EFFECT OF COMPRESSION RATIO ON SPEECH RECOGNITION SCORES IN SUBJECTS WITH SENSORINEURAL HEARING LOSS

Reg. No. A0490009

A dissertation submitted in part fulfillment for the final year
Masters of Science (Audiology)
University of Mysore. Mysore

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May-2006

Dedicated To,

My Dear Parents,
Almighty God,
&
Teachers.

CERTIFICATE

This is to certify that this master's dissertation entitled ***"Effect of Compression Ratio on Speech Recognition Scores in Subjects with Sensorineural Hearing Loss"*** is the bonafide work done in part fulfillment of the degree of Master of Science (Audiology) of the student with **Reg. No.: A0490009.** This has been carried out under the guidance of a faculty of this institute and has not been submitted earlier to any other University for the award of any other Diploma or Degree.

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CERTIFICATE

This is to certify that this master's dissertation entitled ***"Effect of Compression Ratio on Speech Recognition Scores in Subjects with Sensorineural Hearing Loss"*** has been prepared under my supervision and guidance. It also certified that this has not been submitted in any other university for the award of any diploma or degree.

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Declaration

I hereby declare that this dissertation entitled ***"The Effect of Compression Ratio on Speech Recognition Scores in Subjects with Sensorineural Hearing loss"*** is the result of my own study under the guidance of Dr.K. Rajalakshmi, Head of the department of Audiology, All India Institute of Speech & Hearing, Mysore, and has not been submitted earlier at any other University for the award of any Diploma or Degree.

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May-2006

Acknowledgement

*My heartfelt gratitude to my guide **Dr.K.Rajalakshmi**, for her guidance and support .mam, your patience and help has made me this study possible. Thank you mam.*

*Iam thankful to **Prof.M.Jayaram**, director, all India Institute of speech and hearing, Mysore, for permitting me to carry out this study.*

*I would like to express my thanks to **Prof.Asha Yathiraj**, for permitting me to use the instruments for carrying out this study.*

*I express my sincere thanks to **Mrs.Vasanthalakshmi**, for helping in statististical analysis in spite of her busy schedule….thanks a lot mam.*

*I thank **audio staff, library staff** and **Xerox person** for the timely help.*

***All clients** ….thanks for sitting through the test administered patiently and for spending your valuable time.*

***Aapa, Riaz & Zia** … the love and care you have given me and the faith you have in me has brought me a long way. Without you, it would have not been possible to even imagine what iam now. You have given me the support, inspiration, encouragement, and strength to face the challenges in life. I feel I am the luckiest person in the world …Becoz I got you. 'Thank you' is a too little word to express my feelings for you. I wish I could stay with you like this forever.*

***Reddy, Sharu, Vijitha, Lubna, Seema, Shiva, Baba, Prafull, Pradyum, Ramu** …you people have always been beside me sharing my happy and sad moments. Life was worth living Becoz of your care and friendship. I am grateful to god …he showed you people to me.*

***My classmates** …you have made my life easier at **AIISH**. Thank you all so much and i will miss you all.*

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INTRODUCTION

Hearing is one of the most important senses of man. It forms a vital link to the world of communication .hearing is essential for the acquisition of the speech and language. The hearing mechanism also essential for monitoring ones own speech production. In addition, hearing also enables an individual to make judgments regarding the location of the different sound sources in environment. (Yost, 1994).

The essence of a hearing loss thus has its effect on communication and resulting impact on cognitive, speech, language and psychosocial development and functioning (Vernon & Andrews, 1990). The impact of a hearing loss has its onset during adulthood depends on several factors. These include age of onset (i.e., prevocational or post vocational). nature, degree & configuration of hearing loss, life style & occupation of the person and perceived handicap.

Amplification represents the single most important rehabilitation tool available to the hearing impaired population (Ross&giolas, 1978, Bess & McConnell, 1981). Amplification device provide a valuable communication link between the hearing impaired listener and his acoustic environment.

The common observation in individuals with sensorineural hearing loss is recruitment or softness imperception, i.e., the occurrence of steeper than normal loudness growth function, together with an elevated absolute threshold .the typical means by which a hearing aid compensates for this recruitment is the use of a non linear compressor circuit.

With the increased use of digital signal processing in commercial hearing aids, the number of processing parameters available for adjustment has grown substantially. Some multichannel systems allow for very precise frequency specific and level-dependent application of gain. These systems may have specific control, in multiple channels, over parameters such as overall gain, compression threshold, compression ratio, and attack-release times.

The optimal fitting of the hearing aid gain characteristics, both as a function of hearing loss and physical properties of the incoming sound, has been the subject of a large number of studies and has resulted in many standard prescription rules for hearing aid fitting. A few prescriptive formulae also calculate the recommended compression ratio, compression threshold and gain of the static input –output curve of a compressor as a function of hearing loss (Byrne, Dillon, Kitsch & Keidser, 2001).

There has been substantial research examining the effects of many of these parameters on speech recognition as a function of speech input level. In contrast, very little work has been done examining the effects of various hearing aid parameters as a function of output level at the ear. The compression ratio is the parameter that has the greatest effect on the control of the output level.

Compression ratio is defined as the change in input level needed to produce a 1 dB change in output level.

Most studies have focused on the comparison between linearly amplified and nonlinearly amplified speech, rather than on the effect of specific compression parameter. Results of these studies have been mixed. For example some studies showed better speech recognition and higher speech quality ratings with WDRC (Humes et al., 1999)or compression limiting (Hawkins & Naidoo, 1993) hearing aids. Conversely other investigators (Walker, 1982; Neumann & bake, 1998; Festen & Houtgast, 1999) noted that speech quality decreased as compression ratio increased above 1:1.finally, Fikret-Pasa (1994) found no effect of compression ratio on speech intelligibility or quality.

It is difficult to reconcile the results of these studies, although differences in amplification systems, fitting procedures, and concomitant parameters have influenced results. For example, Fikret-Pasa (1994) simultaneously varied compression ratio and compression threshold. A more systematic approach is to vary a specific compression parameter while measuring speech recognition and quality.

Knowledge about compression ratio and presentation levels is important because these factors may interact to affect speech recognition. High presentation levels influence several facets of auditory processing, including speech recognition and discrimination, frequency and temporal resolution and upward spread of masking (Egan and Hake, 1950; Dorman and Dougherty, 1981; Moore and Glasberg, 1987; Studebaker, 1999).

The increasing presentation levels and compression ratios can, independently, have a negative effect on speech recognition. It has been demonstrated that both level and compression ratio interact with other factors (e.g., SNR) to affect speech intelligibility (Yond and Buckles, 1995b; Studebaker, 1999).

The purpose of the present study was to examine the effect of compression ratio on the speech recognition as a function of severity and intensity level.

Aim of the study

The aim to carry out the present study was to examine the interactive effects of compression ratio, presentation level and severity of hearing loss in the following manner:

1) Effect of severity on Speech Recognition scores within each compression ratio & in each intensity level

2) Effect of three compression ratios (1:1, 2:1, and 4:1) at 45 dB and 80 dB input levels on Speech recognition Scores

3) Effect of intensity levels (45 dB & 80 dB) on Speech recognition Scores at each compression ratio.

