST). Consonants levels were increased in 3 dB steps from the normal CVR, holding the vowel level constant, until a level of loudness discomfort was reached (typically about 18 dB greater than the starting level). The results were mixed. As the CVR increased, NST scores improved for some, although not all, of the listeners, with a few showing decreased performances at very high CVRs. Averaging across all listeners and conditions, there was a mean 15% improvement in NST scores with increased CVR.

Support for the role of CV ratio enhancement in improving consonant audibility and intelligibility was shown by Preves, Fortune, Woodruff, and Newton, (1991). They investigated the effects of four types of analog CV ratio enhancement of the recognition of 14 CV and VC syllables from the nonsense syllables test (NST). They suggested that general computers instead of digital computers have several simple methods which are able to produce improvement in some components of speech that are comparable to the most successful digitally based consonant enhancement results. Some of the most simple analog technique commonly found in head worn hearing aids that can significantly increase CVR relative to an unprocessed speech signal are i) fixed high pass filtering, ii) adaptive high pass filtering, iii) adaptive high pass filter with expansion, and iv) infinite amplitude clipper. Results for four voiceless fricatives and three voiceless plosives showed that listener's recognition of the consonants improved over the unmodified CV ratio condition for all modified conditions although the amount of improvement varied across the above four procedures.

Thus, a preponderance of evidence suggests that CV ratio is one of the variables that affect intelligibility among talkers. The combined results of these studies support a conclusion of consistent, though not spectacular, improvement in speech recognition as a consequence of amplifying consonants segments of speech relative to vowels.

As noted by some of the investigators themselves, the effects of CVR increases may have been confounded by an increase in audibility of the consonant energy. That is, improvements in speech recognition performance of the listeners with hearing impairment may have been the result of achieving full audibility of the consonant energy rather than the increase in CVR per se. Gordon-Salant (1987), for example, suggested that scores might have improved with CVR enhancement at the higher, relative to lower, noise levels for the listeners with gradually sloping audiograms because audibility of the high frequency consonant energy was achieved. In the Montgomery and Edge (1988) study CVR enhancement made consonants more audible at the lower level but had no effect at the higher stimulus level because the unmodified consonants were already audible.

All the studies reviewed here have evaluated consonant-to-vowel ratio (CVR) enhancement as a means to improve speech recognition in listeners with hearing impairment, with the intention of incorporating this approach into emerging amplification technology. Most of the studies have enhanced CVRs by increasing consonant energy, thus possibly confounding CVR effects with consonant audibility.

Yet another technique to alter the CVR is to enhance the intensity of the vowel relative to the consonant. The effect of such a enhancement has been investigated by several authors, which will be discussed in the following section.

Vowel enhancement:

To help resolve the issue of relative role of CVR enhancement versus that of enhanced consonant ability, Sammeth, Dorman and Stearns (1999) did a study where they held the consonant audibility constant by reducing vowel transition and steady-state energy rather than increasing consonant energy. Performance-by-intensity (PI) functions were obtained for recognition of voiceless stop consonants (/p/, /t/, /k/) presented in isolation (burst and aspiration digitally separated from the vowel) and for consonant-vowel syllables, with re-addition of the vowel /a/. There were three CVR conditions: normal CVR, vowel reduction by 6 dB, and vowel reduction by 12 dB. Testing was done in broadband noise fixed at 70 dB SPL and at 85 dB SPL. Six adults with sensori-neural hearing impairment and two adults with normal hearing served as listeners. Results indicated that CVR enhancement did not improve identification performance when consonant audibility was held constant, except at the higher noise level for one listener with hearing impairment. The re-addition of the vowel energy to the isolated consonant did, however, produce large and significant improvements in phoneme identification.

Hedrick, Schulte and Jesteadt (1995) found that hearing impaired listeners relied more on relative amplitude information than on formant transitions when asked to label the consonantal portion of synthetic consonant-vowel (CV) syllables. This was a contrast to listeners with normal hearing who showed evidence of using both formant transition and relative amplitude information. Normal hearing listeners also showed an effect of presentation level in that higher presentation levels yielded fewer labial responses. Hearing impaired listeners yielded fewer labial responses than the normal hearing listeners when the stimuli were presented at equivalent overall sound pressure levels. The results of this study are in agreement with two hypotheses. One is that the normally rapid growth of amplitude in the impaired ear might enhance the low-level burst relative to the vowel amplitude. Such an increase in the amplitude of the burst relative to the vowel in the high frequencies might lead to more alveolar responses, since alveolar sounds have more high frequency energy than labials. This hypothesis predicts that at equivalent sound pressure levels, listeners with sensorineural hearing loss may yield significantly more alveolar responses than normal hearing listeners. This significant difference between the listener groups would occur because of the recruitment in the impaired ear. The second hypotheses is that the perceptual weights placed on the relative amplitude and formant transitions by the hearing impaired listeners may be different from that of normal hearing listeners. The differential weighting between the listener groups would presumably occur because sensorineural hearing loss may disrupt coding of spectral information, particularly that of formant transitions.

