

# Comparison between frequency transposition and frequency compression hearing aids

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## Background

High-frequency hearing loss is one of the challenges for accurate hearing. One method of amplification toward improved detection and discrimination of high frequencies is through lowering of high frequencies to a lower-frequency hearing region. Frequency compression (FC) or frequency transposition (FT) can be used for individuals with different configurations of hearing impairment, such as steeply sloping and high-frequency hearing loss (containing high-frequency dead regions).

## Objective

The purpose of this review was to compare the effects of FC and FT on the speech recognition abilities of people with hearing impairment.

## Patients and methods

This study is a systematic review of previous investigations carried out to test the efficacy of frequency-lowering algorithms (i.e. FC or FT) in improving the detection of high frequencies. The concept of FC and FT depends on enhancement of speech recognition in patients suffering from high-frequency hearing loss. In this review, compression shifting and frequency transposition were compared on the basis of improvements in the audibility of high frequency sound to improve the outstanding and acceptance level of speech.

## Conclusion

It can be concluded from this review that both FC and FT are useful in people with high-frequency hearing loss. FC has a potential role in recognition of monosyllabic words, consonants, and sentences in the presence of background noise. In contrast, FT facilitates detection of fricatives that ultimately leads to improvement in the discrimination of consonants. Throughout the literature, only one study has compared both FT and FC using various speech tests to evaluate the performance of different hearing instruments. Therefore, further studies addressing the benefits of both modalities of hearing aids with a more standardized outcome measure for both adult and pediatric patients are required.

## Keywords:

amplification device, frequency compression, frequency transposition, hearing aids, hearing devices, speech perception, speech recognition test

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## Introduction

High-frequency sounds are crucial for communicating the semantic aspects of speech, such as plurals and possessives. Most conventional hearing aid users have access to low-frequency information; however, they may have limited access to high frequencies, which leads to missing out on high-frequency speech consonants and thus a significant impact on speech understanding, especially in the presence of background noise [1]. In previous studies, it has been demonstrated that high-frequency hearing sensitivity declines with age even in the absence of specific pathology [2]. Sensorineural hearing impairment is usually associated with damage to the outer hair cells in the cochlea; sometimes the inner hair cells can be damaged in certain frequency-specific regions in the cochlea [dead regions (DRs)], which can be defined by the range of characteristic frequencies of the inner hair cells and the neurons adjacent to the DR. This region cannot be detected by a typical

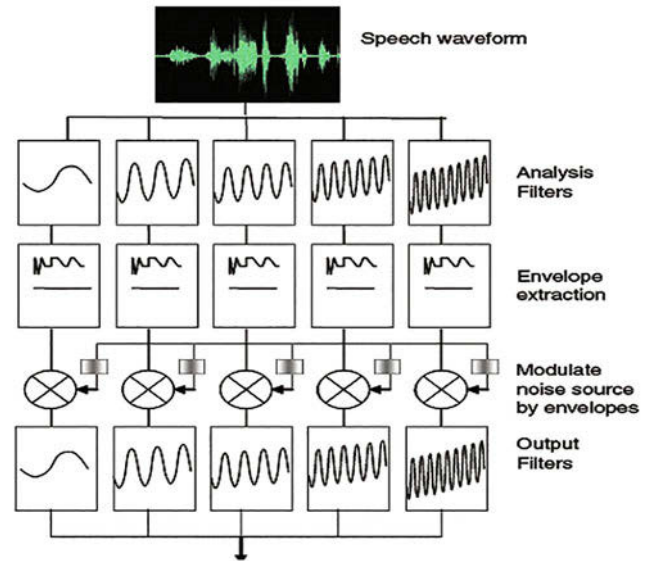
audiogram, but it can be diagnosed by using methods involving psychophysical tuning curves and threshold equalizing noise testing. The treatment of patients with DRs related hearing impairment depends on which frequencies are effected as using hearing aids with suitable amplification is suitable for those with low-frequency hearing loss. For high-frequency DRs, hearing aids with frequency transposition (FT) or frequency compression (FC) can be used [3].