REVIEW OF LITERATURE

Compression often is referred to as automatic gain control (AGC) because it changes the gain of the hearing aid as the input intensity SPL changes.

Sounds around us extend over a huge dynamic range—from below the normal threshold of hearing to above the normal level of discomfort or even pain. Most of the time, people with normal hearing can arrange things so that sounds are between their threshold and discomfort levels. This becomes difficult to achieve for people with hearing loss; the difficulty in achieving it increases with the size of the loss. There is an obvious need for hearing aids to employ some form or forms of dynamic range compression to make as many sounds as possible audible and comfortable.

The reduced dynamic range of hearing impaired listeners compared with normal hearing listeners has inspired several researchers to use full dynamic range compression to fit level-varying signals such as speech into the reduced dynamic range of hearing impaired listeners (Hickson, 1994). Hence one approach to reduction of dynamic range of hearing is to allow gain to be a function of output over the complete range of intensities in the speech signal, rather than only when some maximum desirable output is reached (Boothroyd, Springer, Smith & Schulman, 1988).

Even the most advanced hearing aid technology does not restore “normal hearing”. The human cochlea, with the differential roles played by the outer and inner hair cells, is a magnificent nonlinear sensory organ .all of the recent developments in compression technology are but tiny steps toward the goal of imitating the cochlea and its functions. Still, however, they are the steps in a positive direction. (Venema, 1999).

Despite the complexity, the benefits of compression can be summarized as follows: Compression can make *low-level* speech more intelligible, by increasing gain, and hence audibility (Souza & Turner, 1998); compression can make *high-level* sounds more comfortable and less distorted and, in *mid-level* environments, compression offers little advantage relative to a well fitted liner aid once the input level varies from this, of course, the advantages of compression become evident. Its major disadvantages are a greater likelihood of feedback oscillations and excessive amplification of unwanted lower level background noises.

The three ways in which the mismatch between the dynamic range of sounds and the dynamic range of hearing can be examined are:

1. Reduce the dynamic range of the most intense parts of signals with compression limiting or peak clipping, as appropriate.

2. Reduce the dynamic range of a wider range of input signals with some combination of fast- and slow-acting wide dynamic range compression that has a low compression ratio. Important questions to consider include: How fast should the compression be? How wide is the dynamic range that should be compressed? To what degree should it be compressed?

3. Aim for a low sensation level in some situations, and accept the consequence that some of the speech signal will be inaudible

The review is being discussed under the following headings:

1) Rationales for compression system

2) Different approaches to compression method

   a) Output limiting

   b) Wide dynamic range compression

3) Static aspects of compression

a) Threshold kneepoint

b) Compression ratio

1) Rationales for compression system

The general aim of the compressor is to provide higher gain for the soft sounds than for the loud sounds. Because of the frequency dependence of the recruitment it is necessary to compensate for it by independent compressors in different frequency channels. Dillon (1996) has outlined the rationales of compression system. All of the following rationales include the desire to reduce the dynamic range of the signal in some way.

a) Discomfort and distortion avoidance (compression limiting)

b) Loudness normalization

c) Noise reduction

d) Reduction of signal dynamic range

a) Discomfort and distortion avoidance

If the output of a hearing aid is not limited in some way, output signals will sometimes exceed the loudness discomfort level of the aid wearer. The primary advantage expected for compression is that even if the aid wearer selects a high volume control settings to amplify weak input signals, the compressor will prevent discomfort from occurring without distortion, if a high level wanted or unwanted signals occurs.

b) Loudness normalization

Because of the effects of the recruitment, the equal loudness contours of a person with a high frequency sensorineural hearing loss show the greatest deviation from the normality at low input levels. The principle of loudness perception is that, for any input level and frequency, the hearing aid gain should be such that it is sufficient enough for the wearer to report the loudness to be the same as that which a person with normal hearing would report.

c) Noise reduction

The noise reduction rationale aims to identify frequency component that do not contribute to intelligibility or comfort, and to attenuate those components relative to more useful components. The basic assumption is that at any given time, the signal –to-noise ratio (SNR) will vary with frequency. A second assumption is that noise in one frequency region will mask useful signals in the other frequency regions. The rationale of reducing masking by attenuating the frequency regions with the poorest SNR is supported by the data of Rankovic, Freyman and Zurek (1992).

d) Reduction of signal dynamic range

Because sound in various listening environments vary over a wide range of levels, and because hearing impaired people listen most effectively over a narrow range, compression can be used to translate a wide range of levels at the hearing aid input to a range of levels at the aid output. This reduces the necessity for the aid wearer to vary the volume control.

The major advantage expected for a wide dynamic range compression (WDRC) is that the user has less need to vary the volume control. The major disadvantage expected is the increased gain for low –level inputs makes feedback oscillations more likely for some subjects. Finally, compression at low levels can cause pumping of background noise over a wide range of speech and noise levels.

2) Different approaches to the compression method

There are actually two different philosophical approaches to compression method, not specific controls. They are,

a) Output limiting

b) Wide dynamic range compression (WDRC)

a) Limiting the Maximum Output

Maximum output is limited in every hearing aid. The two questions faced by clinicians are these:

1. What type of limiting should be used—peak clipping, compression limiting, or a combination of the two?

2. How should the maximum output level be adjusted?

Let us first examine what happens when a speech signal reaches the maximum output of a hearing aid and what consequences it has for the aid wearer. The processes are different for compression limiters and peak clippers.

I) Output limiting compression or compression limiting

A compression limiter is an amplifier whose gain is reduced once the output of the amplifier exceeds a certain limit. When the compressor is limiting, every 1 dB increase in input level causes an additional 1 dB gain reduction, so that the output level remains unchanged.

If the hearing aid has just one limiter that is shared by all the frequencies within a speech signal, limiting causes the gain to be reduced for all components in the signal. Similarly, all components within the signal contribute to the level coming out of the limiter and hence jointly determine whether or not limiting is occurring. In short, an excessive amount of compression limiting should be avoided. A small amount of limiting is, however, almost imperceptible (Hawkins & Naidoo, 1993).

Compression limiting hearing aids have two main features, a high compression knee-point and a high compression ratio. Low-level sounds are amplified linearly, but the inputs from moderate to intense sounds are squashed into narrower range of outputs (Dillon, 2001). A high compression ratio is usually defined as being greater than 5:1 (Dillon, 1998).

ii) Peak Clipping

For peak clipping, the conclusions are similar, although the mechanisms are different and the effect of clipping on speech quality is more pronounced (Hawkins & Naidoo, 1993; Storey et al. 1998).

• When signal components in one frequency band are clipped, all signal components that are present simultaneously are clipped.