Recent data from Balakrishnan, Freyman, Chiang, Nerbonne, and Shea (1996) suggested that there might be "optimal" CVRs that differ for different phonemes. They use the stimulus /aCa/ where 22 consonants were used. Although these investigators used only listeners with normal hearing, they also included a spectrally degraded speech condition to simulate hearing impairment. With some minor discrepancies, the results generally indicated that enhancing CVRs for sibilants-fricatives and glides near threshold level (but for audible stimuli) improved recognition performance, whereas decreased performance was found with CVR enhancement for nasals, stops and affricates showed no effect of CVR manipulation. Performance was poorer when spectral degraded speech was presented to simulate hearing impairment.

Hedrick and Jesteadt (1996) made a comparison of relative amplitude manipulation in the presence of neutral formant transitions versus manipulation of both formant transition and relative amplitude. Synthetic CV stimuli were used and, and the amplitude of the burst relative to the vowel in the F4-F5 frequency range was varied across a 20 dB range using a /p-t/ contrast. Results showed no significant difference between listener groups when only relative amplitude information was manipulated. A significant difference was observed when both relative amplitude and formant transition information was present. These results suggested that the listeners with normal hearing weighted the two acoustic cues differently when compared to listeners with a sensorineural hearing loss. Degree of hearing impairment appeared to affect substantially the amount of performance improvement from consonant amplification. In comparison to listeners with moderate or mild hearing impairments, severely hearing impaired subjects did not obtain comparable increases in performance from consonant amplification.

For listeners with moderate or mild hearing impairments, identification at chance levels has been reported for amplified stops (Revoille, Holden-Pitt, Edward, & Pickett, 1987) and amplified fricatives (Revoille, Holden-Pitt, Pickett, & Brandt, 1986). However, these listeners showed considerably improved recognition for distinctions of consonant voicing (errors ignored for consonant place identification) for amplified stops (>20%) and fricatives (20%).

The studies of speech alteration reviewed above typically reported the effects of speech enhancement for hearing impaired listeners. Signal processing techniques that enhance CVR may be useful even if the sole outcome of that processing is to achieve greater audibility of high frequency energy. Predictions for future hearing aids include the expectation that their circuitry will incorporate microprocessors that enable alteration to selected portions of the speech signal prior to amplification. These alterations will be chosen to enhance important speech characteristics that are distorted, weak, or imperceptible for individual hearing aid users. The studies that are reviewed here will help to facilitate phoneme recognition by the hearing impaired.

METHOD

The study was done with the aim to evaluate the extent to which variation in the CV intensity ratio could account for variation in speech intelligibility in adults with normal hearing and adults with hearing impairment.

Subjects:

20 mild-to-moderate sensorineural hearing impaired adults and 20 normal hearing age matched adults served as subjects.

Subject Selection Criteria for the Hearing Impaired Group:

- Subjects had acquired hearing loss
- Onset of hearing loss was after 10 years of age
- They were above the age of 18 years
- They had no history of middle ear pathology
- They had clear speech with no misarticulation
- Subjects were able to read and write
- They had poor to slight difficulty in speech identification as per the criteria given by Goetzinger (1978) i.e., scores between 50 to 80%

Subject Selection Criteria for the Normal Hearing Individuals:

- Hearing sensitivity was within normal limit
- There was no history of middle ear pathology
- They had clear speech with no misarticulation

- They were able to read and write
- Speech Reception Threshold (SRT) was within 5 dB of Pure Tone Average (PTA)
- Score on speech identification (SI) was 100%

Procedure:

Material development:

Consonant Vowel (CV) syllables were used as test stimuli. The consonants were voiceless consonants /p/, /t/, and /k/, voiced consonants *Ibl, /d/* and /g/, and the fricatives /s/ and ,/ʃ/. Each of these consonants were followed by the vowels /a/, /i/ and /u/ In all there were 24 CVs.

Speech stimuli were recorded by a male speaker, whose mother tongue was Kannada. The recording was done on a Pentium IV computer using a unidirectional microphone. The recorded material was scaled /normalized using the Audiolab software so that all the monosyllables/tokens were of the same intensity. Amplitude expansion of these CV syllables was done using the Wavesurfer software. Amplitude expansion was done in the following two steps:

- The CV ratio of the recorded material was increased by reducing the amplitude of the vowel by 3 dB.
- The CV ratio of the recorded material was increased by reducing the amplitude of the vowel by 6 dB.

The intensity of the vowel was reduced only in the steady state portion. No alteration was made to the transition portion of the vowel.

