Frequency Transposition or Nonlinear Compression: which is better for speech?

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Abstract

This study compares two different signal processing strategies implemented in two hearing aids: nonlinear frequency compression using PhonakNaida hearing aid and frequency transposition with Widex Mind hearing aid. Eighteen normal hearing young adults were tested with hearing aids programmed with these two frequency lowering strategies. Subjects were tested with a VCV bisyllabic word test, presented monaurally through the hearing aid. Their performance was tested with each hearing aid in three stimulus conditions: normal speech input with no filtering, low pass filtered speech with high cut set at 2.5 kHz (simulated hearing loss) and frequency processed speech (frequency transposed/compressed speech) with high cut set at 2.5 kHz. In addition to this, a phonemic analysis of responses was carried out to evaluate which processing strategy provided better place and manner of articulation or voicing characteristics. Results showed that, with the hearing aids under frequency processed condition, subjects scored significantly better than simulated hearing loss condition with only low pass filtered speech. The nonlinear frequency compression (Phonak Naida aid) showed better performance on VCV bisyllabic word test than the frequency transposition strategy (Widex Mind aid). This study concludes that in a simulated steeply sloping hearing loss, frequency compression scheme may aid the individual better than a frequency transposition one. In contrast, hearing aid with frequency transposition was found to be better in performance with regard to manner of articulation.

Key words: - Frequency transposition, Nonlinear frequency compression, hearing aid strategies, simulated hearing loss.

Background

Many hearing-impaired individuals, including 24% of those over the age of 60 years, have hearing loss in the high frequency range (Davis, 1995). The severity of high frequency hearing loss adversely affects an individual's speech perception of high frequency consonants such as affricates and fricatives. Certain phonemes such as /s/ and /ʃ/ have significant energy from 4.5 kHz to above 8 kHz (Boothroyd & Medwetsky, 1992; Stelmachowicz, Pittman, Hoover & Lewis, 2001), depending on the age and gender of the speaker; in children and females these frequencies are particularly high. Difficulties in perceiving these sounds can create problems in grammatical distinctions like plurals (cat vs cats), first person vs third person (I sit vs she sits) and possession (Sam vs Sam's), and in differentiating certain words like ship/ chip/ sip. In addition, such hearing loss reduces the quality of life of sufferers by making it difficult to hear music and various other environmental sounds like birdsong or alarms. Children with high frequency hearing loss have limited access to these high frequency acoustic cues, which not only affects their speech intelligibility but also interferes with the development of the spoken language (Bench & Bamford,1979).

Conventional hearing aids, even with the latest digital technology, are unable to provide sufficient gain for high frequency hearing loss, perhaps because of an insufficiently broad bandwidth of amplification in these hearing aids (Stelmachowiczet al., 2001). Sometimes the gain provided by conventional amplification may be inadequate before the hearing aid's acoustic feedback loop starts, yet the most advanced feedback cancellation mechanisms may not be effective enough to eliminate this acoustic feedback. In other cases, people with severe high frequency hearing loss are unable to benefit from amplification of high frequencies, and may even perform more poorly when high frequencies are amplified (Amos & Humes, 2000; Ching et al., 1998; Hogan & Turner, 1998; Moore et al., 2000; Murray & Byrne, 1986; Turner & Cummings, 1999; Villchur, 1973). Moore (2001; 2004) states that some severe

hearing losses can be caused by damaged inner hair cells, preventing frequency-specific decoding. In such cases, high frequency audibility neurons are never activated, even with amplification of high frequencies; instead, nearby lower frequency auditory neurons respond to high frequency stimuli, creating a distortion phenomenon known as off-frequency listening (Johnson-Davis & Patterson, 1979; O'Loughlin & Moore, 1981; Pattereson & Nimmo Smith, 1980; Patterson & Moore, 1986). This makes high frequency amplification worthless in these cases.