• Wide band speech will be clipped even though individual components of the signal are at a level lower than the SSPL at that frequency. The consequences of peak clipping are more audible. Clipping adds new frequencies to the signal, and this is heard as distortion, at least by people with mild and moderate loss, and by some people with severe and profound loss (Storey et al. 1998). Because saturation is more audible when it is caused by peak clipping than when it is caused by compression limiting, SSPL selection is less critical for compression limiting than for peak clipping. In particular, the minimum acceptable value of SSPL is lower for compression limiting (Storey et al. 1998).

b) Wide dynamic range compression (WDRC)

WDRC hearing aids have become extremely popular during the past several years. WDRC is associated with low compression knee-points (below 55 dBSPL) and compression ratio (less than 5:1). The WDRC hearing aid is almost always in compression. It can be seen that many different input levels, from very soft speech to very loud speech, will put the hearing aid in compression. Perhaps it is called wide dynamic range compression because of its low knee-point, which allows compression to take place over a wide range of input levels.

The two different types of WDRC are 1) bass increase at low levels (BILL), with a low knee-point for the low frequencies and a higher knee-point for the high frequencies.2) treble increase at low-level (TILL), in which the knee-points is set at a high input SPL for the low frequencies and at a lower input SPL for the high frequencies (Killion, Staab & Preves, 1990).

In wide dynamic range compression (WDRC), the hearing aid gradually reduces gain as input level rises above a mid input level and gradually increases gain as input level decreases below a mid input level.

Advantages of WDRC

While compression limiting can prevent sounds from being so loud as to cause discomfort, a hearing aid that has limiting as its only form of compression will cause Signals to be very loud very often. A more comfortable result can be obtained with WDRC.

Disadvantages of WDRC

A compressor increases its gain whenever the input level decreases. Unfortunately, the compressor cannot tell the difference between a weaker sound that the aid wearer would like to hear and a weaker sound that the aid wearer would rather not hear. Consequently, if background noise has a level lower than speech, the compressor will amplify the noise (when it is present without the speech) more than it amplifies the speech. The extent to which this happens is reduced if the attack and release times are very long or if the hearing aid is able to recognize that the sound is indeed noise and instruct the compressor not to increase the gain. Because an aid wearer may consider a sound to be noise on one occasion, but a signal of some interest on another occasion, there is obviously a limit to how well the hearing aid can judge whether gain should be increased for soft sounds.

A second disadvantage is that whenever the gain of a hearing aid is increased, so is the potential for feedback oscillation. This does not represent a problem if the hearing aid has a sufficiently high feedback margin, but otherwise can result in the hearing aid whistling whenever the aid wearer is in a quiet environment.

3) Static aspects of compression

a) Prescription of Compression Threshold

One solution to the above disadvantages is to make the compressor active only for medium- and high-level signals, and to revert to linear amplification for low-level signals. That is, the compression threshold is set to a medium level (e.g., 60 dB SPL) rather than a low level (e.g., 40 dB SPL). Although this removes one of the advantages of WDRC, many patients prefer these medium compression thresholds to lower ones.

This has been experimentally evaluated in two studies using single- channel compression with a 2:1 compression ratio. In one study, 14 out of 16 subjects preferred a compression threshold around 66 dB SPL to one around 40 dB SPL (Barker & Dillon 1999). In the second study, 84 out of 140 subjects preferred a compression threshold of 66 dB SPL to one of 50 dB SPL, 43 subjects preferred the lower compression threshold and 13 subjects had no preference (Dillon et al. 1998).

In both studies, the subjects wore multimemory hearing aids, with one compression threshold in each memory, in their own environment for at least a month before deciding on which amplification option they preferred[13] possible that different results would have been obtained with multichannel compressors, but at the very least, we should not assume that a low-compression threshold would be better for patients than a medium-compression threshold.

For adults and older children, it seems reasonable to start with a compression threshold between 50 and 60 dB SPL, and be prepared to vary this depending on their subjective reports. For younger children, where no useful reports can be obtained, it seems wisest to avoid very low or very high compression thresholds.

b) Compression Ratio

Compression ratio is defined as the change in input level needed to produce a 1 dB change in output level.

Compression ratios are the amount of the compression provided by the hearing aid once the compression circuit is activated. Compression ratio can be visualized on an input/output graph by the slant (slope) line after the kneepoint. E.g.; 10:1, in a compression ratio the first number typically refers to the input and the second number refers to the output. A 10:1

compression ratio means that, for every 10 dB increase of input SPL, there is only a 1 dB corresponding increase of the output SPL.

Compression ratio characterizes the amount of compression or automatic gain adjustment that will occur. The formula for calculating ratio is change in input / change in output. If input level increases 20 dB while output level increases 10 dB (20/10 = 2), the compression ratio is 2:1. Ratios are always expressed relative to 1. For every 2 dB increase in input, you will have a 1 dB increase in output. Another example shows a 20 dB increase in input with only a 2 dB increase in output. This would be a 10:1 compression ratio (20/2 = 10).

Linear compression could have two different meanings: 1) a 1:1 compression ratio, meaning linear gain and 2) a compression scheme where the compression ratio is fixed. For example, it will always be 1.8:1 as long as you are in compression. The opposite of this would be curvilinear compression.

Curvilinear compression is a type of compression where the ratio varies with the input level. Typically, as the input level increases, the compression ratio also increases.

Expansion is greater than linear gain. Therefore, if linear is 1:1 (for every 1 dB increase in input there is 1 dB increase in output) and compression is 2:1 (for every 2 dB increase in input there is a 1 dB increase in output) expansion is .5:1 (for every half dB increase in input there is full dB increase in output).

The compression ratio(s) selected for a WDRC hearing aid are a direct result of the rationale behind the use of compression and of the specific prescription procedure used. All nonlinear prescription procedures are to some extent based on the concept of normalizing loudness— that is, enabling the person with a hearing impairment to hear any sound at the same loudness at which it would be perceived by someone with normal hearing.

Complete loudness normalization would result in a sound at threshold for a person with normal hearing to also be at threshold for every person with a hearing impairment. Similarly, a sound that just caused discomfort to a person with normal hearing would also just cause discomfort to a person with a hearing impairment. Most procedures include some variation from loudness normalization within either their philosophy or their implementation.

• **Fig. 6** does not attempt to make audible sounds that lie within 20 dB of normal threshold (Killion & Fikret-Pasa, 1993). This decreases the compression ratio needed for low-level sounds, relative to that required for loudness normalization.

• **International Hearing Aid Fitting Forum (IHAFF)** does not require a compression threshold any lower than that needed to amplify soft speech to normal loudness (Cox, 1995). Amplification thus reverts to linear for low-level sounds.

• **DSL (i/o)** maps an extended dynamic range of inputs rather than a normal dynamic range into the dynamic range of the person with a hearing impairment (Cornelisse, Seewald & Jamieson, 1995). This increases the compression ratio relative to loudness normalization. As with IHAFF, amplification reverts to linear amplification below whatever compression threshold is chosen by the clinician.

• **ScalAdapt** decreases the gain applied to low-frequency signals, relative to that required for loudness normalization, to decrease the dominance of low-frequency sounds and upward spread of masking that would otherwise occur (Kiessling, Schubert & Archut, 1996).

All of these procedures apply their variation of loudness normalization to all narrow band sounds. The first three procedures mentioned should therefore approximately re-create the normal relationship between the loudness of low-frequency sounds and high-frequency sounds for both narrow band and complex sounds. That is, low-frequency sounds will be louder than high-frequency sounds.