Most people with sloping hearing losses and having high-frequency thresholds of about 70 dB and above are unable to extract information from high-frequency parts of the speech. Hearing ability deteriorates if these people are provided with hearing aids that amplify speech frequency range as it leads to reduction in the ability of those individuals to recover useful information from high-frequency parts of the speech signal [2]. One of the solutions to overcome

this problem is bringing down the high-FCs of the speech to lower-frequency regions where the person is more able to analyze sounds. There are two methods of lowering the frequency of high-frequency signals: FT and FC.

The basic principle of FT involves transferring the high-frequency sound to lower frequency by adding the processed signal (transposed) to unprocessed signal in the lower frequency [2]. A number of techniques are available for FT. The first technique was used in a commercial hearing aid (Oticon TP72, UK) that consists of two channels: frequencies below 3 kHz were amplified as in a conventional device, and high frequencies within 4–8 kHz were converted into low-frequency noise below 1.5 kHz by a nonlinear modulator [4]. Inability to preserve the spectral shape of the incoming signal is the main drawback of this technique [4]. The second transposing technique divides the incoming signal into low and high pass bands, with crossover at a frequency of 4 kHz. The incoming information from the high pass band is subtracted by 4 kHz from each frequency and then mixed with the low pass frequency band. However, these transposition schemes can preserve some but not all of the information of the high-frequency spectral shape. These schemes have been developed by Velmans and Marcuson [5] in the frequency RE cording device. More recently, a transposing speech vocoder has been developed to shift down the speech cues, such as level, pitch, and tone. In this method, speech is filtered into a bank of adjacent narrow bands and the level within each band is detected [6]. The transposing speech vocoder works on the principle of using levels detected from high-frequency bands to modulate low-frequency bands of noise or low-frequency tones (Fig. 1). The transposition algorithm is a method of minimizing the problem of overlapping spectra and was discovered by Robinson *et al.* [7], who estimated the edge of the DR to decide the starting point of the transposition. Low-FCs were amplified to ensure that sound remained unaffected by transposition. Transposition was applied only if significantly high-frequency sound components were present for the DR band to just above the edge of the DR and overlapped with the speech that has been low pass filtered. The latest technique for transposition used the audiogram to determine the point of starting frequency for transposition. The start frequency for each patient was calculated individually with the sloping hearing loss greater than 10 dB/octave (within frequencies from 0.5–4 kHz). The baseline performance was measured above the frequency of 1.6 kHz and above the 70 dB threshold. The frequencies below the starting frequency are amplified without transposition. One octave above the starting DR frequency was analyzed

Figure 1



Represents the structure of input and output of the speech signal in vocoder stimulation. Source: McDermott, Dorkos, Dean and Ching, 1999.

by narrow range hearing aid with the highest intensity being transposed linearly and overlapped above the starting frequency. This technique was applied in the transposing device (Widex Inteos, Denmark), which determines the efficacy of the audibility extender program [8,9]. The transposition processing usually does not affect the low-frequency information. As a result, it could produce more natural sound quality and preserve a harmonic relationship between FCs for the high-frequency-transposed region [10]. However, the disadvantage of this processing is the overlap between the transposed high-frequency information and the lower frequency. Moreover, unconditional transposition could add high-frequency noise and mask the useful low-frequency information. As a result, many new approaches attempt to avoid this problem by using the conditional transposition (transposition active when the input signals mostly consist of high-frequency information).

The basic technique of FC is decreasing the bandwidth for the output signals. Furthermore, it can be linear (also known as proportional shifting) or nonlinear (nonproportional shifting). The linear frequency shifting brings down all energy peaks (frequencies) to lower frequencies by a compression factor. For example, if the FC ratio is 2, then sounds at 6000 Hz will be shifted to 3000 Hz and those at 3000 Hz will be shifted to 1500 Hz and so on. This method will preserve the spectral shape information for the frequency component. In this method the constant ratio can offer a constant relationship between frequency component peaks and the important cues

for recognition of the vowels in speech [11]. However, the drawback of this method is that it provides an unnatural sound quality due to low pitch of speech. For instance, a female voice will be more like a male voice. This method is not used in commercial hearing aid devices because of unnatural sound quality. Nonlinear FC decreases the bandwidth for the input speech signals (Fig. 2) by increasing the amount of frequency lowering for high frequencies [12]. The advantage of these schemes is that they avoid the overlap between the high and mid frequencies (shifted and unshifted signals). However, the harmonic ratio for the high frequencies is compressed and will not be preserved. Therefore, speech perception may be affected when the cutoff frequency of compression is moved to lower frequencies. The current commercial device, which incorporates nonlinear FC, is Phonak Naida (Sonava Group, Switzerland).