Given these limitations of conventional amplification, attempts have been made to devise a processing strategy which improves low frequency amplification while also moving high frequency spectral energies to a lower frequency region where the auditory system is able to decode this recoded high frequency information. Johansson (1961) devised a frequency lowering scheme and incorporated it into the Oticon TP72, the first device transposing high frequencies. It consisted of two channels, in one of which the frequencies from 1.5-3 kHz were amplified as in a conventional hearing aid, while in the other, higher frequencies (4-8 kHz) were converted to values below 1.5 kHz. Since then, a variety of frequency lowering strategies, including channel vocoding (Dudley, 1928), slow playback (Beasley, Mosher, & Orchik, 1976; Davis, 2001), frequency transposition (Johansson, 1961), linear frequency compression (Neary, 1989) and nonlinear frequency compression (McDermott & Dean, 2000), have been incorporated into various devices.

Several studies have evaluated the benefits and drawbacks of each of these strategies, but most of the earlier studies were inconclusive or contradictory, while others showed improvements which were statistically insignificant. These poor outcomes may be because the studies were conducted using devices intended to achieve effective frequency lowering, rather than optimal processing results (Braida et al., 1979). For the purpose of frequency lowering, these strategies even interfered with the vital aspects of sounds which were

considered important for speech perception, like pitch and temporal structure (Ladefoged, 1993). Now, however, technological advances and the development of complex digital signal processing (DSP) algorithms allow all the objectives of frequency lowering strategies to be easily achieved with minimal effects on other aspects, which optimises the fitting of a hearing aid to a particular individual. Two such digitally processed frequency lowering strategies are frequency transposition and nonlinear frequency compression.

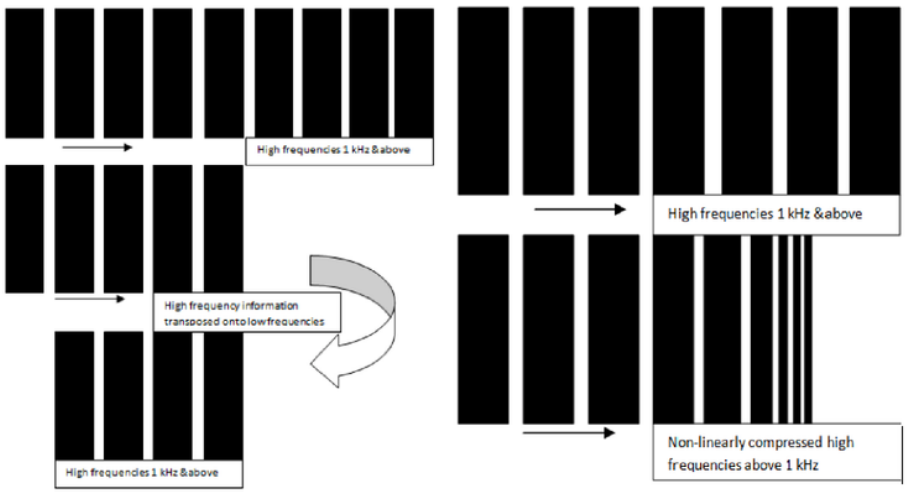

Figure 1: (a) Frequency Transposition; (b) Frequency Compression

In frequency transposition, a high frequency band is selected from the overall input signal and processed so that it is lowered in frequency, then the processed signal is transposed onto the unprocessed low frequency band of the signal, as shown in Figure 1(a). In other words, high frequency sounds are lowered and added to the low frequency signals. This scheme preserves the harmonic relationship between the frequency components and provides a natural sound quality by maintaining perfectly the temporal characteristics of the speech input in the output signal. However, this overlap of high onto low frequencies can distort the output

signal. The Widex mind hearing aid incorporates frequency transposition with a software program known as an audibility extender (Anderson, 2006).

Frequency compression reduces the bandwidth of the outgoing signal, as shown in Figure 1(b); it can be linear or nonlinear. Its advantages include no overlap between the shifted and un-shifted signals. Low- and mid-frequency information is preserved, as all of the first-formant and most of the second-formant frequency range is left unchanged by the processing.

In nonlinear frequency compression, frequency ratios for those high frequencies that are compressed are not preserved; therefore, this scheme preserves vowel intelligibility by preventing the overlap of frequency information, but it does not preserve harmonic relationships between frequency components. Speech perception could therefore be negatively affected if the cut off frequency of compression was decreased to include lower frequencies. The Phonak Naida hearing aid installed with the Sound Recover program is an example of a nonlinear frequency compression enabled device.