The NAL-NL1 procedure applies loudness normalization to the overall loudness of sound, but balances loudness between the frequencies in such a way that the calculated speech intelligibility index is maximized. The effect is to prescribe lower compression ratios than are prescribed by the other procedures.

There are other differences between the prescriptions (Dillon, 2000). There is little experimental evidence as to what compression ratios should be. We know it is possible to make them too high. If compression ratios are high enough to fit the full 30 dB dynamic range of speech into a narrower dynamic range of hearing, and if this is done with multiple narrow bands in the hearing aid, speech intelligibility suffers (De Gennaro, 1986). It is not hard to see why this happens. In the extreme case of very high compression ratios and many narrow bands, all speech sounds are compressed into the same spectral shape, thus destroying spectral shape cues that help identify the place of articulation of speech sounds.

Knowledge about compression ratio and presentation levels is important because these factors may interact to affect speech recognition. High presentation levels influence several facets of auditory processing, including speech recognition and discrimination, frequency and temporal resolution and upward spread of masking (Egan & Hake, 1950; Dorman & Dougherty, 1981; Moore & Glasberg, 1987; Studebaker, 1999).

Several researchers have shown that speech recognition is degraded when speech is presented at high levels at some signal to noise ratios (SNRs). In addition, SNR appears to interact with presentation level to affect speech recognition performance. (French & Steinberg, 1947; Pollack & Pickett, 1958; Goshorn & Studebaker, 1994; Studebaker, 1999).

Neumann and colleagues (1994) showed that sound quality preferences of hearing-impaired listeners were significantly affected by compression ratio, the competing noise type and level, and the dynamic range of the listener. Lower compression ratios were judged to have significantly better sound quality than compression ratios greater than 3:1. Background noise level was found to interact with compression ratio.

Fikret-Pasa (1994) reported that there were considerable variations in performance with different compression ratios (2:1, 3:1 and 8:1) among with similar hearing sensitivity.

When compression is applied independently in multiple frequency channels the spectrotemporal variations of speech can be severely altered, particularly at high compression ratios. This may have a large negative impact on speech recognition (Plomp, 1994).

Hohmann and Kollmeier (1995) reported a negative effect of fast-acting compression, compared to linear processing, on speech intelligibility under some conditions. These authors used a 23 - band phonemic compressor to examine the effects of multiband compression, compression ratio and SNR on speech intelligibility. They showed only a small decrease in intelligibility, compared to linear processing, with a SNR of - 2 dB and compression ratios up to 3:1. At a SNR of - 8, however, performance dropped by over 20% when the compression ratio increased from linear (1:1) up to 3:1.

Crain and Yund (1995) found stop consonant discrimination decreased, compared to linear processing, when normal-hearing subjects listened to speech processed at a 4:1 compression ratio using an eight-channel fast-acting compression system.

Hornsby and Ricketts (2001) examined the interactive effects of signal-to-noise ratio (SNR), speech presentation level, and compression ratio on consonant recognition in noise. Nine subjects with normal hearing identified CV and VC nonsense syllables in a speech-shaped noise at two SNRs (0 and +6 dB), three presentation levels (65, 80, and 95 dB SPL) and four compression ratios (1:1, 2:1, 4:1, and 6:1). Stimuli were processed through a simulated three-channel, fast-acting, wide dynamic range compression hearing aid. Consonant recognition performance decreased as compression ratio increased and presentation level increased. Interaction effects were noted between SNR and compression ratio, as well as between presentation level and compression ratio. Performance decrements due to increases in compression ratio were larger at the better (+6 dB) SNR and at the lowest (65 dB SPL) presentation level. At higher levels (95 dB SPL), such as those experienced by persons with hearing loss, increasing compression ratio did not significantly affect speech intelligibility.

Boike and Souza (2000) measured sentence recognition and sound quality at a fixed level of 80 dB SPL using speech processed through a simulated single-channel compression system with compression ratios ranging from 1:1 to 10:1. In this condition, no decrease in speech recognition was observed for the normal-hearing subjects. In contrast, performance for the hearing-impaired group fell by about 30% as the compression ratio was increased from 1:1 to 10:1.

Goldstein et al. (2002) did Clinical experiments with 32 experienced hearing aid users to determine subjective loudness preferences and objective intelligibility performance for alternative compression prescriptions. Two prescriptions were presented, high and low CR. Intelligibility scores for low probability Speech In Noise (SPIN test), where correct reports of the final words of sentences are scored. The speech to the hearing aid was at 70 dB SPL and 8 dB SNR. Eight prescriptions were tested for each patient, four with low and four with high CR. Prescription with low compression ratio provides significantly better (<1% t- test) speech performance for all preference groups (12 CRlo, 11CRhi, 9 either).

The increasing presentation levels and compression ratios can, independently, have a negative effect on speech recognition. It has demonstrated that both level and compression ratio interact with other factors (e.g., SNR) to affect speech intelligibility (Yond & Buckles, 1995b; Studebaker, 1999).

METHOD

Subjects

Thirty post-lingual hearing-impaired subjects satisfying the following criteria were included in the study

1) With mild to moderately severe sensorineural type of hearing loss in the ear tested (symmetrical and asymmetrical hearing loss)

2) With speech identification scores above 60% or more in the test ear

3) Age ranging from 18-50 years

4) Naïve hearing aid users

5) Native speakers of Kannada

Stimulus

The Phonetically Balanced word list in Kannada developed by Yathiraj and Vijayalakshmi (2005) was used in this study. The speech material consists of eight phonetically balanced word lists & each list has twenty-five words. All the eight lists were used in this study.

Instrumentation & test set up:

- A calibrated dual channel diagnostic audiometer (GSI 61) and a calibrated immittance meter (GSI-TYMPSTAR) were used to recruit subjects.
- A calibrated dual channel audiometer (MAICO MA 53) with two sound field speakers (MAICO) was used for hearing aid testing.
- The DVD player (Philips, DVD729K) was connected to both the channels of the audiometer to present speech material.

- All the testing, both for selecting subjects and for experimental purposes were conducted in an air conditioned, acoustically treated single or double room set up. The ambient noise levels inside the test room were within permissible limits (re: ANSI S3.1 1991, as cited IN Wilber, 1994).
- A Pentium IV computer along with NOAH-3 and CONNEX (V5.0a) software Hi-pro (for connecting the hearing aid with the computer) was used for programming the hearing aid.

Hearing aid description

A non-linear digital behind-the-ear hearing aid with the following features was used in this study

1. 4 compression channels,
2. Compression threshold: from 37 to 69 dB and ‘off,
3. Compression ratio: from 1.33 to 4.0 and ‘off,
4. With the facility to select dual or syllabic compression.

Prescriptive formula used

For fitting the hearing aid to the subject, National Acoustic Laboratory Non linear1 (NAL-NL 1) prescriptive formula was used, as this was the default fitting formula for the hearing aid.

Procedure

- Routine audiological examination was carried out for each individual .The subjects fulfilling the stated criteria were included in the study.