This study reviews published papers to compare the different methods of FC and FT by analyzing the improvement seen on speech tests in patients with high-frequency hearing loss.

### Research rationale, aims, and objectives

A number of studies have been conducted to determine the effectiveness of hearing aids incorporated with different frequency-lowering algorithms. With the development of a range of frequency-lowering techniques, researchers have conducted a number of experiments to test the efficiency of hearing instruments installed with different frequency-lowering algorithms. We conducted this systemic review to ascertain the adequacy, efficiency, and effectiveness of the most effective hearing aid algorithms for people with high-frequency hearing impairment, and compared the effectiveness of FC and FT in hearing aids by assessing the performance of patients with high-frequency hearing loss in speech tests by reviewing previous research findings. The findings of this study can be used as a secondary data source or as reference in other similar studies.

To meet our objective, we focused on the following research questions:

- (1) What are FC and FT?
- (2) How do these methods improve the speech recognition performance of individuals with high-frequency hearing impairment?
- (3) Is there any difference between these methods (FC/FT) in improving speech perception in individuals with high-frequency hearing loss, if studied before in the literature?

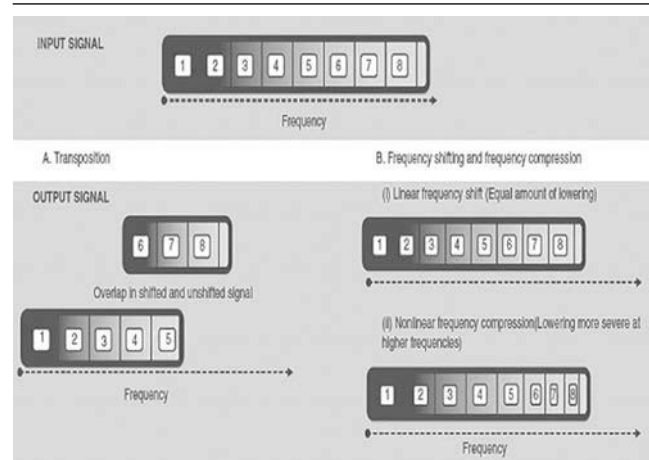
### Patients and methods

A comprehensive systematic review was conducted and was based on an open, preidentified, and reproducible method. The search was conducted at the Centre for Reviews and Dissemination, University of York (2008), and started with 'Database of Abstracts of Reviews of Effects (DARE) and the Cochrane Database of Systematic Reviews (CDSR)' (University of York, 2008). In each study, the main points were discovered, assessed, and summarized. Collectively, all of the selected studies were put together and a generalized conclusion after analysis was finalized. According to the Centre for Reviews and Dissemination (CRD, University of York, 2008), it is important to determine the PICO elements for any systematic review. PICO stands for Participants/population, Interventions, Comparators and Outcomes. A PICO structure was used to frame the objective questions and to ensure that the researcher obtained the maximum studies related to the primary study by using two or more search terms in one of the four parameters [13] as demonstrated in Tables 1 and 2.

### Study selection and data sources

The research method adopted in this study is the systematic review of existing literature on related

Figure 2



Schematic representations of different methods of the frequency transposition and frequency compression (Simpson A, 2009).

