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AMPLITUDE COMPRESSION FOR SENSORINEURAL DEAFNESS - IS IT WORTH IT?

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1. Introduction

Where the dynamic range of signals input to a hearing aid is wider than the available dynamic range of a patient's hearing, as in sensorineural deafness with cochlear involvement, there is a clear need for some form of amplitude compression, so that output signals are always audible but never uncomfortably loud. Two forms of amplitude compression are investigated here: automatic gain control (AGC) with short attack and decay time constants (of order 10 ms) and RF Carrier Clipping (RF). This is a means of performing peak clipping on the input speech wave, but by modulating a $50kH_z$ carrier with the speech, harmonic distortion products are removed outside the audible band. The system is described in Drysdale and Gregory (1978).

There are important differences between the two compression systems. AGC has finite, though short time constants, whereas RF is instantaneous. Even if the long-term input/output functions of AGC and RF are matched, the former is, at any instant, a linear amplifier which preserves, for example, the input S/N ratio; the latter is a non-linear device which compresses the input S/N ratio at any time.

Doubt has been expressed in the literature, see Lippmann et al (1981) whether AGC compression is necessarily beneficial. Our study was designed to look at that question as well, but its primary objective has been to look at the benefits and drawbacks of the RF system. The comparisons therefore encompass a triad of possible amplification systems (and hearing aids): linear, RF and AGC.

2. Method and results

2(i) The Keele two-alternative forced-choice (2AFC) tests were given to a sample of 13 subjects, each of whom was suffering from sensorineural deafness, with an appreciably reduced dynamic range. The tests are designed to measure discriminability of phonemes which cause the most difficulty to subjects with cochlear impairment: Grose and Pick (1979). Target words were presented monaurally, through TDH-39 headphones. All test words were presented at equal peak amplitudes as measured on a peak programme meter. Background noise, mixed with the targets at the input to the amplifier stage, consisted of four-channel speech babble. All conditions were randomised. The results are given in Table 1.

	S/N ratio = 20dB results for 13ss.			S/N ratio = 10dB results for 9 ss.		
	LIN	RF	AGC	LIN	RF	AGC
no, of mistakes	16.2	14.4	15.5	20.1	21.9	20.6
standard error	± 1.4	± 1.2	± 1.8	± 1.2	± 1.0	± 1.1

Table 1. Error scores for two input S/N ratios. Mean chance expectation = 25 mistakes. Signals at comfortable listening level.

It can be seen that, for the 20dB S/N ratio, RF gives the best performance. The AGC system tested here had a 2:1 compression ratio, so its intermediate performance is not surprising. However, for a 10dB S/N ratio, the order reverses, linear amplification giving fewest mistakes and RF clipping the most. The extent of compression here was 12dB, so in the former case RF left an output S/N level of 8dB; in the latter case, the noise was brought up to the level of the signal.

2(ii) The Stevenson Initial Plosive 2AFC word list, Stevenson and Martin (1977) was given to 32 subjects selected from the records of the Royal National Institute for the Deaf in London. Again, presentation was monaurally via TDH39 headphones. Noise masking was used, this time consisting of pink noise. The R.N.I.D.'s Master Hearing Aid unit provided the linear and AGC amplification, with a peripheral RF device giving the third condition. As before two S/N ratios were used (20dB and 10dB at input). In half the presentations, the words were presented at comfortable listening level (CLL). In the other half, the inputs were attenuated by 20dB. Similar input/output characteristics were used here as in 2(i) but the AGC had a compression ratio of 20:1, not 2:1.

Two dependent variables were measured: error scores and mean reaction time for button press. The apparatus is described in Wright et al (1981). The usual randomisation procedures were used to balance for learning effects and handedness. The results are shown in Table 2.

	INPUTS FOR CLL					
	S/N 20db			S/N 10db		
a. Errors	LIN	RF	AGC	LIN	RF	AGC
(MCE=15)	2.6	3.2	3.0	6.6	6.9	8.0
b. RT (secs.)	0.76	0.78	0.80	0.88	0.92	0.92
	ALL INPUTS ATTENUATED BY 20db					
	S/N 20db			S/N 10db		
a. Errors	LIN	RF	AGC	LIN	RF	AGC
(MCE=15)	5.8	2.9	3.3	7.3	7.0	6.0
b. RT (secs.)	0.93	0.78	0.79	1.01	0.90	0.87

Table 2 (a) Mean error scores for 32 subjects,
(b) Mean reaction times (seconds).

The results of this experiment suggest that, with quiet pink noise, linear amplification gives best results and compression seems to be counterproductive. The reaction time results closely mirror the error scores. However, if the input is attenuated by 20db, compression (which results in a higher output signal, linearly amplified) gives fewer errors and faster reaction times.