- Pure tone thresholds (from 250 HZ to 8 KHz for air conduction and from 250 Hz to 4 kHz for bone conduction) of the test ear were fed into the NOAH software.
- The subject was made to sit comfortably.
- The subject was fitted with the hearing aid on the test ear using an appropriately sized ear tip.
- The hearing aid was connected to the Hi-pro that was in turn connected to a computer with the programming software.
- The hearing aid was detected by the connex (V5.0) software after switching on the hearing aid.
- The following general settings were selected for the first fit.
    - Test ear (right ear or left ear)
    - Acclimatization level: two (as all the subjects were naïve hearing aid users)
    - Prescriptive formula: NAL-NL1
    - Acoustical and other parameters were set to default setting.
- Compression option was selected for changing the compression ratios.
    - The target gain curve was used which is set by the software.
    - The syllabic compression was selected for all the channels.
    - The compression ratio is changed equally for all the channels.

CONDITION 1 (compression ratio at 1.33)

- After getting the target gain, compression ratio was set to 1.33 & save the settings.
- Hearing aid was fitted to the subject.

- The two PB word lists (each list consists of 25 words, totally 50 words) were presented through the loud speakers at 45 dB input level in quite condition.
- The subject is instructed to repeat the words after he heard and the tester noted down the responses in a response sheet.
- Then present the stimulus at 80 dB input level. The tester noted down the responses.
- In speech identification testing, each correct response was given the score of one, and the total number of correct responses was noted down for each condition for each subject.

CONDITION 2 (compression ratio at 2.00)

- Compression ratio was changed to 2.00 & save the settings.
- Test at 45 dB and 80 dB input levels.
- Note down the responses

CONDITION 3 (compression ratio at 4.00)

- Compression ratio was changed to 4.0 & save the settings.
- Test at 45 dB and 80 dB input levels.
- Note down the responses

Results

The data obtained from thirty sensorineural hearing loss subjects were analyzed to investigate the effect of compression ratio (1:1, 2:1, and 4:1) on speech recognition scores (SRS).SPSS, Statistical Package for Social Sciences, (version 10) for windows was used to analyze the following:

1) Effect of severity on Speech Recognition scores within each compression ratio & at each intensity level
2) Each group was separately analyzed for
    a) Effect of three compression ratios (1:1, 2:1, and 4:1) at 45 dB and 80 dB input levels on Speech recognition Scores
    b) Effect of intensity levels (45 dB & 80 dB) on Speech recognition Scores at each compression ratio

Statistical tools used to analyze the data:

i) One way ANOVA was used to see the Effect of severity on Speech Recognition scores at each compression three compression ratios (1:1, 2:1, and 4:1) at 45 dB and 80 dB
ii) Repeated measure ANOVA was done to compare the Speech Recognition scores among three compression ratios at 45 dB and 80 dB
iii) Paired sample test (t-test) was done to compare the Speech Recognition scores at each compression ratios at two input levels (45 dB & 80 dB).

1. **Effect of Severity on Speech Recognition scores at each Compression Ratio & at each intensity level:**

Table 1: Mean, Standard deviation (SD) of Speech Recognition Scores at each Compression Ratio at two input levels among three hearing loss groups

Compression ratio	Input level	severity	Mean	SD
1:1	45 dB	Mild	98.20	2.74
		Moderate	93.80	3.82
		Mod. severe	78.00	6.93
	80 dB	Mild	97.60	2.46
		Moderate	88.60	4.72
		Mod. severe	72.00	6.86
2:1	45 dB	Mild	97.80	2.90
		Moderate	90.60	4.53
		Mod. severe	70.20	7.51
	80 dB	Mild	96.40	2.27
		Moderate	87.40	4.22
		Mod. severe	67.00	6.48
4:1	45 dB	Mild	95.40	3.78
		Moderate	87.40	4.99
		Mod. severe	64.20	5.29
	80 dB	Mild	92.80	4.34
		Moderate	82.60	2.32
		Mod. severe	60.40	4.88

The mean speech recognition scores (SRS) of three groups of hearing loss as a function of compression ratio, intensity level are presented in table 1.The results revealed that speech recognition scores decreased in all groups of hearing loss as compression ratio is increased from 1:1 to 4:1 and there was a decrease in SRS when input level increased from 45 to 80 dB input level.

Table 2: Comparison of SRS among the groups at each compression ratio and at two input level (One-way ANOVA test).

Compression ratio	Input level	F(2,27)	Sig. (P value)
1:1	45 dB	48.268	<.001
	80 dB	67.084	<.001
2:1	45 dB	72.094	<.001
	80 dB	104.768	<.001
4:1	45 dB	117.316	<.001
	80 dB	171.366	<.001

The One-way ANOVA shows that there was a significant difference (P<0.001) across all the groups at each compression ratio at two input levels.

The Tukey's post hoc analysis was done to compare the groups at each compression ratio at each input level. The results showed that at 1:1 compression ratio at 45 dB level there was no significant difference between mild and moderately severe hearing loss groups (at 0.05 level).in all other compression ratios and at 45 dB& 80 dB there was significant difference (at 0.05 level).

a) Effect of 1:1, 2:1 and 4:1 compression ratios on speech recognition scores in mild sensorineural hearing loss at 45 dB and 80 dB input levels.

i) At 45 dB input level

Table 3: Mean and SD of the SRS at three compression ratios (1:1, 2:1 and 4:1) at 45 dB input level.

Severity	Compression Ratio	Mean	Std.deviation
Mild	1:1	98.20	2.74
	2:1	97.80	2.60
	4:1	95.40	3.78

The mean speech recognition scores in mild hearing loss group as a function of compression ratio at 45 dB input level were presented in table 3.The results shows that there was decrease in SRS when compression ratio is increased from 1: to 4:1

Repeated measure ANOVA was done to compare the speech recognition scores between three compression ratios (1:1, 2:1 and 4:1) at 45 dB presentation level. The results revealed that there was a significant difference between speech recognition scores between three compression ratios, [F (2, 18) =9.214, P<0.001].

Table 4: Pairwise comparison between three compression ratios (Bonferroni's multiple comparison test)

(I) 45 dB	(J) 45 dB	Mean Difference (I-J)	Sig.
1:1	2:1	.400	1.000
	4:1	2.800*	.020
2:1	1:1	-.400	1.000
	4:1	2.400*	.039
4:1	1:1	-2.800*	.020
	2:1	-2.400*	.039

* The mean difference is significant at the .05 level.

The results from table 4 revealed that there was a significant difference between 1:1 & 4:1 and 2:1 & 4:1 ($P<0.05$), but there was no significant difference between 1:1 and 2:1 ($P>0.05$).

ii) At 80 dB input level:

Table 5: the Mean and SD of the speech recognition scores at three compression ratios (1:1, 2:1 and 4:1) at 80 dB input level.

Severity	Compression Ratio	Mean	Std.deviation
Mild	1:1	97.60	2.46
	2:1	96.40	2.27
	4:1	95.40	3.78

The mean speech recognition scores in mild hearing loss group as a function of compression ratio at 80 dB input level were presented in table 5. The results shows that there was decrease in SRS when compression ratio is increased from 1:1 to 4:1

Repeated measure ANOVA was done to compare the speech recognition scores between three compression ratios (1:1, 2:1 and 4:1) at 80 dB presentation level. The results revealed that there was a significant difference between Speech recognition scores between three compression ratios, [$F(2, 18) = 12.687$, $P<0.001$].

