Critical Review: Effects of Frequency Transposition on the Speech Perception of Individuals with High-Frequency Hearing Loss

Melissa Polonenko, M.Cl.Sc. (AUD) Candidate
University of Western Ontario: School of Communication Sciences and Disorders

This critical review examined the effect of frequency transposition on speech perception in individuals with high-frequency hearing loss. Study designs included: one single subject 'n-of-1' study, three single group pre-posttest studies, and two case studies. Overall, the evidence failed to provide sufficient support for the beneficial effects of frequency transposition on speech perception in individuals with hearing loss. Additional studies involving more subjects, additional and/or alternative procedures for measuring speech perception, and controlled fitting of hearing instrument parameters are recommended.

Introduction

The majority of modern hearing instruments and currently available technology are limited in bandwidth and do not provide sufficient audibility to individuals with high-frequency hearing loss (Stelmachowicz et al, 2004). Many important speech sounds and grammatical markers, such as /s/, /sh/ and /f/ are higher in frequency and less intense. Therefore, audibility of these sounds is restricted for these individuals. This is particularly important in children who have permanent hearing loss, since the development of spoken language is dependent on the audibility of speech during childhood. Limited access to these sounds may have ramifications on speech perception and discrimination for all ages, as well as speech production in children (Elfenbein et al, 1994; Moeller et al, 2007).

Frequency transposition signal processing has been introduced in a few hearing instruments as a strategy for improving high-frequency audibility in hearing instrument fittings. This technology lowers the high-frequency energy in speech, presenting it at a lower frequency that is more audible to the listener. However, this change in the spectral envelope of certain sounds positions new cues into frequency regions that are also occupied by other sounds. This acoustic overlap may introduce perceptual confusions of sounds and thus, individuals may have altered speech perception and discrimination after a period of using frequency transposition, despite improvement in audibility.

Early studies of older hearing instruments containing frequency transposition processing indicated little or varied benefit for speech perception over conventional amplification (MacArdle, Bradley, Mackenzie & Bellman, 2001; McDermott, Dorkos, Dean & Ching, 1999; Parent, Chmiel & Jerger, 1997). Limited peer-reviewed literature exists on speech perception in individuals wearing currently available hearing instruments containing frequency transposition. Therefore, a critical review of all literature examining frequency transposition and speech perception has important implications for the selection and prescription of this technology by Audiologists and the expected benefit over conventional technology for the individual with a high-frequency hearing loss.

Objectives

The primary objective of this review is to critically evaluate the existing literature on the effects of frequency transposition in currently available hearing instruments on the speech perception of individuals with high-frequency hearing loss. A secondary objective is to propose an evidence-based recommendation regarding the prescription of hearing instruments containing frequency transposition processing for individuals with high-frequency hearing loss.

Methods

Search Strategy

Computerized databases, including PubMed, Medline, CINAHL, Cochrane, Proquest, PsychInfo, and Scopus were searched using the following search strategy: [(frequency lower*) OR (frequency transpos*) OR (frequency translat*) OR (frequency shift*)] AND [(amplification) OR (hearing aid*) OR (hearing instrument*)]. The search was limited to the English language and Humans.

Selection Criteria

Studies included in this critical review were required to investigate the effects of frequency transposition processing in any currently available hearing instrument on the speech perception of individuals with hearing loss. No limits were set on the demographics (age, gender, culture, race, or socioeconomic status) of research participants, or type of speech perception outcome measure.

Data Collection

Results of the literature search yielded four articles and one poster presentation consistent with the selection criteria: one single subject 'n-of-1' study, three single group studies with a pre-posttest design, and one study presenting two case studies. The intention was to review all current literature that focused on the effect of frequency transposition on speech perception in individuals with hearing loss, which required inclusion of non peer-reviewed literature.

Results and Discussion

Widex Inteo Hearing Instruments

Pre-Posttest Study #1. Korhonen and Kuk (2008) investigated the effects of frequency transposition on speech perception and phoneme confusions for fourteen adults with precipitous high-frequency hearing loss and thresholds greater than 70 dB HL in the high-frequencies. Open-fitting Widex Inteo élan (IN-9é) hearing instruments were fitted binaurally with two programs set with frequency transposition off (conventional processing) and applied. Performance on the Edgerton-Danhauer Nonsense Syllable Test (NST) presented at a soft level (50 dB SPL) was measured at the initial fitting and after a one month period, during which time subjects participated in a computerized training program designed to train identification of transposed speech sounds.