Table 1 PICO of the study (University of York, 2008)

Population	Individuals with hearing impairment especially high-frequency hearing loss
Interventions	Devices with frequency-lowering algorithms (frequency compression)
Comparators	Frequency lowering — conventional hearing aids Frequency lowering with and without training
Outcomes	Speech recognition performance of subjects

PICO, Participants/population, Interventions, Comparators and Outcomes.

topics. Selected studies were based on qualitative research methodology. Data were collected from the following databases: Medline, OVID, PubMed, Embase, CINAHL, and ScienceDirect. The search used the following keywords:

- (1) Amplification device
- (2) Frequency compression
- (3) Frequency transposition
- (4) Speech recognition test
- (5) Hearing devices
- (6) Hearing aids
- (7) Speech perception

These keywords were used as subject headings in the databases. Special focus was directed toward amplification devices, FT, and FC as the main keywords. The number of hits found from the databases for amplification device was 53 643 and for FT was 3485 hits. The hits for amplification combined with FC added up to 6743 hits. Finally, total of 54384 hits encountered from a combination of FT, FC, amplification, and speech recognition test. The result of all these keywords combined with 'AND' resulted in a total of 545 hits. A number of articles were collected. The articles for review were selected on the basis of its relevance to the topic, research question, and research objectives. Articles with a low level of evidence, such as single-case studies, anecdotal reports, surveys and expert opinions, were excluded from this systemic review.

This classification aims to assess the strength of evidence for the benefits of intervention or treatment, such as hearing aids with FT or FC. Data in this study were analyzed by means of meta-analysis. Follow-up of references in relevant publications was undertaken so that all relevant publications were included. The studies collected from the databases were classified and coded according to the topic, techniques used, number of subjects, results, and research methods, as shown in Fig. 3. In this review we included all nonrandomized studies, prospective cohort studies, and case-controlled series published in English language only from 1990 onward. Our study population included children and adults with high-frequency hearing loss. The studies included in our review were those with definite outcome terms such as speech perception score or significant difference. Studies on other types of hearing loss, such as conductive hearing loss or flat sensory neural hearing loss, were excluded from this review.

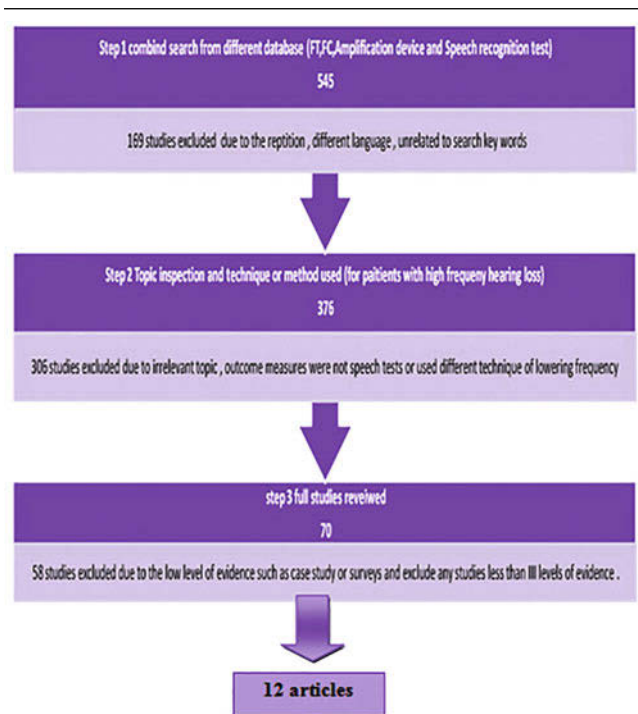
**Results**

This section will give a brief description of the included studies (Tables 2 and 3). Table 2 summarizes all studies addressing FT and Table 3 presents those addressing FC.

**Frequency transposition in patients with high-frequency hearing loss**

Two out of five papers, that is 40%, showed overall improvement in speech recognition from FT in patients with different degrees of high-frequency hearing loss, this improvement was due to training given for the device [15,25]. However, in three of five (60%) studies no improvement was seen in the speech recognition test on using different techniques for the transposition hearing aid [6,14,16]. In the study by Rees and Velmans [14] an improvement of 8% was reported with FT as compared with conventional hearing aids and consonant detection score (40%). Robinson *et al.* [17] reported a small improvement of 20% in the detection of affricates in seven patients. However, the overall results showed that there is no significant improvement. Kuk *et al.* [16] showed improvement in FT-enhanced fricative detection by 43%. The combined analysis (using pass/fail speech score criterion for any score above 60% in patients, indicating significant improvement) of these studies indicated that FT improved affricate detection, consonant recognition, and high-frequency fricative production in both adults and children suffering from high-frequency and sensorineural hearing loss. For instance, 10 children showed significant improvement in consonant recognition from 18 to 69% and in vowel identification from 56 to 90% after auditory training.