In addition a list with the materials being unaltered was included for evaluation. Thus, three lists were prepared in all. List I included the unaltered stimuli. List II and list III included the material with the vowels reduced by 3 dB and 6 dB respectively. The material from the three lists were combined and randomized to form two master lists, list A and list B, with each containing 72 CVs. This was done to avoid any order effect of the lists.

Procedure for Subject Selection:

A preliminary pure tone test was done to find out the hearing threshold using Madsen OB 922 clinical audiometer and TDH 39 earphone. Air conduction thresholds were obtained between 250 and 8 kHz and bone conduction thresholds were obtained between 250 and 4 kHz. Screening tympanometry and reflex threshold testing was done using GSI 33 impedance audiometer to rule out the presence of any middle ear pathology. Speech recognition threshold (SRT) and speech identification (SI) were obtained in the language spoken by the subjects. For evaluation of SRT the Kannada speakers were evaluated using Kannada spondee word list (Rajashekhar, 1976), Tamil speakers using spondee word list in Tamil (Samuel, 1976), English speakers using English speech test material developed by Chandrashekhara (1972), Hindi speakers by Hindi PB list (De, 1973), Bengali speaker using speech material in Bengali (Ghosh, 1986). The speech identification (SI) scores were obtained using The Common Speech Discrimination Tests for Indians (Mayadevi, 1974).

Procedure for CV Material Evaluation:

Using the Audiolab software the developed material containing 72 randomized CVs were played. The output from the computer was routed to the tape input/ auxiliary input of the audiometer (OB 922). Prior to the presentation of the stimuli, a 1 kHz calibration tone was played to set the VU meter deflection to '0'. Subjects heard the token through a headphone. All the normal hearing subjects were tested in both the right ear and the left ear using the two master lists. Master lists A and B were presented randomly to the right and left ear of both normal and hearing-impaired subjects. 18 of the hearing impaired subjects were tested in right ear, while 17 were tested in left ear. The normal hearing individuals received the tokens at 45 dB HL which is the normal conversation level. The hearing-impaired individual tokens were tested at 40dB above SRT.

All subjects listened to all the stimuli. This included the two amplitude variations as well as the natural unaltered speech signals. Subjects were asked to write down the tokens they heard. A key was formed to note which list each of the test items belong to. Scoring was done separately for the unaltered (UA) condition, and 3 dB and 6 dB vowel reduction conditions.

Scoring:

A key was formed to note which list each of the test items belong to. Scoring was done separately for the unaltered (UA) condition, and 3 dB and 6 dB vowel reduction conditions. Each correct response was given a score of "1". An incorrect response was given a score of "0". The data thus collected was subjected to statistical analysis as well as an error analysis.

RESULTS AND DISCUSSIONS

The aim of the study was to find out the effects on speech perception when amplitude modified stimuli were presented to normal hearing individuals and individuals with a mild, moderate and severe degree of hearing loss. The stimuli contained unaltered (UA) CVs, and CVs with the vowels reduced by 3 dB and 6 dB. The raw data obtained from the clients was subjected to statistical analysis. Mean and standard deviation were calculated. The t- test was done to determine the effect of the alterations in consonant-vowel ratio on the perception of normal hearing individuals and individuals with varying degrees of hearing impairment.

Totally forty subjects above the age range of 18 years were tested for the study. Of them, twenty were normal hearing and twenty were hearing impaired. Seven right ears and six left ears of 10 subjects formed the mild category (only three subjects had bilateral mild hearing loss). The moderate category was formed by seven right ears and five left ears of 10 subjects (two of them had bilateral moderate degree of hearing loss). Four right ears and six left ears formed the severe category. Out of the eight subjects with a severe hearing loss, two had a bilateral severe degree of hearing loss. Five ears which had a normal hearing, mixed hearing loss or profound hearing loss were not included in the study (two right ears and three left ears).

The analysis is done in four ways.

- The unaltered (UA) condition was compared with the 3 dB alteration condition
- The unaltered (UA) condition was compared with the 6 dB alteration condition

- The 3 dB alteration condition was compared with the 6 dB alteration condition
- Error analysis was done for each of the conditions, i.e. UA, 3 dB alteration and 6 dB alteration

The above comparison was done for different groups of subjects, which included:

I) Normal hearing subjects

II) Hearing-impaired subjects

a. Mild hearing-impaired subjects

b. Moderate hearing-impaired subjects

c. Severe hearing-impaired subjects

HI) Normal hearing vs. hearing-impaired groups

I) Effect of CV amplitude ratio in normal hearing subjects:

Table 1 shows the scores of twenty normal hearing individuals when the stimuli were given in all three conditions i.e. unmodified natural stimuli, 3 dB vowel reduction and 6 dB vowel reduction, for both the right ear and left ear. The mean and standard deviation were calculated for each condition. In addition, the significance of difference between means for the three different conditions was calculated separately for each ear.