The results indicated that frequency transposition combined with training increased speech perception by 12% for word-initial consonants and 16.1% for medial consonants, and improved identification of phonemes in all phoneme classes (fricatives, affricates, stops, nasals, vowels); however, no statistics or descriptive statistics (i.e. standard deviation, confidence intervals) were provided. Furthermore, important details regarding the methodology were excluded, including: whether stimuli were presented with monitored live voice (more variable) or were pre-recorded; blinding for the subjects and personnel administering the NST with respect to which program contained frequency transposition or which condition was being tested; what training program was used; and whether testing in each program (frequency transposition on or off) was counterbalanced or randomized. These considerations can affect the validity of the study. Thus, the positive speech results of this study do not provide sufficient support for the benefits of frequency transposition on speech perception, because of the absence of statistics and inadequate reporting of methodology.

Pre-Posttest Study #2. Kuk, Peeters, Keenan and Lau (2007) examined the speech perception of thirteen adults with, on average, normal sloping to severe high-frequency hearing loss, who were exposed to conventional and frequency transposition processing for two weeks. Subjects were binaurally fitted with open-fit thin-tube Widex Inteo élan hearing instruments containing two programs with frequency transposition on and off in a counterbalanced, double-blind order. Performance on the Edgerton-Danhauer NST presented at 30 and 50 dB HL was measured for all subjects at the initial fitting, and a subset of the subjects for each level after two weeks. During the two week interval, subjects were instructed to switch between the two programs containing the two types of processing.

The largest change in speech scores occurred when the NST was presented at a quieter level (30 dB HL). Differences in consonant identification between conventional and frequency transposition conditions at the initial and final visits were 6% and 12% at 30 dB HL, versus 4% and 3% at 50 dB HL respectively. Frequency transposition did not appear to have a negative effect on vowel perception. With regard to the speech results from the initial fitting, the authors state that speech scores were significantly higher for both levels of presentation when frequency transposition was applied, but they failed to indicate which statistical tests were employed or report any descriptive statistics. Furthermore, there were no statistics reported for the two week visit, and subjects were not tested at both levels, as in the initial visit. The decision criteria was not specified for which subjects to test at 30 dB HL or 50 dB HL at the second visit. Therefore, the results of this study need to be interpreted cautiously due to the inadequate reporting of statistical results.

While having a good design with counterbalancing and blinding, the methodology has some weaknesses, in addition to the statistics and splitting of subjects on the second visit, which may affect validity of the findings. A standardized protocol for fitting the hearing instrument parameters was not discussed beyond determination of the start frequency for frequency transposition and thus, it is unknown whether default settings were used or adjustments made based on subject reactions and preferences. Also, subjects were educated about frequency transposition prior to commencement of the study, which may introduce subject bias by influencing subject expectations, performance and perceptions. Finally, two weeks with inconsistent use of frequency transposition across time and subject is a relatively short duration for acclimatization to the new sound cues presented with frequency transposition. Different results may be generated upon further follow-up of the subjects. Therefore, given the insufficient statistical analysis and methodological weaknesses, the overall results do not provide sufficient support for the benefits of frequency transposition on speech perception in adults with high-frequency hearing loss.

Case Studies. Auriemmo, Kuk and Stenger (2008) described two case studies of school-aged children with normal hearing sloping to a profound high-frequency hearing loss. Speech perception of the 13 and 8 year old children were measured using the California Consonant Test (CCT) and NST respectively, with their own hearing instruments and then after six weeks of wearing Widex Inteo hearing instruments containing frequency transposition. Both children participated in weekly half-hour auditory training sessions during the six weeks. Other outcome measures of speech production and environmental sound awareness were assessed, but are not relevant to the purposes of the present review and therefore, will not be discussed further.