A review of the existing literature reveals that very few studies have compared frequency transposition and nonlinear frequency compression using the same design. Thus the present study was aimed to compare the frequency compression and frequency transposition techniques implemented in two different hearing aids. The objectives of the study were:-

a. To compare the performance of two hearing aids, one with frequency compression and the other with frequency transposition in three conditions (normal speech, simulated hearing loss and frequency lowered).
b. To determine which of these provide a better speech identification score.
c. To evaluate the benefits occurring with the use of such frequency lowering strategies in normal hearing participants in comparison with those from a simulated steeply sloping high frequency hearing impairment.

Methods

Participants

Eighteen subjects participated in the study: five males and thirteen females. This sample size was decided after conducting a power analysis of the results obtained from a pilot study of 4 subjects, who were not included in the subsequent study. In order to reduce the effect of familiarity across the 6 conditions, counterbalancing was employed. Subjects were tested monaurally using a VCV bisyllabic word test.

The subjects selected for the study were otologically and neurologically normal adults in the age range of 18-40 years. The selection criterion was set such that the hearing threshold of each participant should be less than 10 dB HL across the frequency range of 250-8000 Hz.

The study was approved by the School of Psychological Sciences Research Ethics Committee and was conducted in soundproof booths at the University of Manchester. All participants were provided with an information sheet and their written consent was obtainedprior to participation.

Equipment for hearing screening

Otoscopy was performed on subjects prior to the tests. All subjects were screened with a Kamplex KLD21 diagnostic audiometer and middle ear status was analysed using a Tympstar tympanometer. The subjects were considered to have passed the screening only if they had a normal tympanogram (A type). Stage A equipment and calibration checks were carried out on all audiometric equipment before testing.

Equipment for hearing aid fitting and validation

Before carrying out the testing on subjects, both hearing aids (Phonak Naida &Widex mind) were programmed with the frequency lowering enabled. The Phonak aid was programmed using Phonak fitting guidelines (iPFG 2.1a) with Sound Recover enabled and the audibility extender of the Widex mind hearing aid was set up using Compass software (v4.7). The programmed settings for the devices were similar, as shown in Table 1. Validation of the outputs of these hearing aids was done by a Bruel and Kjaer 2250 sound level meter using three different input stimuli: broadband noise, speech babble and a 1 KHz tone presented through the audio shoe of the hearing aids. Only audio shoe input presentations were assessed, as stimulus was presented through the audio shoe in the study. The output spectra of the hearing aids were verified, so as to ensure that these devices performed as stated in the manufacturers' specifications.

Stimuli

A VCV bisyllabic word test was used (Baer et al., 2002; Vickers et al., 2001) to assess the ability of the subjects to discriminate consonants. Initially they were presented with the 20 practice samples to familiarise them with the testing conditions and the computer interface. After the presentation of a VCV stimulus the subjects were asked to choose one of the 20 possible consonants displayed on the screen by clicking on the appropriate consonant. The vowel /i/ in initial and final position was combined with each of 20 consonants (/p,t,k,l,m,n,b,v,ch,w,r,t,y,,f,d,s,sh,z,g/). Presentations were done by a British female speaker. The combinations of the vowel and consonants were presented for a total of 90 VCV stimuli in blocks of 10, 20, 20, 20 and 20 items respectively.

Testing procedure

Complete testing was conducted using VCV bisyllabic test software, developed by the MRC Institute of Hearing Research, Nottingham and the Department of Phonetics and Linguistics,

University College London. The VCV stimuli were presented through the hearing aid coupled to the subject monaurally with an ear mould and without vent/horn. The participants were instructed as follows: "If you hear 'ee-B-ee' then press 'B', if you hear 'ee-Sh-ee' then press 'Sh' and do the same for the other letters as well. The words will be presented by a female speaker". The presentation level for the word lists was calibrated at 60 dB for both hearing aids. The output was controlled using an output control at the sound card. The testing procedure consisted of three conditions using each hearing aid and in order to prevent biasing of results due to familiarity and tiring all conditions were counterbalanced across subjects; therefore every condition appeared in every position the same number of times and e.g. condition 1 appeared first as many times as it appeared last. The familiarity effect was reduced by not providing any feedback for the correct and incorrect responses given by the subjects. Three conditions were; normal speech, simulated hearing loss and frequency lowered condition.