Table 1: Scores of normal hearing subjects in both the right ear and the left ear

Ear	Alterations in dB	Mean (Max score = 24)	SD	t-Score	Level of Significance
Right ear	UA Vs. 3	22.70	1.301	0.545	Not Significant
		22.90	0.967		
	UA Vs. 6	22.70	1.301	1.636	Not Significant
		23.25	0.910		
	3 Vs. 6	22.70	0.967	1.505	Not Significant
		23.25	0.910		
Left ear	UA Vs. 3	23.05	1.276	0.213	Not Significant
		23.10	1.020		
	UA Vs. 6	23.05	1.276	0.721	Not Significant
		23.30	0.864		
	3 Vs. 6	23.10	1.020	0.809	Not Significant
		23.30	0.864		

Results show that there was an improvement in the scores for all the conditions. However, this improvement was not statistically significant. From the mean scores it is evident that the normal hearing subjects obtained almost perfect scores in the UA condition. Hence, further reduction of vowel energy only made a slight improvement in scores. Decreasing vowel amplitude that approximated some of the acoustic modification found in naturally produced clear speech, does improve speech intelligibility marginally in normal hearing subjects.

Studies that altered CV ratio by enhancing the energy of consonants showed similar results. Balakrishnan et al. (1996) also reported an enhancement in CV syllables scores in normal subjects when the CVR was altered from -25 to 0 dB. They suggested that as long as the modification was done to increase the difference between the consonant and the vowel, little harm was done by altering the CVs.

The finding in the present study is in consonance with that of Hecker (1974, cited in Freyman & Nerbonne, 1989) who increased the CVR of a low intelligibility talker and produced a 3.75% improvement in intelligibility using normally hearing listeners. Gordon-Salant (1986) reported a significantly higher score in young and elderly normal hearing adults when the CVR was increased by 10 dB. They too suggested that increased consonant energy could improve consonant identity in a number of ways, including reducing the background masking of the consonant by the vowel. Such findings have also been reported by Danaher and Pickett (1975), Danaher, Wilson, and Pickett (1978), Ohde and Stevens (1983).

The results of the present study contradict those of Freyman, Nerbonne, and Cote (1991). The latter study reported that performance reduced in normal hearing individuals in an amplified consonant condition presumably because the waveform envelope cues had been distorted. The differences in the findings of the studies are probably because of the methods utilized. While in the present study the CVR has been increased by reducing the vowel amplitude, in their study it has been increased by amplifying the consonant. Boothroyd, Springs, Smith, and Schulman (1988), Moore and Glassberg (1986) and Plomp (1988) expressed concern that amplitude compression using short attack and release time could distort waveform envelope cues and decrease speech recognition performance in hearing impaired individuals. Hence, it is recommended that the CVR be increased by reducing the vowel amplitude rather than amplifying the consonants.

II) Effect of CV amplitude ratio in hearing impaired subjects:

Table 2 shows the scores of all the twenty hearing impaired subjects in all the three conditions. Mean, S.D and t-score were calculated. It shows that for both the right ear and the left ear, the scores improved with a reduction in vowel energy. This improvement was statistically significant when the UA condition was compared with the 3 dB and the 6 dB alteration condition. However, the improvement in scores was not significant when the 3 dB alteration condition was compared with the 6 dB alteration condition. This result was true for both the ears. Though there was no statistically significant difference, there was a marginal improvement in the mean scores between these two conditions. Thus, by enhancing the consonant-vowel amplitude ratio, speech perception can be enhanced in the hearing impaired.

Table 2: Scores of hearing impaired subjects in both the right ear and the left ear

Ear	Alterations in dB	Mean (Max score = 24)	SD	t-Score	Level of Significance
Right ear	UA Vs. 3	11.00	4.74	4.123	Significant at 0.01
		13.33	4.15		
	UA Vs. 6	11.00	4.74	3.77	Significant at 0.01
		13.38	4.40		
	3 Vs. 6	13.33	4.15	0.10	Not Significant
		13.38	4.40		
Left ear	UA Vs. 3	9.82	4.83	4.43	Significant at 0.01
		12.05	4.43		
	UA Vs. 6	9.82	4.83	4.90	Significant at 0.01
		12.35	5.54		
	3 Vs. 6	12.05	4.43	0.51	Not significant
		12.35	5.54		

Further analysis was done to determine the effect of CVR alterations, when the hearing impaired subjects were divided into subgroups i.e. mild, moderate and severe degree. The results of different subgroups of hearing-impaired subjects are given below.

II a) Effect of CV amplitude ratio in subjects with mild hearing impairment:

Table 3 shows the scores of ears with a mild hearing-impairment. It is seen that the subjects with a mild hearing impairment also showed an improvement in scores, as the vowel energy was decreased, like the normal hearing subjects. Their scores significantly improved in the right ear when the UA condition was compared with the 3 dB and the 6 dB vowel reduction conditions and also when the 3 dB alteration was compared with the 6 dB alteration conditions. However, in the left ear significant improvement in scores were seen when the UA condition was compared with the 3 dB and 6 dB alteration only. When the 3 dB alteration was compared with the 6 dB alteration in the left ear, though the scores improved, it was not statistically significant.