Perception of consonants by the 13 year old changed by 7% at 30 dB HL and 9% at 50 dB HL after six weeks with frequency transposition and training. The 8 year old showed considerable improvement in perception of consonants at 30 and 50 dB HL, both at the initial fit and after six weeks. However, these comparisons were made to the children's previous hearing instruments, which may have different frequency responses than the Inteo hearing instruments used in the study, irrespective of the application of frequency transposition. Also, limited information is given with respect to the hearing instrument fitting protocol in this study, and it is unclear whether default settings were used or adjustments were made to the Inteo instruments. Therefore, other factors than frequency transposition may account for the observed increase in speech perception. Also, it was not reported whether the tests were conducted with recorded stimuli or monitored live voice, which can affect reliability of results obtained in different sessions.

These results need to be interpreted with caution, as they may not generalize to other children with high-frequency hearing loss. Overall, the results do not provide sufficient evidence to infer that frequency transposition improves speech perception in children due to a small sample size and the presence of a nuisance variable in the methodology.

Summary. Results of the three studies using Widex Inteo hearing instruments show a trend that frequency transposition may improve speech perception in children and adults; however, causality cannot be established due to small sample sizes, insufficient information regarding methodologies, and inadequate statistical analysis. Therefore, in general, the existing evidence does not sufficiently support prescription of these hearing instruments over conventional technology.

<u>AVR Sonovation ImpaCt Hearing Instruments</u>

Pre-Posttest Study #3. Miller-Hansen, Nelson, Widen and Simon (2003) retrospectively reviewed word recognition scores obtained using the Phonetically Balanced Kindergarten Test (PBK-50) from chart notes of children who were binaurally fitted with AVR ImpaCt hearing instrument containing frequency transposition. Data for conventional (previous) hearing instruments and one month after fitting the ImpaCt instruments were available for 16 of 78 children. Hearing loss varied in configuration and severity from mild/moderate to profound. Parental report on the Parent Abbreviated Profile of Hearing Aid Benefit (PA-PHAB), aided audiograms and repair rates were also examined, but will not be discussed further.

Paired t-tests ($P < 0.05$) were used to evaluate performance on the PBK-50. Overall, the children scored 12.5% better with the ImpaCt hearing instruments over their previous hearing instruments, which was statistically significant (standard deviation = 15.7, 95% confidence interval = 4-21, $p = 0.006$). Improvement was also noted in each category of hearing loss (mild to moderate, moderately-severe, severe and profound), and a calculation of Cohen's d indicates that effect sizes for the categories of hearing loss range from medium to large.

Despite the statistical significance and good effect sizes, weaknesses in the study design and concerns with the methodology limit interpretation of the evidence. Although there appeared to be a standard protocol for treatment at the hospital from which the charts were obtained, this study was retrospective and thus, did not offer any means of controlling for unknown or systematic variables that may have influenced selection of participants or their experiences unrelated to the study. Therefore, fidelity or reliability of the study's treatment and measurement procedures are difficult to assess, and weakens the validity of the results (Dollaghan, 2007). Furthermore, the children's previous instruments were used as a baseline measure, which represents a nuisance variable in the study. Electroacoustic characteristics of the previous hearing instruments, other than frequency transposition, may have been inappropriate or at the very least different than those of the ImpaCt hearing instruments. Therefore, an improvement in the speech scores could be due to improved audibility irrespective of frequency transposition processing. Finally, the authors did not indicate how patient responses were monitored, or whether monitored live voice or recorded stimuli were used. Monitored live voice may not be consistent across sessions and speakers, which also may affect the performance scores aside from the frequency transposition. Verbal responses from the children may be difficult to decipher and can be distorted, and subjective decisions are required to score correct replies. Therefore, even though importance of the results is suggestive, they must be interpreted with caution due to design and methodology concerns.

Single Subject Study. McDermott and Knight (2001) analyzed the effects of frequency transposition on the speech perception of three adults with varying degrees of hearing loss, using three tests for each subject: monosyllables similar to the consonant-vowel nucleus-consonant (CNC) test, consonant recognition in an /a/-consonant-/a/ context, and speech in competing noise. Multiple baseline measures were obtained with their previous hearing instruments and at two week intervals for six weeks with the ImpaCt instruments in an ABA sequence. The frequency responses of their previous hearing instruments were controlled for when fitting the ImpaCt hearing instruments.

