Effect of Compression Ratio on Speech Recognition Scores in Subjects with Sensorineural Hearing Loss

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Abstract

Compression ratio is the amount of compression provided by the hearing aid once the compression circuit is activated. This study examined the effect of varying compression ratio on speech recognition scores in subjects with sensori-neural hearing loss. Listeners with mild-to-moderately severe sensori-neural hearing loss participated. The test material was phonetically balanced word list in Kannada (Yathiraj & Vijayalakshmi, 2005). The speech recognition scores were obtained with PB words in quite condition at 45 dB and 80 dB presentation levels. The compression ratio was varied from 1.0 to 4.0. Results indicated that as compression ratio increased from 1.0 to 4.0 the speech recognition scores are decreased. The speech recognition scores also decreased when speech was presented at higher presentation levels i.e., at 80 dB. These results suggest that high compression ratios and high presentation levels would interact to reduce speech recognition.

Introduction

With the increased use of digital signal processing in commercial hearing aids the number of processing parameters available for adjustment has grown substantially. Some multi-channel 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. 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., in a compression ratio 10:1,

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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 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 0.5:1 (for every half dB increase in input there is 1 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.

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).

Many studies have focused on 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.

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) along with similar hearing sensitivity.

When compression is applied independently in multiple frequency channels the spectro-temporal 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 multi-band 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 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, 11 CRhi, 9 either).

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 & Buckles, 1995b; Studebaker, 1999). 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. 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 of 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 and 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 SRS at each compression ratio.

Method

Subjects

Thirty post-lingual hearing impaired subjects with mild to moderately severe sensori-neural type of hearing loss in the ear tested (symmetrical and asymmetrical hearing loss) and with speech identification scores above 60% or more in the test ear participated in the study. Their age range was from 18-50 years. All were naïve hearing aid users and native speakers of Kannada. Pure-tone testing showed no significant air-bone gaps in the test ear and all listeners had normal immittance results.

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 with twenty-five words each. All the eight lists were used in this study.

Instrumentation and 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 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 aid.

Hearing aid description

A non-linear digital behind-the-ear hearing aid with the features of 4 compression channels, compression threshold ranging from 37 to 69 dB and 'off, compression ratio ranging from 1.33 to 4.0 and 'off, and with the facility to select dual or syllabic compression was used in this study. 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. 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. After getting the target gain compression ratio was set to 1.33 and the settings were saved. 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 was instructed to repeat the words after he heard and the tester noted down the responses in a response sheet. Then the stimulus was presented 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. Compression ratio was changed from 1.33 to 2.00 and settings were saved. Speech recognition testing was done at 45 dB and 80 dB input levels and the responses were noted down. Finally compression ratio was changed to 4.0 and speech recognition testing was done at 45 dB and 80 dB input levels and the responses were noted down.

Results and Discussion

The mean speech recognition scores (SRS) of three groups of hearing loss as a function of compression ratio, intensity levels 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 1: Mean, SD of SRS at each C R 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

Table 2: SRS among the groups at each CR 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 (Table 2) 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 and 80 dB there was significant difference (at 0.05 level).

The mean speech recognition scores in mild hearing loss group as a function of compression ratio at 45 dB and 80 dB input level 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 and 80 dB presentation levels. The results revealed that there was a significant difference between speech recognition scores between three compression ratios, [$F(2, 18) = 9.214$, $P<0.001$], [$F(2, 18) = 12.687$, $P<0.001$] respectively.

Table 3: SRS at two input levels at each compression ratio in mild hearing loss groups

Compression ratio	T	df	Sig. (2-tailed)
CR 1:1(45 dB) & CR 1:1(80 dB)	.709	9	.496
CR 2:1(45 dB) & CR 2:1(80 dB)	1.769	9	.111
CR 4:1(45 dB) & CR 4:1(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 ratio. The results from Table 3 revealed 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 whereas at compression ratio 4:1 [t (9) =4.993, P<0.01] there is a significant difference between 45 and 80 dB.