**Figure 3**



Percentage of patients who benefited from frequency transposition (FT) and frequency compression (FC).

### Overall benefit from frequency transposition in patients with high-frequency hearing loss

Data were collected from five papers showed that 17 patients (39%) benefit from the intervention. This percentage is for patients in general (adults and children). For pediatric age group, the beneficial outcome was achieved in 7 out of 10 children (70%). Table 4 illustrates comparative data for FT studies (number of patients benefited and speech score).

### Frequency compression with high-frequency hearing loss

Five (71.5%) of the seven patients who underwent training on device usage showed improvement from FC [19,21–24]. In contrast, two (28.5%) of seven papers reported reduced performance for speech

recognition [18,20McDermottHJ]. Frequency-compression outcomes in listeners with steeply sloping audiograms. *International Journal of Audiology* 2006; 45:619–629.”]. The review of FC schemes showed overall improvement in the sentence recognition ability of patients in the presence of background noise and plural recognition, compared with conventional hearing aids.

### The overall outcome for frequency compression

Forty-five (53%) of 85 patients benefited from FC compared with the conventional hearing aid. In addition, the patients showed greater benefit when the compression ratio was decreased [26]. Patients trained on device usage and pediatric patients achieved better

**Table 2 Summary of literature addressing frequency transposition**

References	Participants	Speech test	Training	Outcomes
Rees and Velmans [14]	8 patients with severe to profound SNHL	Nonsense syllables and monosyllabic words	No training	8% improvement in consonant detection (40% correct identification)
Robinson <i>et al.</i> [7]	7 patients with high-frequency dead regions	VCV and high-frequency phonemes /s/ and /z/ detection for consonant detection	4 sessions for 2 h	20% improvement in detection for affricates; no overall significant improvement
Aurimmo <i>et al.</i> [15]	10 children with severe to profound high-frequency HL	Nonsense syllables, conversational speech and oral reading passage	6 weeks	51% improvement in group average score in consonant recognition from 18 to 69%, and 33% improvement in vowel identification from 56 to 90% with training ( $P < 0.05$ )
Kuk <i>et al.</i> [16]	8 adults with severe to profound SNHL	Nonsense syllables test (NST)	2 months	43% improvement in fricative detection under both quiet and noisy conditions ( $P < 0.05$ )
Robinson <i>et al.</i> [17]	5 adults with high-frequency dead region	VCV, /s/ detection, and speech in noise using questionnaires	4 weeks	No significant improvement in consonant identification

VCV, vowel–consonant–vowel; SNHL, sensorineural hearing loss.

**Table 3 Summary of literature addressing frequency compression**

References	Intervention	Participants	Speech test	Training	Outcomes
Sakamoto <i>et al.</i> [18]	Nonlinear frequency compression	5 patients with severe to profound SNHL	Sentence recognition test	1–2 weeks home training	No statistically significant improvement
Simpson <i>et al.</i> [19]	Nonlinear frequency compression	17 patients with moderate to profound HL	Monosyllabic words	4–5 weeks	6% improvement for phoneme score for 8 patients
Simpson <i>et al.</i> [20]	Nonlinear frequency compression	7 patients with steeply sloping hearing loss	Monosyllabic words and sentences under noisy condition	3–4 weeks	No improvement over conventional hearing aids ( $P = 0.11$ )
Gifford <i>et al.</i> [21]	Digital frequency compression (DFC)	6 patients with high-frequency HL	Monosyllabic words and sentences under quiet and noisy conditions	5 weeks	Average improvement of 17% in monosyllabic words tests in 2 of 6 patients, with no benefits achieved in the other 4 patients
Glista <i>et al.</i> [22]	Multichannel nonlinear frequency compression (NFC) signal processing	24 patients (13 adults and 11 children)	Consonant, plural, and vowel recognition. Aided detection using Ling-six sound	4 weeks	90% correct detection of tasks and self-reported preference in children vs. 50% in adults
Bohnert <i>et al.</i> [23]	Nonlinear frequency compression algorithm	11 patients with severe to profound SNHL	OLSA (older burger sentence test) adaptive speech test in noise	4 months	64% improvement in 7 of 11 patients in comparison with conventional hearing aids ( $P = 0.08$ )
Wolfe <i>et al.</i> [24]	Nonlinear frequency compression	15 children with moderate to severe hearing loss	Nonsense syllables speech recognition under quiet condition and speech recognition under noisy condition	6 months	15% improvement in group average score for speech test from 84 to 99%