1. Normal speech condition

The hearing aids were programmed to provide minimal gain to the input, while outputs were presented at a level comfortable to the listeners (i.e. 60 dB SPL). In this condition the audiogram used for programming the hearing aids was set at 0 dB HL across frequencies from 250 Hz to 8 KHz. This replicated the presentation of stimuli through headphones and represented the maximum scoring capability of the participant on the test. The condition was completed twice with each hearing aid. Ideally, with the headphones, a normal hearing individual should score 100% on the VCV task when presented at a comfortable loudness level, so the same should happen when presented through the hearing aids. If a subject does not achieve a normal score in this condition, this may be due to various factors: the hearing aids are distorting the output signals or the speech perception of the individual being tested is poor, thus this condition will aid in ruling out such possibilities.

2. Filtered speech condition

This stimulus was used to determine baseline scores similar to high frequency hearing loss patients.As in the first condition, both hearing aids were programmed to a flat audiogram with hearing threshold levels at 0 dB HL. Even in this condition there was no gain provided using the hearing aids, while the stimuli used for the test were filtered at high frequencies with the high cut filter placed at 2.5 kHz using Blackman windowing. The stimuli were filtered using Adobe Audition software and the process of filtering was further confirmed by passing the outputs of both hearing aids through a Bruel & Kjaer 2250 sound level meter. This condition was adopted to simulate a steeply sloping high frequency hearing loss above 2.5 kHz, similar to one occurring due to the presence of high frequency/basal cochlear dead regions. This condition was performed to assess whether any of the hearing aids provided better low frequency characteristics and also to re-establish the outcomes (evident errors occurring due to high frequency hearing loss) of a study by Miller and Nicely (1955).

3. Frequency processed condition

This condition was tested with unfiltered VCV bisyllabic word stimuli, but the audiogram configuration used to program the hearing aid was changed to replicate the simulated hearing loss. The hearing thresholds levels from 0.25 kHz-2 kHz were stored at 0 dB HL, while at 3 kHz and above hearing thresholds were set at 120 dB HL. This was done to simulate a steeply sloping high frequency hearing loss. The hearing aids were programmed to nonlinearly compress for Phonak Naida aid or transpose in case of Widex mind hearing aid, the stimulus at high frequencies desirably. Table 1 shows the programmed settings of both the devices.

Table 1: Programmed settings of the hearing aids for condition three

Features	Hearing aid 1	Hearin
Settings	Frequency compression device	Frequency transposition

Fitting program	NAL NL1	NAL NL1
Experience on the hearing aid	Long term user	Long term user
Feedback test	Not performed	Not performed
Programs	P1- FM/Audio shoe input	P1-Master
Compression ratio	4:1	-----
Transposition start frequency	-----	2.5 kHz
Compression start frequency	1.5 kHz	-----
Transposed band	-----	2.5 – 8 kHz
Compressed band	1.5- 2.5 kHz	-----
Audibility extender gain	-----	6
Bass boost	Off	-----

Overall the test procedure took about 1.5 to 2 hours, which included a total of 6 sessions using both hearing aids. The subjects were unaware of which hearing aid was being used and the condition under which they were being tested.

Results

a. Cross-group comparison

The results of the VCV tests completed by the 18 subjects were compared using paired *t*-tests for both the hearing aid groups. Overall correct percentage scores were compared under similar conditions for both hearing aid types.

Normal speech condition (frequency lowering disabled)

Table 2 shows that in paired *t*-tests there was no significant difference between the two hearing aids across overall scores.

