New Life for Frequency Lowering?

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requency lowering in hearing aids is one of those ideas that has been around for a long time but has never seemed to work very well. The concept is simple enough. If a person has trouble hearing high-frequency consonants because of high-frequency sensorineural hearing loss, shift the frequency spectrum of the speech signal downward into a lower-frequency region where there is less loss. But, of course, the devil is in the details.

Attempts to implement the concept in hearing aids have taken three principal forms: linear frequency shifting, frequency transposition, and frequency compression. In simple linear frequency shifting, the entire spectrum of the speech signal is shifted downward by a fixed amount. Linear frequency transposition is a special case of linear frequency shifting in which only a limited portion of the speech spectrum is lowered, or “transposed.” into a lower range, then added back to the original, unshifted signal. Finally, in frequency compression, each frequency is lowered by a predetermined proportion.

The advantage of linear frequency shifting is the comparative simplicity of implementation. The energy at each frequency is shifted downward by the same number of cycles per second (Hz). Thus, if the amount to be shifted is 1000 Hz, then 4000 Hz becomes 3000 Hz, 3999 Hz becomes 2999 Hz, 3998 Hz becomes 2998 Hz, and so on. The principal disadvantage of linear shifting of the entire speech spectrum is the fact that the pitch of all components, but especially the fundamental frequency of voicing, is lowered. There is also the problem of dealing with the negative frequencies inevitably created by the algorithm (e.g., 500 Hz becomes –500 Hz).

The main advantage of frequency transposition is that the original spectrum is substantially preserved. Only a limited range of high frequencies is superimposed on the original spectrum. Thus the audibility of high-frequency consonants is aided without serious distortion of the vocal characteristics of the talker. The disadvantage is the difficulty in avoiding artifacts when the transposed signal is added to the original signal.

The advantage of frequency compression is that it more nearly reflects the familiar octave structure of the frequency scale. If, for example, each frequency is shifted by a proportion of 0.5, then 4000 Hz becomes 2000 Hz, 3000 Hz becomes 1500 Hz, 2000 Hz becomes 1000 Hz, and so forth. This deftly avoids the problem of the negative frequencies resulting from linear shifting (e.g., 1 Hz becomes 0.5 Hz, 0.5 Hz becomes 0.25 Hz, etc.). But the problem resulting from the downward shift of the fundamental frequency of voicing remains.

Early efforts to exploit these frequency-lowering schemes encountered two serious problems. First, it became evident early on that the hearing aid user would have to learn new acoustic percepts. Second, because of limitations in early analog technology, disturbing conversion artifacts could not be easily removed from the mixture of the original and the transposed signals in transposition algorithms.

But modern digital signal processing has altered the playing field substantially, renewing interest in frequency lowering strategies, especially frequency transposition. In this issue of JAAA, authors Jane Auriemmo, Francis Kuk, and Chi Lau of Widex USA, and Susan Marshall, Natalie Thiele, Margaret Pikora, Debra Quick, and Patricia Stenger of the Special School District of St. Louis, in their paper entitled “Effect of Linear Frequency Transposition on Speech Recognition and Production of School-Aged Children,” report results of a study of a specific linear frequency transposition (LFT) algorithm. They tested 10 children in the age range of 6 to 13 years, all with normal to moderate loss in the low frequencies but severe to profound loss in the high frequencies. Both phoneme recognition and fricative articulation performance were compared under three conditions: (1) with the child’s own aid, (2) with an experimental aid employing LFT, and (3) with the same experimental aid but with the LFT feature turned off. For the latter two conditions, weekly half-hour auditory training sessions were provided over a six-week period.

A number of the results are noteworthy. First, after six weeks of training and experience with the LFT-enabled aid, improvement was noted in consonant identification, in fricative production, and in the identification of environmental sounds. There was also consistent evidence of the importance of auditory training in order to experience maximum benefit from LFT. Finally, and not unexpectedly, benefit from LFT was strongly negatively related to the consonant identification score with LFT turned off. In other words, the children who did least well without LFT received the most benefit from LFT.

These encouraging findings suggest that frequency transposition may, after many years of challenge, finally be coming of age.

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