Table 4: SRS at two input levels at each CR in moderate hearing loss group

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

The mean speech recognition scores in moderate hearing loss group as a function of compression ratio at 45 dB and 80 dB input level 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 and 80 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], [F (2, 18) =8.062, P<0.001] respectively.

Paired sample test (t-test) was carried out to see the differences between two input levels at each compression ratios. The results from Table 4 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.

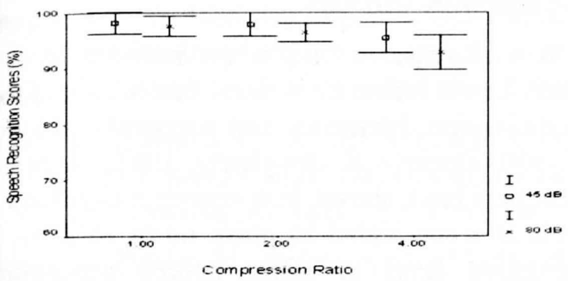
The mean speech recognition scores in moderately severe hearing loss group as a function of compression ratio at 45 dB and 80 dB input level shows that the SRS were decreased as compression ratio is increased from 1:1 to 4:1. Repeated measure ANOVA was done to compare the speech recognition scores between three compression ratios (1:1, 2:1 and 4:1) at 45 dB and 80 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], [F (2, 18) =65.103, P<0.001] respectively.

Table 5: SRS at two input levels at each CR in moderately severe hearing loss group

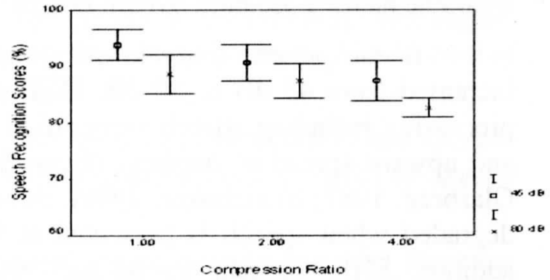
Compression ratio	T	df	Sig. (2-tailed)
CR1:1(45 dB) & CR1:1(80 dB)	7.225	9	.000
CR2:1(45 dB) & CR2:1(80 dB)	5.237	9	.001
CR4:1(45 dB) & CR4:1(80 dB)	10.585	9	.000

Paired sample test (t-test) was carried out to see the differences between two input levels at each compression ratios. The results from Table 5 revealed that at compression ratio 1:1[t (9)

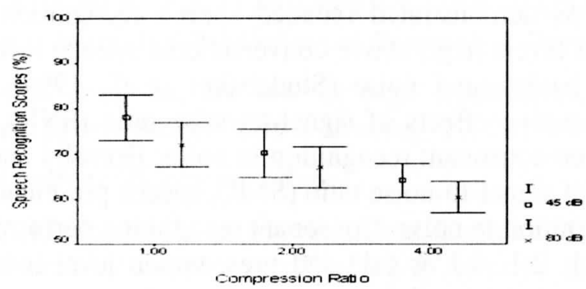
=7.225, P<0.05], 2:1 [t (9) =5.237, P<0.05) and at 4:1 [t (9) =10.585, P<0.05] there was a significant difference between 45 and 80 dB.



A) Mild hearing loss group



B) Moderate hearing loss group



C) Moderately- Severe hearing loss group

Figure1: Speech recognition scores as a function of three compression ratios (1.0,2.0 & 4.0) at two presentation levels (45 dB & 80 dB) for mild, moderate and moderately severe hearing loss groups.

Discussion

Results of the study indicate that the SRS are significantly different in different hearing loss groups at different compression ratios and two presentation levels. In the present study results showed that the SRS 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 compression ratio increased from 1:1 to 10:1. They also found that SRS 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 which 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.

In the present study in all groups there is a decrease in SRS 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. 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 pair wise 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.

Conclusion

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

Further research should focus on these effects in the presence of noise and on speech quality ratings.

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