A two-way analysis of variance ($P < 0.05$) was used to evaluate performance in each condition. There were no statistical differences in speech scores for all three subjects on the monosyllable and consonant tests. However, ceiling effects were observed for two of the three subjects. A significant decrement in scores existed for speech in noise with frequency transposition, although the authors acknowledge that this could be due to the narrower bandwidth generated in the noise program of the ImpaCt hearing instrument, and not necessarily the frequency transposition processing alone. Overall, the results of this study fail to provide evidence for an improvement in speech perception of adults fit with hearing instruments containing frequency transposition, and may suggest a negative effect on speech in noise. Even though the methodology was valid, results may not generalize to all adults with hearing loss due to the small sample size.

Summary. The two studies using AVR Sonovation ImpaCt hearing instruments do not provide evidence of the benefits of prescribing frequency transposition over conventional processing for speech perception in adults and children.

Conclusion

The evidence from these five studies needs to be interpreted with caution because: i) all of the studies included a fairly small sample size, which ranged from two to sixteen subjects; ii) concerns exist regarding experimental procedures in some of the studies; and iii) there was inadequate statistical analysis in some studies. Given these considerations, there is limited evidence for the beneficial effects of frequency transposition on speech perception in children and adults. Furthermore, it should be noted that not all frequency transposition technology is created equal. Although there was a general trend for improvement in speech scores with the Widex Inteo hearing instruments, no such trend was observed with the AVR ImpaCt instruments across studies.

Recommendations

All of the studies in this review used word recognition scores (WRS) as an outcome measure of speech perception. Edgerton, Danhauer and Rizzo (1993) found that there were no practice effects for normal hearing subjects with multiple administrations of the NST on the same day. Therefore, the NST may be appropriate as a pre-posttest measure. However, Thornton and Raff (1978) found that reliability was low for word recognition scores anywhere between 0 and 100% correct. According to their established 95% confidence intervals, the score of 56% correct from the Miller-Hansen et al. (2003) study, for example, would not be considered significantly different than a score of 32 to 80%. The ranges are larger and scores more variable when fewer words are used, such as the 25 to 50 word lists of the NST and PBK-50 respectively. Therefore, in order to ensure that a change in score is actually representative of a true improvement in speech perception, multiple lists of the tests should be administered to increase the number of words presented and to ensure adequate reliability of the scores. Also, ceiling effects were obtained for the WRS measures in the study conducted by McDermott and Knight (2001). In order to focus on a performance level and eliminate floor and ceiling measures, multiple outcome measures can be used, or adaptive procedures can be used as an alternative to a WRS when assessing speech perception.

It is also important to note that most studies did not indicate whether stimuli were recorded or presented with monitored live voice, or the method of monitoring responses from the subjects. There are multiple issues with monitored live voice, such as inconsistent presentation across sessions and tester. Also, the performance at a given intensity can differ if the tester is a male or female (Wilson, Zizz, Shanks & Causey, 1990). Therefore, monitored live voice can introduce inconsistency in administration of the test and variance in results that may not be attributed to the treatment condition. This imposes limits on causality and validity of results. Also, verbal responses from subjects may be distorted through the talk-back system or difficult to decipher depending on the phoneme (e.g. /f, v, ð, Θ/) or speech production abilities of the subject, especially for nonsense syllables, as in the NST. Incorrect or uncertain identification of responses can produce incorrect percent correct scores. Therefore, greater reliability and validity are established if recorded stimuli and responses are used.

Procedures for fitting hearing instruments used in the study are also important to ensuring valid results and inferring causality. In the studies by Auriemmo et al. (2008), Miller-Hansen et al. (2003) and McDermott and Knight (2001), baseline results were measured using hearing instruments that were previously worn by the subjects. However, only McDermott and Knight (2001) matched the frequency response of these instruments when fitting the hearing instruments used for the frequency transposition condition. Without controlling for the frequency response, improvements in speech perception cannot be singularly attributed to the frequency transposition technology, but may also be due to differences in electroacoustic characteristics other than frequency transposition between the two types of hearing instruments.