Table 6: Pairwise comparison between three compression ratios at 80 dB input level (Bonferroni's multiple comparison test).

(I) 80 dB	(J) 80 dB	Mean Difference (I-J)	Sig.
1:1	2:1	1.200	.334
	4:1	4.800*	.008
2:1	1:1	-1.200	.334
	4:1	3.600*	.025
4:1	1:1	-4.800*	.008
	2:1	-3.600*	.025

* The mean difference is significant at the .05 level

The results from table 6 revealed that there was a significant difference between 1:1 & 4:1 and 2:1 & 4:1 ($P<0.05$), but there is no significant difference between 1:1 & 2:1 ($P>0.05$).

Table 7: The comparison of SRS at two input levels at each compression ratio [Paired sample test (t-test)].

Compression ratio	t	df	Sig. (2-tailed)
CR1:1(45 dB) & CR1:1(80 dB)	.709	9	.496
CR2:1(45 dB) & CR2:1(80 dB)	1.769	9	.111
CR4:1(45 dB) & CR4:1(80 dB)	4.993	9	.001

Paired sample test (t-test) was carried out to see the differences between two input levels at each compression ratios. The results from table 7 reveled that at compression ratio 1:1[t (9) =0.709, P>0.05] and 2:1 [t (9) =1.769, P>0.05), there is no significant difference between 45 dB and 80 dB, where as at compression ratio 4:1 [t (9) =4.993, P<0.01] there is a significant difference between 45 and 80 dB.

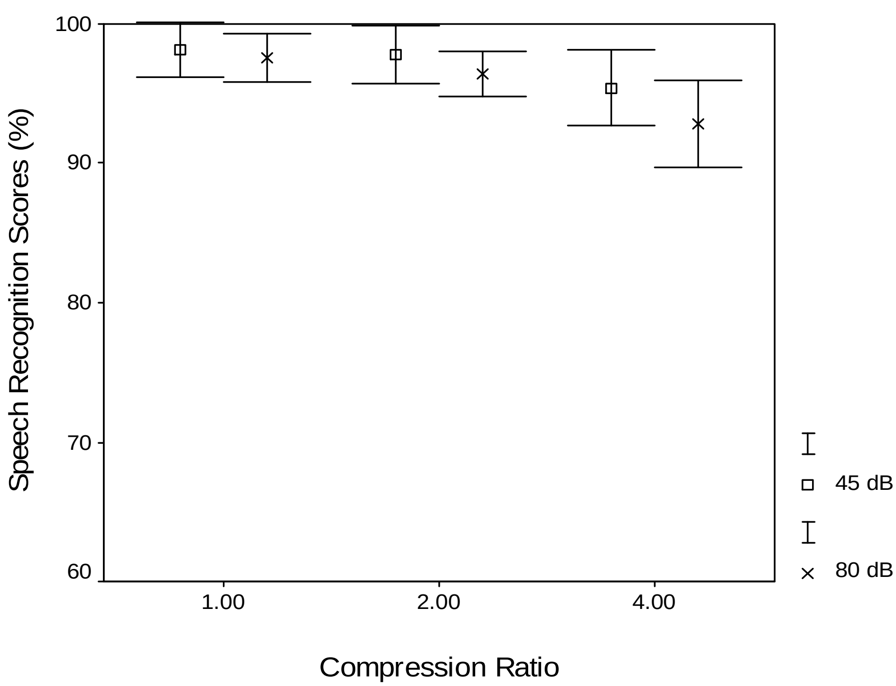

Figure 1: Mean, SD of the Speech Recognition Scores at three Compression Ratios (1.1, 2.1, and 4.1) at two input levels (45dB & 80 dB).

The figure 1 shows that three was no much difference in the SRS at 1:1 & 2:1 compression ratios, where as when compression ratio was increased to 4:1 the SRS scores are decreased.

b) Effect of 1:1, 2:1 and 4:1 compression ratios on speech recognition scores in moderate sensorineural hearing loss at 45 dB and 80 dB input levels.

i) At 45 dB input level

Table 8: Mean and SD of the SRS at three compression ratios (1:1, 2:1 and 4:1) at 45 dB input level.

Severity	Compression Ratio	Mean	Std.deviation
moderate	1:1	93.80	3.82
	2:1	90.60	4.53
	4:1	87.40	4.99

The mean speech recognition scores in moderate hearing loss group as a function of compression ratio at 45 dB input level were presented in table 8.The results shows that there was decrease in SRS when compression ratio is increased from 1:1 to 4:1

Repeated measure ANOVA was done to compare the speech recognition scores between three compression ratios (1:1, 2:1 and 4:1) at 45 dB presentation level. The results revealed that there was a significant difference between SRS between three compression ratios, [F (2, 18) =22.887, P<0.001].

Table 9: Pairwise comparison between three compression ratios (Bonferroni's multiple comparison test)

(I) 45 dB	(J) 45 dB	Mean Difference (I-J)	Sig.
1:1	2:1	3.200*	.014
	4:1	6.400*	.000
2:1	1:1	-3.200*	.014
	4:1	3.200*	.032
4:1	1:1	-6.400*	.000
	2:1	3.200*	.032

* The mean difference is significant at the .05 level.

The results from table 9 revealed that there was a significant difference between 1:1 & 4:1, 2:1 & 4:1 and 1:1 & 2:1 (P<0.05).

i) At 80 dB input level

Table 10: Mean and SD of the SRS at three compression ratios (1:1, 2:1 and 4:1) at 45 dB input level.

Severity	Compression Ratio	Mean	Std.deviation
moderate	1:1	88.60	4.72
	2:1	87.40	4.22
	4:1	82.60	2.32

The mean speech recognition scores in moderate hearing loss group as a function of compression ratio at 80 dB input level were presented in table 10. The results shows the SRS were decreased as compression ratio is increased from 1:1 to 4:1

Repeated measure ANOVA was done to compare the speech recognition scores between three compression ratios (1:1, 2:1 and 4:1) at 80 dB presentation level. The results revealed that there was a significant difference between SRS between three compression ratios, [$F(2, 18) = 8.062$, $P<0.001$].

Table 11: Pairwise comparison between three compression ratios (Bonferroni's multiple comparison test)

(I) 80 dB	(J) 80 dB	Mean Difference (I-J)	Sig.
1:1	2:1	1.200	1.000
	4:1	6.000	.015
2:1	1:1	-1.200	1.000
	4:1	4.800	.018
4:1	1:1	-6.000	.015
	2:1	-4.800	.018

* The mean difference is significant at the .05 level

The results from table 11 showed that there was a significant difference between 1:1 & 4:1 and 2:1 & 4:1 ($P<0.05$), but there was no significant difference between 1:1 and 2:1($P>0.05$).

*Table 12: Comparison of SRS at two input levels at each compression ratio (*Paired sample test (t-test).