Table 2: Mean performance on VCV (±1 SD) for each condition and the results of significance tests

Condition	Mean & SD of Overall Scores (%)	Significance

Normal speech condition		Frequency compression device	Frequency transposition device	(p<0.05)
		93.0(±5.17)	94.4(±3.03)	t(18)= -1.71, p=0.25
Simulated hearing loss	Frequency compression disabled & Filtered input @2.5kHz	38.3(±10.02)		t(18)= 0.97, p=0.34
	Frequency transposition disabled & Filtered input @2.5kHz		36.1(±10.06)	
Frequency lowered condition	Frequency compression enabled	52.7(±8.83)		t(18)= 2.24, p=0.03
	Frequency transposition enabled		49.33(±10.43)	

Filtered speech condition (frequency lowering disabled)

Table 2 shows that in paired *t*-tests, the overall scores of the frequency compression device were higher than for the frequency transposition device but there was no significant difference between the hearing aids on overall scores under condition two.

Frequency processed condition (frequency lowering enabled)

Table 2 shows that under condition three, the frequency compression scheme scored significantly higher on overall scores in paired *t*-tests when compared to the frequency transposition scheme. Table 2 shows slightly better overall percentile correct scores for the frequency transposition device under the normal speech condition. Under the simulated hearing loss condition, the bar graph of the mean percentile scores shows clearly that subjects had better overall scores when using the frequency compression device. Table 2 also clearly shows higher values for the frequency compression device. The overall scores were higher for the frequency compression device and this difference is significant.

b. Phonetic analysis

It was very important to establish whether the phonetic features of place, manner and voicing were affected by the frequency lowering strategy. Sequential information analysis (SINFA)

(Wang and Bilger, 1973) was used to analyse the transmitted information. The input information transmitted for a given feature was determined using the SINFA FIX analysis suite (Mike Johnson, Department of Phonetics and Linguistics, University College London, http://www.phon.ucl.ac.uk/resource/software.html). The percentages of information transmitted on voicing, manner and place of articulation were then analysed and compared across both the hearing aids using paired *t*-tests.

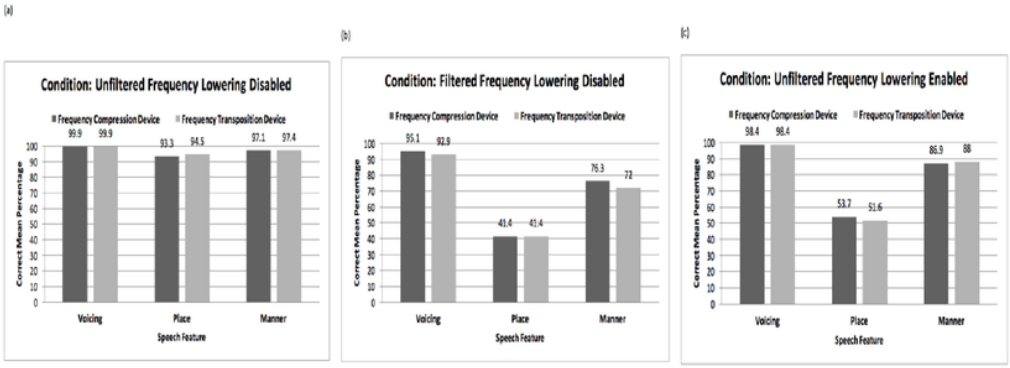

Figure 2: Phonetic feature (voicing, place & manner) scores and level of significance for all three conditions.

Normal speech condition

Results of the paired *t*-tests as shown in Figure 2 indicate that the frequency transposition device showed a slight increase in the place scores under this condition. Voicing and manner scores were similar for both the hearing devices under this condition.

Filtered speech condition

Figure 2 shows the percentile scores, while the bar graph clearly shows higher values for the frequency compression device and these seem visually significant. Place scores are similar for both devices.

Frequency lowered condition

The frequency compression device scored slightly better than the frequency transposition device for place, whilst the manner scores for the frequency transposition device were superior. Voicing scores remained similar for both hearing aids.

c. Within-group analysis

Paired *t*-tests were applied to evaluate the benefit of adopting the frequency lowering strategy when compared to the simulated hearing loss condition. These results indicate the benefits of frequency transposition and frequency compression over the control (i.e. simulated hearing loss) condition.