Therefore, in order to address the concerns associated with experimental procedures, it is recommended that future studies of frequency transposition consider including the following: a greater number of subjects, statistics, recorded stimuli and responses, multiple outcome measures of speech perception, adaptive procedures, and procedures to match electroacoustic characteristics of hearing instruments used for baseline and treatment condition measurements.

Clinical Implications

Overall, the evidence failed to provide sufficient support for improvement in speech perception in individuals with high-frequency hearing loss fitted with the commercially available hearing instruments containing frequency transposition processing. Therefore, based on the existing literature, there is no compelling evidence to prescribe hearing instruments containing frequency transposition over conventional processing for individuals with high-frequency hearing loss on the basis of speech perception outcome measures.

References

Auriemmo, J., Kuk, F., & Stenger, P. (2008). Criteria for evaluating the performance of linear frequency transposition in children. *The Hearing Journal, 61(4),* 50, 52-54.

Dollaghan, C. A. (2007). *The handbook for evidence-based practice in communication disorders* (p. 35). Baltimore: Paul H. Brookes Publishing Co.

Edgerton, B. J., Danhauer, J. L., & Rizzo, S. Jr. (1981). Practice effects for normal listener's performance on a nonsense syllable test. *Journal of Auditory Research, 21(2),* 125-131.

Elfenbein, J. L., Hardin-Jones, M. A., & Davis, J. M. (1994). Oral communication skills of children who are hard of hearing. *Journal of Speech and Hearing Research, 37(1),* 216-226.

Korhonen, P., & Kuk, F. (2008, August). The effect of linear frequency transposition on speech identification n adults. *Poster presented at the International Hearing Aid Conference (IHCON), Lake Tahoe, CA.*

Kuk, F., Peeters, H., Keenan, D., & Lau, C. (2007). Use of frequency transposition in a thin-tube open-ear fitting. *The Hearing Journal, 60(4),* 59-60, 62-63.

MacArdle, B. M., West, C., Bradley, J., Worth, S., Mackenzie, J., & Bellman, S. C., (2001). A study of the application of a frequency transposition hearing system in children. *British Journal of Audiology, 35,* 17-29.

McDermott, H. J., Dorkos, V. P., Dean, M. R., & Ching, T. Y. C. (1999). Improvements in speech perception with use of the AVR TranSonic frequency-transposing hearing aid. *Journal of Speech, Language, and Hearing Research, 42,* 1323-1335.

McDermott, H. J., & Knight, M. R. (2001). Preliminary results with the AVR ImpaCt frequency-transposing hearing aid. *Journal of the American Academy of Audiology, 12(3),* 121-127.

Miller-Hansen, D. R., Nelson, P. B., Widen, J. E., & Simon, S. D. (2003). Evaluating the benefit of speech recoding hearing aids in children. *American Journal of Audiology, 12,* 106-113.

Moeller, M. P., Hoover, B., Putman, C., Arbataitis, K., Bohnenkamp, G., Peterson, B., et al. (2007). Vocalizations of infants with hearing loss compared with infants with normal hearing: Part I – Phonetic development. *Ear and Hearing, 28(5),* 605-627.

Parent, T. C., Chmiel, R., & Jerger, J. (1997). Comparison of performance with frequency transposition hearing aids and conventional hearing aids. *Journal of the American Academy of Audiology, 8,* 355-365.

Stelmachowicz, P. G., Pittman, A. L., Hoover, B. M., Lewis, D. E., & Moeller, M. P. (2004). The importance of high-frequency audibility in the speech and language development of children with hearing loss. *Archives of Otolaryngology – Head & Neck Surgery, 130(5),* 556-562.

Thornton, A. R., & Raffin, M. J. M. (1978). Speech-discrimination scores modeled as a binomial variable. *Journal of Speech and Hearing Research, 21,* 507-518.

Wilson, R. H., Zizz, C. A., Shanks, J.E., & Causey, G. D. (1990). Normative data in quiet, broadband noise, and competing message for Northwestern University auditory test no. 6 by a female speaker. *Journal of Speech and Hearing Disorders, 55,* 771-778.