Compression Ratio	t	df	Sig. (2-tailed)
CR1:1(45 dB) & CR1:1(80 dB)	5.212	9	.001
CR2:1(45 dB) & CR2:1(80 dB)	3.073	9	.013
CR4:1(45 dB) & CR4:1(80 dB)	3.882	9	.004

Paired sample test (t-test) was carried out to see the differences between two input levels at each compression ratios. The results from table 12 showed that at compression ratio 1:1[t (9) =5.212, P<0.05], 2:1 [t (9) =3.073, P<0.05) and at 4:1 [t (9) =3.882, P<0.05] there is a significant difference between 45 and 80 dB.

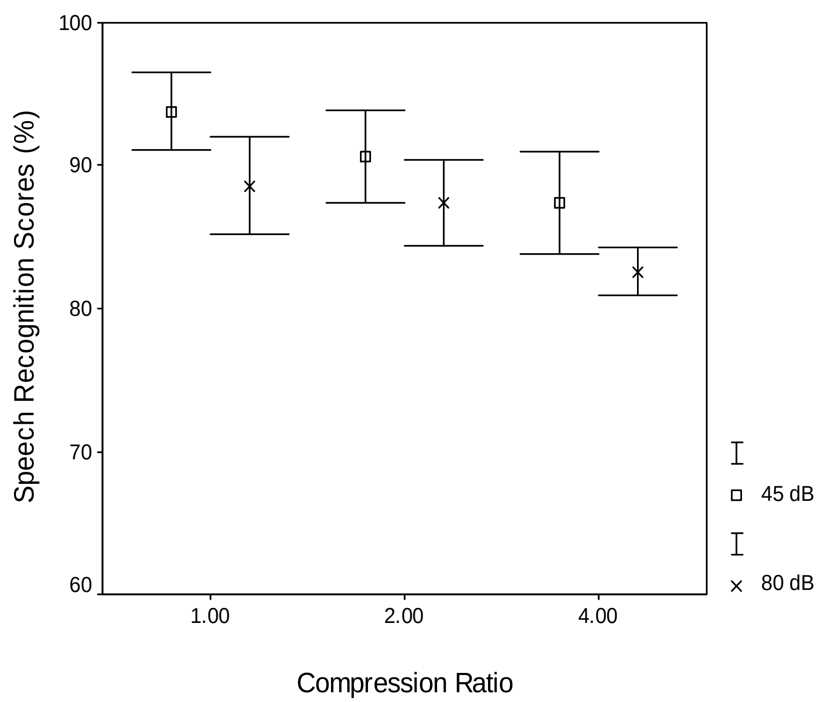

Figure 2: Mean, SD of SRS at three Compression Ratios (1.1, 2.1, and 4.1) at two input levels (45dB & 80 dB).

Figure 2shows that as compression ratios increased from 1:1 to 4:1, the SRS scores were decreased.

c) Effect of 1:1, 2:1 and 4:1 compression ratios on speech recognition scores in moderately severe sensorineural hearing loss at 45 dB and 80 dB input levels.

i) At 45 dB input level

Table 13: Mean and SD of the SRS at three compression ratios (1:1, 2:1 and 4:1) at 45 dB input level.

Severity	Compression Ratio	Mean	Std.deviation
moderate	1:1	78.00	6.93
	2:1	70.20	7.51
	4:1	64.20	5.29

The mean speech recognition scores in moderately severe hearing loss group as a function of compression ratio at 45 dB input level are presented in table 13. The result shows that the SRS were decreased as compression ratio is increased from 1:1 to 4:1.

Repeated measure ANOVA was done to compare the speech recognition scores between three compression ratios (1:1, 2:1 and 4:1) at 45 dB presentation level. The results revealed that there was a significant difference between SRS between three compression ratios, [F (2, 18) =71.980, P<0.001].

Table 14: Pairwise comparison between three compression ratios (Bonferroni's multiple comparison test)

(I) 45 dB	(J) 45 dB	Mean Difference (I-J)	Sig.
1:1	2:1	7.800*	.000
	4:1	13.800*	.000
2:1	1:1	-7.800*	.000
	4:1	6.000*	.004
4:1	1:1	-13.800*	.000
	2:1	-6.000*	.004

* The mean difference is significant at the .05 level

The results from table 14 revealed that there was a significant difference between 1:1 & 4:1 and 2:1 & 4:1 (P<0.05) and 1:1 & 2:1(P<0.05).

i) At 80 dB input level

Table 15: Mean and SD of the SRS at three compression ratios (1:1, 2:1 and 4:1) at 45 dB input level.

Severity	Compression Ratio	Mean	Std.deviation
moderate	1:1	72.00	6.86
	2:1	67.00	6.48
	4:1	60.40	4.88

The mean speech recognition scores in mild hearing loss group as a function of compression ratio at 80 dB input level are presented in table 15. The results shows that there was decrease in SRS when compression ratio is increased from 1:1 to 4:1

Repeated measure ANOVA was done to compare the SRS between three compression ratios (1:1, 2:1 and 4:1) at 80 dB presentation level. The results revealed that there was a significant difference between Speech recognition scores between three compression ratios, [F (2, 18) =65.103, P<0.001].

Table 16: Pairwise comparison between three compression ratios (Bonferroni's multiple comparison test)

(I) 80 dB	(J) 80 dB	Mean Difference (I-J)	Sig.
1:1	2:1	5.000*	.000
	4:1	11.600*	.000
2:1	1:1	-5.000*	.000
	4:1	6.600*	.001
4:1	1:1	-11.600*	.00
	2:1	-6.600*	.001

* The mean difference is significant at the .05 level

The results from table 16 revealed that there was a significant difference between 1:1 & 4:1 and 2:1 & 4:1 (P<0.05) and 1:1 & 2:1(P<0.05).

Table 17: Comparison of SRS at two input levels at each compression ratio (Paired sample test (t-test).

Compression ratio	t	df	Sig. (2-tailed)
CR1:1(45 dB) & CR1:1(80 dB)	7.225	9	.000
CR2:1(45 dB) & CR2:1(80 dB)	5.237	9	.001
CR4:1(45 dB) & CR4:1(80 dB)	10.585	9	.000

Paired sample test (t-test) was carried out to see the differences between two input levels at each compression ratios. The results from table 17 revealed that at compression ratio 1:1[t (9) =7.225, P<0.05], 2:1 [t (9) =5.237, P<0.05) and at 4:1 [t (9) =10.585, P<0.05] there was a significant difference between 45 and 80 dB.