Table 3: Scores of subjects with mild hearing-impairment in both the right ear and the left ear

Ear	**Alterations in dB**	**Mean (Max score = 24)**	**SD**	**t-Score**	**Level of Significance**
Right ear	**UA Vs. 3**	12.143	3.579	4.973	Significant at 0.01
		15.857	4.099		
	UA Vs. 6	12.143	3.579	2.248	Significant at 0.05
		17.0	7.249		
	3 Vs. 6	15.857	4.099	7.249	Significant at 0.01
		17.0	7.249		
Left ear	**UA Vs. 3**	10.166	5.419	3.796	Significant at 0.01
		13.666	6.615		
	UA Vs. 6	10.166	5.419	4.394	Significant at 0.01
		14.0	6.723		
	3 Vs. 6	13.666	6.615	0.260	Not significant
		14.0	6.723		

The results given in table 3 above clearly show substantial benefit of amplitude processing in individuals with a mild degree of hearing loss. This benefit is not surprising because the effect of the processing is to decrease the vowel level while holding the consonant energy constant. This amplitude alteration results in making the less audible consonants more audible, thus increasing their scores. Also the success of CVR enhancement was probably associated with an effective increase in the consonant-to-noise ratio that should improve speech recognition performance according to the Articulation Index theory (French & Steinberg, 1947, cited in Gordon-Salant, 1986).

Gordon-Salant (1987) also manipulated CVs whose consonant energy relative to the vowel energy was increased by +10 dB and presented to elderly hearing-impaired individuals. She reported that CVR increment enhanced nonsense syllable recognition and reduced the frequency of major consonant confusions by elderly hearing-impaired subjects. The overall improvement in nonsense syllable scores as a result of CVR enhancement was 14%, for both subject groups.

In the present study, though there was a significant difference between all the conditions in the right ear, the improvement in scores were not significant in the left ear when the 3 dB alteration was compared with the 6 dB alteration condition. Results show that the left ear mean scores were poorer than the right ear mean scores. Although they showed a statistically significant improvement when vowels were reduced by 3 dB, further reduction of vowels improved their scores only marginally.

It was noted that two subjects had a minimal to mild degree of hearing impairment in the right ear which could account for the better scores in this ear. Further, five of the six subjects who had a mild hearing loss in the left ear had it for a duration of approximately twenty years. However, in the right ear, only two of the subjects had the loss for such a long period. The remaining subjects had the problem for a duration of less than five years. This prolonged duration of a hearing loss might have resulted in the reduced left ear scores.

II b) Effect of CV amplitude ratio in subjects with moderate hearing impairment:

Table 4 shows the scores of ears with a moderate hearing impairment. From the table it is clear that scores were least in the UA condition and improved when vowel energy was reduced by 3 dB, but performance decreased when vowel energy was reduced further by 6 dB. This was observed in both the right ear and the left ear. Thus, they performed the best in the 3 dB alteration condition.

Table 4: Scores of subjects with moderate hearing-impairment in both the right ear and the left ear.

Ear	Alterations in dB	Mean (Max score = 24)	SD	t-Score	Level of Significance
Right ear	**UA Vs. 3**	9.571	3.994	4.666	Significant at 0.01
		11.714	3.860		
	UA Vs. 6	9.571	3.994	1.987	Not significant
		11.0	3.829		
	3 Vs. 6	11.714	3.860	0.826	Not significant
		11.0	3.829		
Left ear	**UA Vs. 3**	9.4	4.98	5.099	Significant at 0.01
		12.0	4.795		
	UA Vs. 6	9.4	4.98	3,651	Significant at 0.05
		11.4	5.319		
	3 Vs. 6	12.0	4.795	0.688	Not significant
		11.4	5.319		

The improvement in score was significant when the UA condition was compared with the 3 dB alteration in both the right ear and the left ear. Again when the UA was compared with the 6 dB alterations in the left there was a significant improvement in the left ear scores whereas in the right ear the increment in performance was not statistically significant. Though the scores decreased in the 6 dB alteration condition, this decrement in performance was not statistically significant. Thus, the subjects with a moderate degree of hearing impairment performed best with a slight change in the CV ratio (i.e. 3 dB). Further enhancement of the CVR probably deprived them of intensity contrasts that they probably used for the perception of the speech sounds, leading them to have lower scores.

Similar findings have been reported by Montgomery and Edge (1988). They showed that increasing amplitude of stop consonants produced a significant improvement (10 to 12%) in intelligibility over the unprocessed speech for subjects with moderate hearing-impairment.