speech performance, which was indicated in one paper that compared between children and adults with a benefit percentage of 91% [27–30]. Table 5 illustrates comparative data for FC studies (number of patients benefited and speech score).

**Comparison outcome between frequency transposition and frequency compression**

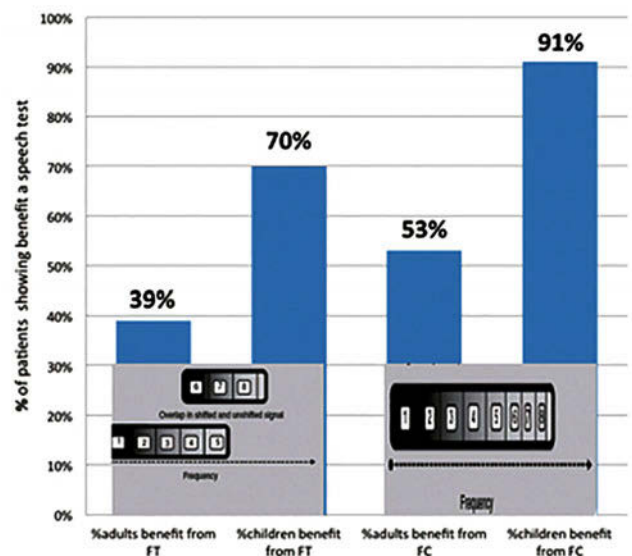
As there was only one study that compared between FC and FT [27] and it was a very old review, it was not possible to carry out the meta-analysis for all 12 studies. This leaves a potential gap in the methodological references and a question of how to compare the outcome between FT and FC when there is no recent paper that has conducted a direct comparative study between the two. To overcome these problems, it is recommended to look at the percentage of benefit from the different speech tests in patients with high-frequency hearing loss using amplification with transposition and the percentage of benefit for the same conditions using amplification with FC. Figure 4 demonstrates the percentage of pediatric and adult patients showing benefit from FT and FC and reflects the differences between them (39% FT and 53% FC). Although the achieved improvement in hearing level depends on other factors such as sufficient training time, the presence of moderate high-frequency hearing loss with normal to mild low frequency and shifting the specific area (DR) the percentage of benefit among children is greater than that among adults for both FT and FC. A high percentage of children using FC showed benefit (91%) compared with children who benefited from FT (70%).

**Summary of the results for the quality of the review**

In this systemic review, we used level III and higher evidence, such as prospective cohort studies and case-controlled series, to review all studies in the literature addressing both FT and FC. A slight change was allowed in sample size, study design, objective, and outcome measures (speech test) across all studies. This heterogeneity led to inappropriate use of meta-analysis, which conventionally needs strict similarities between the studies for specific parameters. As a result, the review applies metaethnography of the data and a qualitative form to integrate data synthesis [28]. The findings of each study are tabulated and summarized in Tables 2 and 3. The relative feature of metaethnography is that it provides a general idea of what the evidence indicates, without prejudice to the results of each primary study. Regarding the inclusion and exclusion criteria, the review has a big collection of good-quality papers evaluating the performance of the transposition and FC and applies data for the knowledge base.