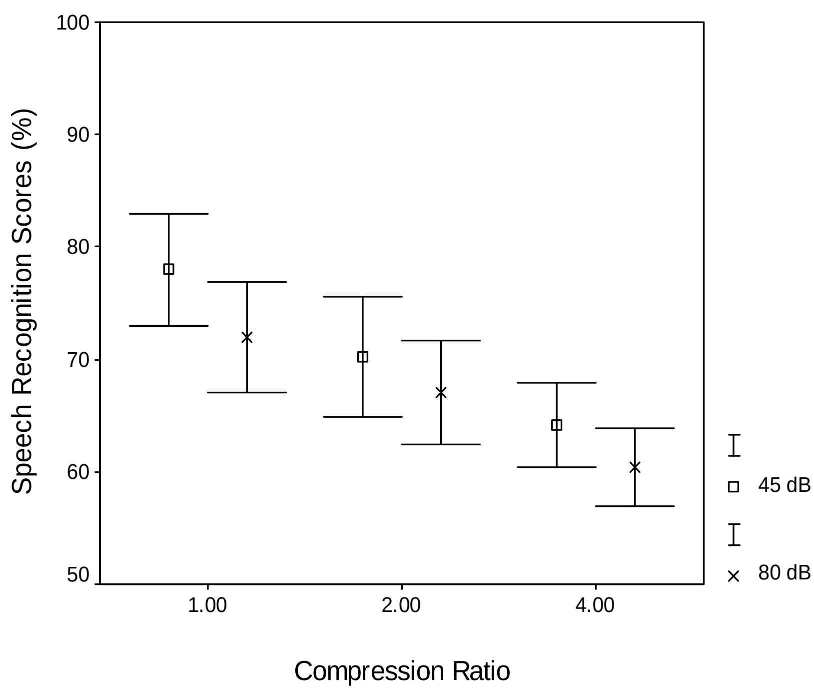

Figure 3: Mean, SD of the SRS at 3 Compression Ratios (1.1, 2.1, and 4.1) at two input levels (45dB & 80 dB).

The figure 3 shows as compression ratios increased from 1:1 to 4:1, the SRS scores were decreased.

Discussion

Results of the study indicate that the Speech Recognition Scores are significantly differ in different hearing loss groups at different compression rations at two presentation levels.

a) Effect of severity on speech recognition scores as a function of 1:1, 2:1 & 4:1 compression ratios at two presentation levels (45 dB & 80 dB) :

In the present study, results showed that the speech recognition scores are decreased in all three groups when the compression ratio was increased from 1:1 to 4:1.

Hornsby and Rickets (2001) found that the consonant recognition performance decreased as compression ratio increased.

Boike and Souza (2000) found that the sentence recognition and sound quality performance fell by about 30% as the as the compression ratio increased from 1:1 to 10:1.They also found that speech recognition scores decreased at higher compression ratios for listeners with hearing loss but not for listeners with normal hearing. This may be due to the alteration of temporal cues at higher compression ratios may have a relatively greater impact on listeners with hearing loss and, presumably, poorer spectral discrimination ability than listeners with normal hearing.

The listeners with sensorineural hearing loss show poorer recognition scores than listeners with normal hearing for compression amplified (Souza & turner, 1996) and linearly amplified speech (Dubno, 1989; Souza & turner, 1994).

For a compression hearing aid, high frequency output levels increased slightly as compression ratio increased. These small changes in the frequency response presumably had a little effect on recognition, particularly since recognition decreased at high compression ratios. When compression ratio is adjusted in a wearable hearing aid, both overall output levels and audibility will vary.

b) Presentation level and compression ratio:

In the present study in all groups there is a decrease in speech recognition scores when intensity level is increased from 45 dB to 80 dB.

High presentation levels influence several facets of auditory processing, including speech recognition and discrimination, frequency and temporal resolution and upward spread of masking (Egan & Hake, 1950; Dorman & Dougherty, 1981; Moore & Glasberg, 1987; Studebaker, 1999).

Several researchers have shown that speech recognition is degraded when speech is presented at high levels at some signal to noise ratios (SNRs). In addition, SNR appears to interact with presentation level to affect speech recognition performance. (French & Steinberg, 1947; Pollack & Pickett, 1958; Goshorn & Studebaker, 1994; Studebaker, 1999).

Research has demonstrated reduced speech recognition when speech is presented at Higher-than-normal levels (e.g., above conversational speech levels), particularly in the presence of speech-shaped background noise (Studebaker et al., 1999).

Hornsby and Ricketts (2001) examined the interactive effects of signal-to-noise ratio (SNR), speech presentation level, and compression ratio on consonant recognition in noise. Consonant recognition performance decreased as compression ratio increased (1:1, 2:1, 4:1 & 6:1) and presentation level increased (65, 80, & 95 dB SPL). Interaction effects were noted between SNR and compression ratio, as well as between presentation level and compression ratio. It has not been clear, however, how these two factors would interact to affect speech recognition. One possible scenario is that high compression ratios and high presentation levels would interact to further reduce speech recognition.

In the present study , Pairwise comparison between 45 and 80 dB input levels shows that in mild hearing loss group there is no significant difference between 45 and 80 dB at 1:1 and 2:1 compression ratio, whereas in other groups there is a significant difference between 45 and 80 dB at each compression ratios.

Neumann and colleagues (1994) showed that sound quality preferences of hearing impaired listeners were significantly affected by compression ratio, the competing noise type and level, and the dynamic range of the listener. Lower compression ratios were judged to have significantly better sound quality than compression ratios greater than 3:1. Sound quality judgments were significantly affected by compression ratio, and dynamic range. Preference decreased with increasing compression ratio. The selection of compression ratios <2:1 was significantly higher than of compression ratios> 3:1.

Future directions:

1. The effect of compression ratio on SRS in presence of noise
2. The effect of compression ratio on speech quality

Summary and conclusion

There has been substantial research examining the effects of many of compression parameters on speech recognition as a function of speech input level. In contrast, very little work has been done examining the effects of various hearing aid parameters as a function of output level at the ear. The compression ratio is the parameter that has the greatest effect on the control of the output level.

Most studies have focused on the comparison between linearly amplified and nonlinearly amplified speech, rather than on the effect of specific compression parameter. Results of these studies have been mixed. For example some studies showed better speech recognition and higher speech quality ratings with WDRC (Humes et al., 1999)or compression limiting (Hawkins & Naidoo, 1993) hearing aids. Conversely other investigators (Walker, 1982; Neumann & bake, 1998; Festen & Houtgast, 1999) noted that speech quality decreased as compression ratio increased above 1:1.finally, Fikret-Pasa (1994) found no effect of compression ratio on speech intelligibility or quality.

It is difficult to reconcile the results of these studies, although differences in amplification systems, fitting procedures, and concomitant parameters have influenced results. For example, Fikret-Pasa (1994) simultaneously varied compression ratio and compression threshold. A more systematic approach is to vary a specific compression parameter while measuring speech recognition and quality.

Knowledge about compression ratio and presentation levels is important because these factors may interact to affect speech recognition. High presentation levels influence several facets of auditory processing, including speech recognition and discrimination, frequency and temporal resolution and upward spread of masking (Egan and Hake, 1950; Dorman and Dougherty, 1981; Moore and Glasberg, 1987; Studebaker, 1999).The increasing presentation levels and compression ratios can, independently, have a negative effect on speech recognition.

Hence the present study aimed at investigating the effect of compression ratio (1:1, 2:1 & 4:1) on the speech recognition as a function of severity (mild, moderate & moderately severe) and intensity level (45 dB & 80 dB).

In the present study, thirty adult subjects with mild to moderately severe sensorineural hearing loss were tested. The Speech Recognition Scores were measured across three compression ratios and at two input levels.

The following conclusions were drawn from the study:

a) There was a significant difference in speech recognition scores in all groups at three compression ratios.
b) The speech recognition scores were decreased when compression ratio is increased from 1:1 to 4:1.
c) The speech recognition scores were decreased when input level is increased from 45 dB to 80 dB.
d) The better speech recognition scores are obtained at low compression ratio

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