II c) Effect of CV amplitude ratio in subjects with severe hearing impairment:

Table 5 depicts scores of ears with a severe hearing impairment. The subjects with a severe hearing impairment also showed improvement in performance as the vowel energy was decreased by 3 dB and 6 dB when compared to the UA condition. However, it was seen that this improvement in scores was not statistically significant for any of the condition, in both the ears. Thus, it can be concluded that a reduction in the vowel intensity would help those individuals also to perceive speech better, but not to the same extent that it would help individuals with a mild or moderate degree of hearing impairment.

Table 5: Scores of subjects with severe hearing impairment in both the right ear and the left ear

Ear	Alterations in (IB	Mean (Max score = 24)	SD	t-Score	Level of Significance
Right ear	UA Vs. 3	9.75	4.5	2.00	Not significant
		11.75	3.201		
	UA Vs. 6	9.75	4.5	1.260	Not significant
		12.25	3.20		
	3 Vs. 6	11.75	3.201	0.346	Not significant
		12.25	3.20		
Left ear	UA Vs. 3	9.833	4.98	1.000	Not significant
		10.5	4.795		
	UA Vs. 6	9.833	4.98	1.746	Not significant
		11.5	5.319		
	3 Vs. 6	10.5	4.795	1.291	Not significant
		11.5	5.319		

Johnson, Whaley, and Dorman (1984) have also reported that individuals with a mild and moderate hearing impairment are able to perceive VOT boundaries like normal hearing individuals, while those with a severe hearing impairment had deviant perception of the boundaries. This indicates that as the degree of hearing impairment increases, the hearing impaired are unable to perceive consonantal information well.

Thus, it appears that vowel reduction loses its beneficial effect as the hearing sensitivity reduces. Selective enhancement of CVR by modifying amplitude appears to be of limited practical value atleast for the severely hearing impaired individual. However, performance might improve if stimuli were presented at a higher level and the CVR was expanded by increasing the duration of the stimulus along with a vowel amplitude reduction. Hedrick and Jesteadt (1996) reported no significant differences in performance in subjects with a sensorineural hearing-impairment when only relative amplitude information was manipulated. However, a significant difference was noted when both the relative amplitude and formant transition information was present.

III) Comparison across normal hearing and hearing impaired groups:

The scores in table 6 show the mean scores of all the subjects. The scores reveal that the normal hearing subjects performed better than all the other groups. There was a gradual decline in performance as the degree of hearing impairment increased from mild to moderate. The scores of the subjects with a moderate and severe degree of hearing loss were comparable.

Table 6: Mean scores of normal hearing and hearing-impaired subjects in both the right ear and the left ear

Ear	**Alterations in dB**	**Normal hearing**	**Mild HI**	**Moderate HI**	**Severe HI**
Right Ear	UA	22.70	12.14	9.57	9.75
	3dB	22.90	15.85	11.71	11.75
	6dB	23.25	17.00	11.00	12.25
Left ear	UA	23.05	10.16	9.40	9.83
	3dB	23.10	13.66	12.00	10.50
	6dB	23.30	14.00	11.40	11.50

The significance of difference between means was calculated to compare the normal hearing subjects with that of the hearing impaired subgroups (i.e. mild, moderate and severe hearing impairment). It was found that there was a statistically significant difference in scores when scores of normal hearing subjects were compared with that of the subjects with mild, moderate and severe hearing-impairment. This was statistically significant at the 0.01 level. No such significant improvement was seen when scores were compared among the hearing impaired groups.

IV) Error analysis:

The scores of the normal hearing and hearing impaired groups were subjected to error analysis for place, manner and voicing errors. Results showed that the responses of the normal hearing individuals were almost accurate and they made very few consonant or vowel confusions. Phonemic confusions were more observed in subjects with a hearing impairment.

Consonant Error:

The subjects with the hearing impairment showed many consonantal errors. It was seen that regardless of vowel context, the recognition of voiceless fricatives *I si* and /ʃ/ and stop consonant /g/ were better. The lesser confusion for the voiceless fricatives might be due to the presence of noise in the stimuli which increased the recognition of those fricatives. Freyman, Nerbonne, and Cote (1991) reported increase in the percentage of voiceless fricative responses where the stimuli largely consisted of white noise. They created a white noise-masked speech waveform by digitally adding speech to its corresponding modulated noise waveform. Also, the greater audibility of fricatives might be due to the longer average duration (94-140 msec for fricatives versus the stops which are 54-64 msec) as reported by Revoille and Pickett (1982). The better perception of velar /g/ can be attributed to the fact that they have a longer voice onset time (VOT) compared to the bilabial and alveolar stops and also due to the presence of mid-frequency peaks (Kewley-Port, 1982).