The simulated hearing loss condition was compared with the frequency lowered condition to detect any improvement in consonant recognition. The overall percentage of consonants identified correctly was calculated for the simulated hearing loss (filtered unaided) condition and then compared with the frequency lowered condition for the same device, using paired *t*-tests. The mean differences in percentage correct scores overall and for each of the features (voicing, place & manner) for the simulated hearing loss and frequency lowered condition were calculated across the 18 subjects, as shown in Table 3 for the frequency compression and transposition devices respectively.

Table 3: Level of significance of differences between frequency lowered and simulated hearing loss condition mean scores for the frequency compression and transposition devices.

Simulated hearing loss Vs Frequency compressed conditions		
Features	Mean difference	Level of significance
Overall	14.43	0.00
Phonetic features (frequency transposed condition scores - simulated hearing loss condition scores)		
Voicing	3.27	1.00
Place	12.34	0.00
Manner	10.63	0.01
Simulated hearing loss Vs Frequency transposed condition		
Features	Mean difference	Level of significance
Overall	13.25	0.00
Phonetic features (frequency transposed condition scores - simulated hearing loss condition scores)		
Voicing	5.53	0.61
Place	10.22	0.00
Manner	15.97	0.00

It is clearly evident from Table 3 that overall scores for the frequency compressed condition were significantly better than those for the simulated hearing loss condition. For place and manner, percentile scores were significantly higher under the frequency compressed condition, while the voicing scores remained constant as a whole across the two conditions for the frequency compression device, there being no significant difference.

Table 3 shows that the overall percentile scores under the frequency transposed condition were significantly higher than those for the simulated hearing loss (filtered hearing aid) condition. Phonetic feature scores of place and manner also showed significant differences between the two conditions, while the voicing feature showed an increase from the simulated hearing loss to the frequency transposed condition.

Discussion

The overall mean scores were 93.0% and 94.4% for the frequency compression (FC) and frequency transposition (FT) devices respectively under the normal speech condition. Indicative of parameters of testing like presentation level (i.e. 60dB SPL), speech perception scores of the subjects being tested, Direct Audio Input (DAI) shoe output etc; were set at optimal levels. Under the simulated hearing loss condition, these overall mean scores reduced to 38.3% and 36.1% respectively, while again under the frequency processed condition they increased to 52.7% and 49.33%.

The increase under the frequency lowered condition clearly indicates the extent of the benefit that a simulated steeply sloping high frequency hearing loss individual will obtain on the fitting of the frequency lowering device. When the overall mean scores of each hearing aid were compared under each condition, overall correct percentage scores were higher for the frequency compression hearing aid than for the frequency transposed device, under both the simulated hearing loss and frequency processed conditions.

Phonetic feature analyses showed that for the normal condition, the scores of place, manner and voicing were similar for both devices, whereas in the simulated hearing loss (filtered) condition, place scores decreased the most. Manner scores also decreased, but not as much as place scores, while the percentage scores for correct voicing remained approximately similar to those under the normal condition. These results are consistent with the findings of Miller and Nicely (1955), who report that when they set the low pass filter at 2.5 kHz and high pass at 200 Hz, the voicing feature was found to be greatly superior to the place of articulation. Manner (frication, affrication & duration) were superior to place but far inferior to voicing and nasality.

For the frequency processed condition, manner and place scores showed a slight growth compared to the filtered speech (simulated hearing loss) condition and this increase in manner was greater for the frequency transposition device.

This study used normal hearing listeners as subjects for the purpose of comparison because hearing-impaired individuals usually have different patterns of audiometric configuration as well as differences in cognitive level, in the amount of distortion in the auditory system, in the extent of potential cortical reorganisation consequent to the hearing loss and subsequent hearing aid use. To assess complex amplifying algorithms effectively it is essential that these must be optimally fitted onto hearing-impaired individuals with the same parameters across all subjects, which is impractical. If, however, the sole motive of the study is to measure the efficiency of a frequency lowering scheme or to compare two schemes, then fitting these devices to hearing impaired individuals is not vital; instead, these schemes can be tested on normal subjects with simulated high frequency hearing loss and variation among speech perception scores can be evaluated. The use of normal listeners with simulated hearing loss can help to standardise testing across patients and remove the effect of variables such as those noted above, making the fittings optimal across patients (Korhonen & Kuk, 2008).