A total 12 studies (level III studies, nonrandomized studies, prospective cohort studies, and case-controlled series) met the inclusion criteria. Most of the 12 studies were selected according to the inclusion criteria. There

Figure 4



Summary of the results of frequency transposition and frequency compression for adults and children showing improved speech test performance.

Table 4 Comparative data for frequency transposition studies

References	Number of patients	Patients benefited	Speech score (%)
Rees and Velmans [14]	8	1	40
Robinson <i>et al.</i> [7]	7	2	20
Auriemmo <i>et al.</i> [15]	10	7	69
Kuk <i>et al.</i> [16]	8	4	43
Robinson <i>et al.</i> [17]	5	1	50
Total	38	15	

Table 5 Comparative data for frequency compression studies

References	Number of patients	Patients benefited	Speech score
Sakamoto <i>et al.</i> [18]	5	0	No improvement
Simpson <i>et al.</i> [19]	17	8	Increased by 6%
Simpson <i>et al.</i> [20]	7	0	No improvement
Gifford <i>et al.</i> [21]	6	2	Increased by 17%
Glista <i>et al.</i> [22]	24	Children > adults (13 patient)	90% in children, 50% in adults
Bohnert <i>et al.</i> [23]	11	7	Not clearly stated
Wolfe <i>et al.</i> [24]	15	Reported as average improvement (all)	84% for hearing aid 99% for frequency compression
Total	85	45	

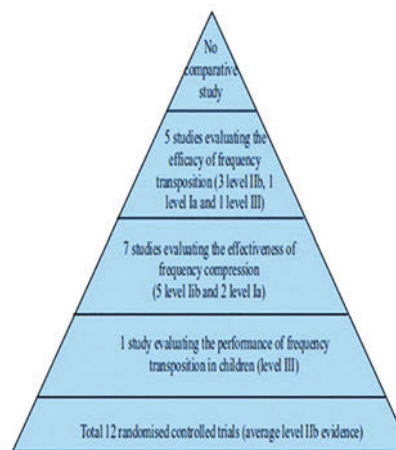
were seven papers on FT and five studies on FC. There was only one paper that aimed to make a direct comparison between FC and FT [27], but it was not included in our review as it was using older techniques that produced poor natural quality of sound.

## Discussion

In theory, shifting frequency hearing aids (such as FT and FC) have been reported to compensate the loss of audibility due to high-frequency loss (sloping threshold) and to lead to improvement in the speech score. When the clinician recommends FT or FC devices, they should be aware of many factors, such as the frequency range, which can support useful auditory information, and the sharpness of the sloping audiogram. These devices using FT or FC achieve better results with patients who have moderate high-frequency hearing loss with normal to mild low-frequency hearing as compared with patients with profound hearing loss. Stelmachowicz *et al.* [30] reported improvement in fricative perception, which is important for children, for learning grammatical rules and articulation. This improvement was higher in patients with moderate high-frequency loss under a variety of low pass filter conditions [29]. In the same study, they found that the patient needed to extend the bandwidth up to 9 kHz when there was exposure to female or child speakers. With the introduction of digital signal processing, a number of researchers have tested the efficacy of new frequency-lowering algorithms, such as FC and FT, with careful sample selection and training of patients and have reported benefits among adults and children with hearing loss [8,15]. The results of these studies indicate benefits of using FC or FT-based hearing aids, which is consistent with the findings of previous researchers. It is evident from the findings that children benefit more than adults because of greater neural plasticity. The auditory sensations produced by these systems are initially unfamiliar when perceived by the cochlea. The cochlea is not tuned to hear higher frequency sounds delivered at lower frequency places along the basilar membrane. Therefore, it is beneficial to provide adaptation or training to users, regardless of the type of system used, to help users get acclimatized to these devices.

The hierarchy of evidence level in Fig. 5 indicates that none of the studies directly compared the performance of FC and FT. Therefore, different studies evaluating the performance of these schemes separately were reviewed and compared on the basis of outcomes. Most of the studies were case-control studies. From these results, this review shows the different performance levels when looking at the individual users. There is no

Figure 5



Hierarchy of evidence obtains from the systematic review.

doubt that many factors may be relevant in predicting better performance for an individual user.