Stops were poorly identified by the hearing impaired. This was probably due to their short duration. Further, the responses of the hearing-impaired listeners were examined according to the features of voicing, manner and place of articulation. Place errors occurred the most, manner errors lesser, and voicing errors the least. This pattern of error was seen for the UA, 3 dB and 6 dB alteration conditions. This result is supported by Cox (1969, cited in Revoille & Pickett, 1982) who evaluated feature analysis by hearing impaired listeners and reported that confusion of place of articulation was more followed by manner and voicing errors. Further, it was noted that amplitude reduction improved the perception of place, manner and voicing features in all the hearing impaired groups.

Consonant error in vowel context:

The majority of consonant errors were observed in the vowel /i/ context followed by /u/ and then the /a/ context. Cox (1969, cited in Revoille & Pickett, 1982) also reported more errors of place and manner confusion of consonants with the /i/ vowel context which has a high frequency second formant (F2), when compared to the /u/ and /a/ context. These findings indicate that the vowels did influence the perception of consonants in hearing impaired listeners. However, this influence was not seen for all consonants.

Vowel Error:

In addition to the consonant confusion, four of the subjects also showed vowel confusion. They perceived /i/ each time /u/ was presented along with a consonant. This was seen in the UA condition and the 3 dB alteration condition. With the reduction of vowel by 6 dB, such vowel confusion was not observed. Of the four subjects, three had a sloping hearing loss in the high frequency region. The vowels /u/ and /i/ have similar first formant frequency (Fl), and differ only in the second formant frequency (F2). It can be construed that these subjects did not perceive the F2 information and depended only on the Fl information. Pickett et al. (1972) also reported the tendency for the confusion to occur between vowels having Fl in the same frequency region, especially for vowels with Fl in the low frequencies. For such subjects auditory training should be more frequency based rather than intensity based.

Only one subject showed vowel confusion in the /a/ and /u/ vowel context where the subject perceived tokens as /a/ whenever /u/ was presented along with a consonant. This vowel confusion was seen in all three conditions. The vowels /a/ and /u/ differ in Fl and F2, but are similar in frequency for F3 and F4 (Risberg, 1976, cited in Revoille & Pickett, 1982). Their study reported that the mean recognition for vowels was reduced for the vowels with different formant frequencies below 1500 Hz. It was suggested that for discriminating the vowels /u/ and /a/, the listener also should use intensity cues.

The results of the present study can be summarized as:

1) The scores improved in all the groups with the reduction in vowel energy except in the subjects with a moderate hearing impairment where the scores decreased when vowel energy was reduced by 6 dB.
2) The improvement in performance was not statistically significant in normal hearing subjects.
3) In the hearing-impaired group, subjects with a mild hearing-impairment showed maximum improvement when compared with the subjects having moderate and severe degrees of hearing loss.
4) The improvement in scores were significant in all conditions except the 3 dB vs. 6 dB alteration condition where it was not significant in the left ear in the subjects with mild hearing impairment and in both the ears in the subjects with moderate hearing impairment. Also, the UA vs. 6 dB alteration condition was not significant in subjects with moderate hearing impairment.
5) Performance increment was not statistically significant for the subjects with a severe hearing-impairment.
6) Error analysis of the responses of hearing impaired subjects showed that consonants were misperceived more than the vowels.
7) Among consonants, place of articulation errors were the most, followed by manner. In comparison, fewer misperceptions occurred between voiced and voiceless consonants.
8) Poorer vowel perception seemed to depend on the frequency location of the first and the second formants. Subjects with a high frequency sloping hearing loss tended to misperceive vowels with a high second formant frequency, i.e./i/.

SUMMARY AND CONCLUSION

Individuals with hearing impairment due to cochlear pathology frequently experience a deficit in speech understanding. The result is that the probability of recognition of the underlying language pattern is reduced. For improvement of the recognition of speech by hearing impaired subjects, signal processing has been studied for many years. One such technique to improve perception is through speech enhancement where the consonant-vowel (CV) ratio is increased. Literature reveals that consonant amplification or vowel reduction has the maximum effect in enhancing speech intelligibility in hearing impaired population.

The present study was carried out with the aim of finding the effects of amplitude modified stimulus on the speech perception of normal hearing subjects and subjects with a mild, moderate and severe degree of hearing impairment. The study compared the performance of subjects in three conditions: UA, 3 dB vowel reduction and the 6 dB vowel reduction condition. In addition, an error analysis was done for each of the conditions.

Forty subjects above the age of 18 years were tested for the study. Of them twenty were normal hearing subjects and twenty were hearing impaired subjects. The hearing impaired subjects were subdivided into three subgroups: mild, moderate and severe degrees of hearing impairment. All of the subjects were tested to establish their pure tone thresholds, speech reception thresholds (SRT) and speech identification (SI) scores. The latter two tests were established by using language appropriate tests. The normal hearing subjects had hearing threshold within 15 dB in the frequencies from 250 to 8000 Hz. The hearing impaired subjects had acquired hearing loss with no history of middle ear pathology. They had SI scores between 50-80%.