A repetition of the experiment on a sample of 8 normally-hearing subjects gave qualitatively similar results though, of course, error scores were lower and reaction times faster by a factor of about 1.5 – 2.

2(iii) Estimation of subjective loudness of pure tones and speech. The 32 subjects participating in (ii) were asked to estimate the subjective loudness of pure tone stimuli at 3 frequencies (0.25, 1 and 4kHz) and of continuous spoken material (female voice) processed through linear, RF and AGC amplification. The stimuli were presented at 5 levels between threshold and loudness discomfort level (LDL). Tones were pulsed, with a 0.58s on/0.58s off cycle. Speech extracts were presented for 5s. Subjects used a standard magnitude estimation procedure.

The results were analysed by fitting regression lines through individual subjects' data points in each of the six experimental conditions (3 tone and 3 speech conditions). The results are given in Table 3. The results shown here are for a log/linear regression of the type

$$\text{Response} = A \log(\text{stimulus}) + B \quad \ldots\ldots\ldots\ldots(1),$$

i.e. a Fechner type response curve. Stevens (power function) curves were also fitted, but the regressions showed no difference in correlation coefficients. Since data averaging is easier in the Fechner case, only those results are given here. Table 4 also gives comparison values for a sample of 8 normally-hearing subjects doing the same tests.

	TONES			SPEECH		
	0.25	1	4kHz	LIN	RF	AGC
Impaired ss.	8.7	7.7	11.9	6.8*)	9.2*)	9.0*)
Normal ss.	5.6	3.8	3.9	5.2	6.6	6.6

*) 30ss

Table 3. "Gradients" ("A" in Equation 1) of tone and speech stimuli presented to 32 impaired and 8 normal subjects. Log-linear regression.

Note that there is clear evidence of loudness recruitment, i.e. the gradients for the impaired subjects are higher than those for normally-hearing subjects. Note that for pure tones, recruitment increases with frequency. For spoken material, amplitude-compressed material gives steeper functions than linear.

An interesting finding concerns the subjective loudness of speech at loudness discomfort level. LDL's were obtained for 13ss, and the results show that RF compressed speech sounds louder by about 16% at LDL than does "linear" speech at LDL. Hence, compression can give a signal which appears louder without being more painful.

2(iv) BKB Sentence Lists. In order to approximate more closely to a task which subjects may perform in real life, sentence lists were presented to a sample of 12 subjects (chosen at random from the original 32 R.N.I.D. subjects). The sentence lists were the Bamford-Kowal-Bench (BKB) standard sentence lists, Bench et al (1979). The stimuli were presented via a loud-speaker positioned in a anechoic chamber. Subjects were given a "behind-the-ear" hearing aid which was connected to the R.N.I.D.'s Master Hearing Aid system. The gain of the linear amplifier was adjusted for each subject using spoken material peaking at 80dB SPL. The gain was then left constant, and sentences were presented peaking at 55, 65, 80 and 95 dB SPL. The experimenter scored responses by picking up the hearing aid's microphone response - this also prevented the possibility of "howling", since the experimenter would instantly detect this.

As well as repeating sentences, subjects rated the apparent difficulty of doing the tests in the 12 conditions (3 types of amplification x 4 levels). Results are given in Table 4. At comfortable listening level (CLL) there is no advantage from compression. However, if the input level to the aid is reduced, intelligibility is better preserved with a compressive system. If the stimuli are presented at 15db above CLL input, performance deteriorates with compression, particularly at RF. It is likely that this is due to the intrusion of distortion products.

Mean error scores (max.50)

	LIN		
55db SPL 45.4(4.8)	65db SPL 32.4(4.3)	80db SPL 9.6(2.8)	95db SPL 6.2(2.2)
	RF		
55db SPL 35.3(4.3)	65db SPL 15.8(3.3)	80db SPL 10.0(3.1)	95db SPL 13.8(3.3)
	AGC		
55db SPL 34.0(4.4)	65db SPL 15.8(3.3)	80db SPL 8.7(2.7)	95db SPL 9.8(2.8)

Table 4. Number of errors, and apparent difficulty (on a 5 point rating scale) - shown in brackets - on BKB sentences. Data for 12 impaired subjects.

4. Conclusions.

The results show that the advantagesof compression systems are the property of rendering audible a wider range of input amplitudes, and the ability to make speech sound louder without sounding more painful. The drawbacks of compression, particularly RF, are a loss of S/N ratio and the production of distortion products. Both these counterindicate the use of compression with high ambient input noise levels. An unqualified "yes" or "no" answer cannot thus be given to the question posed in the title.

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6. References.

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