It is clear from the results of this study under the simulated hearing loss (filtered) condition that the frequency compression device provided better low frequency amplification. Thus, the frequency compression device used in the study would be capable of providing more benefit to patients with sloping sensori neural hearing losses as compared to the frequency transposing device. Mc Dermott and Dean (1999) stated that improved low frequency audibility leads to better consonant perception. They argue that this increase can be credited to the improved perception of the frequency transitions in the first two formants of the vowels surrounding the consonants, as the frequency of these formants is usually below 2.5 kHz;

1 therefore, more emphasis should be placed on obtaining adequate low frequency
2 amplification, even in people having sloping hearing loss, whether they are fitted with
3 conventional amplification or transposition hearing aids.

4 Fraga and Morotta (2004) compared the frequency compression and frequency shifting
5 strategies using a speech intelligibility test comprising 21 CV phonetic syllables presented by
6 6 different speakers in Portuguese. Each stimulus was processed for low pass filtering,
7 frequency compression and frequency shifting. These processed stimuli were further passed
8 through the three low pass filter cutoff settings of 1.5 kHz, 2.0 kHz and 2.5 kHz, then
9 presented to the subjects randomly. The results of this study were inconclusive, as for some
10 syllable, scores were better under frequency shifting and for others under compression.
11 Overall, the authors concluded that frequency transposition was slightly better than frequency
12 compression. The present study challenges this conclusion by finding that a frequency
13 compression scheme was significantly better than a frequency transposition scheme, which is
14 evident from the results of the frequency lowered condition.

15 The scores under the normal speech condition reached an average of 94%, but the percentage
16 correct scores of the frequency lowered condition reached only a mean of 51%. This large
17 difference and low growth in scores can be explained by the loss of frequency resolution in
18 the cochlea due to frequency lowering. Pickles (1988) revealedthat the loss of frequency
19 resolution in the cochlea leads to a particular difficulty in understanding broadband complex
20 sounds. Even if acoustic amplification can adequately increase the magnitude of the acoustic
21 signal to restore sensitivity, it is inefficient at restoring the cochlea's frequency resolution, so
22 that while sounds are now audible, they may be incomprehensible. As all subjects were
23 normal listeners, frequency lowering strategies created electronically or physically a
24 condition of off-frequency listening (Florentine & Houtsma, 1983; Thomton & Abbas,1980)

and distorted the frequency characteristics of speech, affecting the performance of subjects and restricting their scores. However, further tests are required to verify this assumption.

One of the limitations of this study is that it did not consider either the training or the acclimatisation effect of these two frequency lowering strategies on subjects, which is not only a vital aspect in comparing the performance of the two strategies, but also an important factor in confirming the above-mentioned hypothesis that frequency lowering in normal subjects is actually a simulation of off-frequency listening or dead regions.

Conclusion

This study has compared the performance of normal hearing listeners using two frequency lowering strategies: frequency compression and frequency transposition. Results indicate that the frequency compression scheme performed significantly better. This study proves that even at low frequencies, the performance of the frequency compression device was better than that of the frequency transposition device and shows clearly that frequency lowering strategies provide a significant benefit over an unaided hearing loss condition. Therefore, in cases with simulated steeply sloping high frequency hearing losses, a frequency compression strategy will provide a better performance for the hearing impaired individual. In contrast, hearing aid with frequency transposition was found to be better in performance with regard to manner of articulation. As this study used normal subjects to make the comparisons, it is not possible to generalise the performance of these hearing aids to the hearing impaired population; therefore, another study with a similar design with subjects drawn from the hearing impaired population is required.

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2	Petri Korhonen. "Use of Linear Frequency Transposition in Simulated Hearing Loss", Journal of the American Academy of Audiology, 09/01/2008 Publication	1%
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