24 CV tokens were made utilizing eight consonants in three vowel contexts. Using the 24 CV tokens three lists were prepared. The first list consisted of the 24 natural UA stimuli, the second list had the same 24 stimuli with a 3 dB reduction in vowel energy and the third list had the stimuli with a 6 dB reduction in vowel energy. The Wavesurfer software was used to reduce the vowel energy in the CV stimuli thereby increasing the CV ratio. Two master lists were prepared, each having 72 CVs.

Responses were obtained by asking the subjects to write down the tokens they heard. Scoring was done in terms of correct and incorrect responses. The raw data was statistically analyzed where mean, S.D were calculated. The t-test was used to find the significance of the difference between mean of different conditions in the normal hearing and different subgroups of hearing impaired subjects.

The results of the study are summarized as:

I) Effect of CV amplitude ratio in normal hearing subjects:

Analysis of the mean scores in normal hearing revealed an improvement in scores in both the ears when vowel energy was reduced by 3 dB and 6 dB. However, this improvement was not statistically significant. This finding was supported by Hecker (1974, cited in Freyman & Nerbonne, 1989), Balakrishnan et al. (1996), Gordon-Salant (1986), Danaher and Pickett (1975), Danaher, Wilson, and Pickett

(1978), and Ohde and Stevens (1983) who also reported an improvement in perception with increase in consonant-vowel (CV) ratio.

II) Effect of CV amplitude ratio in bearing impaired subjects:

Analysis of mean scores showed that for both the right ear and the left ear, scores significantly improved when the UA condition was compared with the 3 dB and the 6 dB alteration conditions. The improvement was not statistically significant when the 3 dB and 6 dB alteration conditions were compared.

The subjects with a hearing impairment were further divided into three subgroups (i.e. mild, moderate and severe degree) and their scores were compared in all the three CV ratio conditions.

II a) Effect of CV amplitude ratio in subjects with mild hearing impairment:

In subjects with a mild hearing impairment, scores improved with a reduction in vowel energy. This improvement was statistically significant when the UA condition was compared with the 3 dB and 6 dB alteration condition in both the ears. When the 3 dB alteration was compared with the 6 dB alteration, improvement was statistical significant only in the right ear and not in the left ear. This is in agreement with the findings of Gordon-Salant (1987) who reported that CVR increment reduces consonant confusion in hearing impaired subjects.

II b) Effect of CV amplitude ratio in subjects with moderate hearing impairment:

In subjects with a moderate hearing impairment, significant improvement was seen in UA vs. 3 dB condition in both ears. The improvement was significant in the UA vs. 6 dB condition only in the left ear and not in the right ear. Though the scores decreased when the vowel energy was reduced from 3 db to 6 dB, this decrement in performance was not statistically significant. Montgomery and Edge (1988) also reported improvement in intelligibility in subjects with moderate hearing impairment with increase in CVR.

II c) Effect of CV amplitude ratio in subjects with severe hearing impairment:

The subjects with a severe hearing impairment also showed improvement in performance as the vowel energy was decreased by 3 dB and 6 dB. However, this improvement in scores was not statistically significant for any of the condition, in both the ears. Hedrick and Jesteadt (1996) reported that no significant improvement in performance when only relative amplitude was manipulated. Thus, CVR enhancement is of limited practical value for subjects with severe hearing impairment.

III) Comparison across normal hearing and hearing impaired groups:

The normal hearing subjects performed better than all the other groups. There was a gradual decline in performance as the degree of hearing impairment increased from mild to moderate degree. The difference in scores between the normal hearing and hearing impaired subjects was statistically significant for all three CVR conditions. This was not the case when the scores among the hearing impaired groups were compared.

IV) Error analysis:

Error analysis of the responses of the normal hearing and the hearing impaired subjects was carried out. The results showed that the responses of the normal hearing individuals were almost perfect and they made very less consonant or vowel confusion.

The subjects with a hearing impairment showed more of place error followed by manner and voicing errors for all the three CVR conditions. They showed better responses of fricatives /s/ and /ç/ and voiced stop /g/. Cox (1969, cited in Revoille & Pickett, 1982) also reported place confusion in hearing impaired subjects followed by manner and voicing errors. The consonants were most accurately perceived in the /a/ vowel context followed by the /u/ context. Responses were least in the /i/ context. In addition, some subjects also showed vowel confusion. Such error patterns have been reported by Pickett et al. (1972) and Risberg (1976, cited in Revoille & Pickett, 1982).

The utility of the findings of this study would be in providing rehabilitation to the hearing impaired. The information can be incorporated in future hearing aids which might be able to extract formant information of vowels and reduce their intensity thus enabling the hearing impaired to perceive clearer speech.

Therapy material can be developed utilizing expanded CVRs. Individuals with hearing impairment can initially be trained with expanded CVR material prior to being trained with natural material.

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