This systematic review found statistical improvement from FC in 53% (45/85) of adult patients with high-frequency hearing loss as compared with 39% (15/36) on using FT. Regarding children, overall they demonstrated significant improvement of 91% for FC and 70% for FT. Providing auditory training to patients with a specific hearing device is more effective for speech recognition compared with not providing training. This is supported by the findings of the study conducted by Kuk and colleagues [8,15,21].

## Training

Providing auditory training to patients with a prescribed hearing device is more effective for speech detection as compared with not providing training; this is supported by the findings of many studies [8,15,18,19]. There are two main reasons for that. First, patients adjust to the quality of frequency-lowered sounds because it will seem unnatural or outlandish at first. Second, patients learn to discriminate or detect lowered signals; for instance, fricative sounds like /s/ and /ʃ/ will be first perceived as noise or unwanted sound rather than as speech.

As mentioned earlier, there are many studies reporting benefit from training with both FC and FT. Posen *et al.* [31] showed suitable performance after 15 h of training in a speech test with transposition. Moreover, another study compared the performance of nine children who had severe high-frequency hearing loss with and without training, and reported good performance after training in the speech recognition test [32]. The overall results of training are encouraging. However, the training provided in previous studies

was in speech tasks used in the specific test. Therefore, the improvement could be a result of adapting to the specific speech task rather than due to shifting frequency (FC/FT). McDermott and Dean [33] found that no significant improvement with FT and FC on patients trained on different tasks. Similarly, Velmans [34] and Blamey *et al.* [35] reported on participants trained in articulation with a FT device and the results showed improvement in the articulation test but not in the speech recognition task. Unfortunately, the patients cannot generalize the training materials and transfer the trained skills for other materials spontaneously. With regards to previous studies addressing the effect of training including exposure to the lowered (FC/FT) signals with take-home within 10–20 h, compared with patients who have a small amount of training time. Sweetow and Sabes [36] reported that intensive training for speech in general (lowered speech or not) can give significant benefit compared with specific training for lowered speech.

Our current research is important for clinicians to evaluate features of different hearing aids and select the most appropriate hearing device for their patients. It also provides compiled results of various studies on FT and compression conducted to date for future researchers and a potential source of secondary data and reference for research works aimed to develop advanced hearing technologies. The results have clinical implications in determining the clinical efficacy of hearing devices on the basis of incorporated frequency-lowering features. The results of this review may be debatable because of certain limitations. The validity of our study results can be questioned as conclusions are derived from a combination of disparate studies/randomized controlled trials, having widely heterogeneous samples, small sample sizes, varied methods for application of the intervention, and possible selection and observation bias. The study suffers from lack of availability of high-quality randomized trials due to incomplete information about the patient's clinical history, hearing characteristics, and baseline information about individual hearing loss. Also, the study of patients varied largely from study to study, as a result of which it is difficult to analyze their findings on a common platform and may result in bias. In addition, only studies published in English were included in the review, as a result of which several papers with relevant findings published in other languages were excluded. These limitations can be overcome by testing these frequency-lowering algorithms on a larger sample with minimum variation in the type of hearing loss, patient's age, and experience of using the device. More scientific databases can be searched for a more refined search.

More research is required to compare the efficacy of FC and FT techniques. There is no study in this systematic review that directly compares the two algorithms. Therefore, studies that carry out comparison between the two techniques in the same research with common participants and common fitting strategies are required.

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## Conclusion

Past literature indicated that both FC and FT are useful in people with high-frequency hearing loss. The findings of past studies have revealed that FC has a potential role in the recognition of monosyllabic words, consonants, and sentences in noise, whereas FT has a role in fricative detection that ultimately leads to improved discrimination of consonants, but does not negatively affect vowel recognition. Only one study has compared both FT and FC using various speech tests such as the vowel–consonant–vowel test, the nonsense syllable test), etc., to evaluate the performance of different hearing instruments. Therefore, further studies addressing the benefits of both hearing aids and standardizing the outcome measure for both adults and children are needed.

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## Acknowledgements

### Conflicts of interest

None declared.

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