Critical Review:
What is the effect of frequency transposition on speech perception in children?

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This critical review examines the effect of linear frequency transposition (LFT) on speech perception in children. Study designs include: single group with repeated measures and one case study. Overall, the research failed to provide sufficient evidence to support the use of frequency transposition to improve the speech perception abilities in children with hearing loss. Future research should include more subjects, more homogenous hearing losses across subjects for group level analysis, valid and reliable procedures for measuring speech perception, and standardized hearing aid fitting and verification procedures.

Introduction

Children with hearing loss require appropriate amplification for the development of speech and language (Stelmachowicz, 1999). High-frequency phonemes, such as /s/, /sh/ and /z/ are important speech sounds and grammatical markers. Conventional hearing aids are limited in their ability to provide sufficient gain for high-frequency sounds (Stelmachowicz et al., 2004) due to resonant properties of their receivers and gain limitations because of feedback. Even with early intervention with conventional amplification, children with hearing loss, particularly in the high frequencies, can have delayed speech and language development and fricative acquisition (Stelmachowicz et al., 2004).

Frequency transposition is a type of signal lowing technology that attempts to improve the high-frequency audibility by lowering the high-frequencies to regions of better hearing. Frequency transposition technology takes high-frequency sounds over a set bandwidth (or start frequency) and transposes them to a lower frequency region by adding them to an unprocessed lower frequency signal. Frequency transposition typically does not affect low-frequency information and has the advantage of a more natural sound quality because it preserves the spectral shape of the incoming signal (Simpson, 2009). A disadvantage of transposition is that by overlapping high and low-frequencies there is a chance that the low-frequencies can be masked, as well as unwanted high-frequency noise being made audible (Simpson, 2009). LFT has the potential to improve high-frequency audibility but at the same time cause confusion and decreased discrimination due to new sounds being audible and changed spectral envelopes.

Previous research has been conducted on the effect of LFT in adults and children alike. The results have been mixed, some show unfavourable results with decreases in speech perception, while others have shown promising results.

Objectives

The primary objective of this paper is to critically evaluate existing literature regarding the impact of frequency transposition compared to conventional hearing aids on the speech perception of children with high frequency hearing loss. Furthermore, evidence-based practice recommendations regarding the clinical prescription of frequency transposition devices for children will be made.

Methods

<u>Search Strategy</u>
Computerized databases, including CINAHL, PubMed, Scopus, Medline and Google Scholar were searched using the following search terms: [frequency transposition OR frequency transp* AND speech perception OR speech understanding OR speech recognition OR speech reception OR speech detection AND child OR pediatric OR infant OR toddler].

<u>Selection Criteria</u>
The papers selected for inclusion in this critical review were required to investigate the effects of linear frequency transposition in hearing instruments on the speech perception in children under the age of 18. No limits were placed on the age or current availability of the technology or the type of speech perception outcome measures used. Frequency lowering technology that was excluded from this review were channel vocoders, slow playback and nonlinear frequency compression. Each type of frequency lowering technology may have different effects on the ability to detect high frequency sounds

and therefore effect audibility. Technology related speech perception benefit may be different across technologies.

Data Collection

Results of the literature search yielded the following types of articles congruent with the aforementioned selection criteria: single group with repeated measures (4) and case study (1).

Results and Discussion

Auriemmo et al. (2009) used a single group with repeated measures method to investigate the efficacy of linear frequency transposition for a group of ten school aged (6-13 year old) children with sloping sensorineural hearing losses. All the children spoke English, met various developmental milestones, were in regular classrooms and were experienced users of digital hearing aids that had been fitted with DSL v5.0. The children were fitted with Widex Inteo IN9 or IN19 (power) BTEs with customized skeleton-style, soft material earmoulds, vent size dependent on low frequency thresholds. The Inteos were fitted using DSL v5.0 and RECDs with two programs, LFT on or LFT off. The start frequency for LFT was set on an individual basis. Speech intelligibility was assessed using the CUNY Nonsense Syllable Test, which is a 25 item list in the CVCV format. The children were fitted and tested with the default (no LFT) program at 30 and 50 dB HL, they wore the hearing aids for three weeks and were tested again. They were then fitted and tested with the LFT program at 30 and 50 dB HL, they wore them for six weeks while being tested every three weeks. Auditory training was provided for 30 minutes per week for the entire study. Paired sample t-tests were used to revealed that performance with LFT (at 30 dB HL) after six weeks of training was significantly better than with the default program ($p < 0.05$) as well as the baseline LFT performance ($p < 0.05$). At the 50 dB HL presentation level only statistically non-significant trends, similar to results seen at the 30 dB HL presentation level, were observed. A repeated-measures ANOVA was used to test the significance of the three within-subjects effects: level (30 or 50 dB HL) * aided conditions (six) * phoneme position (two, initial and medial), significant effect for level ($F(1,9) = 48.228$, $p < 0.001$, $\eta_p^2 = 0.84$) and aided conditions ($F(5,45) = 20.005$, $p < 0.001$, $\eta_p^2 = 0.69$) were observed.

However, limitations must be placed on these results because of some weaknesses in the methods. Double blinding was not used, the clinicians were not blinded to the technology being used, therefore biases could be introduced. The greatest effects were observed after the greatest amount of auditory training was received, it is impossible to separate developmental, adaptation and training factors. The improvements seen in speech perception ability could be due to the auditory training or even normal development as opposed to the LFT. When doing group level analysis better to have large sample size, therefore individual analyses may be warranted due to differences in hearing loss and small group size. Overall, the results do not provide sufficient evidence to conclude that frequency transposition improves speech perception in children.

MacArdle et al. (2001) used a case study approach to investigate the use of the Transonic FT 40 frequency transposition system in a group of 36 children with pre-lingual hearing loss or post-lingual profound sensorineural hearing losses. The children were fitted with the FT device and tested with two closed set speech tests. Of the 36 subjects that began the study, 48 months after the initial fitting only 11 children still wore the device. These 11 children were tested again. 25 children stopped their use of the device because of cosmetic (6), ergonomic (4), cochlear implantation (11) or other (4). The testing was done with live voice using the E2L toy test (contains 12 toys which are in pairs with matched vowel sounds) and the Manchester Picture test (presented as a set of cards, each has four pictures with the same vowels or consonants). On the E2L, two children moved from a chance to a ceiling score, two children achieved a 50% improvement and six children there was no change in score. On the Manchester two children demonstrated a change from chance score to 90-100%, two children demonstrated a 50% improvement and seven children did not show any change in score.

Results need to be interpreted carefully due to many weaknesses. It is a body worn device that is coupled to the patient's conventional hearing aids with no mention of how the hearing aids programmed and fitted. Live voice was used for testing, which is inherently more variable. The high drop out rate, resulted in a small sample size. There was a long time between assessments, some improvements could be accounted for in normal development/maturation. A high amount of children did not improve. No statistics or descriptive statistics were provided. Some of the children had learning difficulties, the effect of these difficulties on task performance is unknown. No double or single blinding occurred, possibly introducing biases. A lack of evidence is provided to support findings related to speech perception improvement in children using LFT.

Miller-Hansen, Nelson, Widen and Simon (2003) used a single group with repeated measures method to evaluate the benefits of frequency lowering hearing aids in a group of 16 children (aged 1.3 to 21.6 years old) with bilateral sensorineural hearing loss. The children, all previous hearing aid wearers, were fitted with the AVR Sonovation ImpaCt DSR hearing aids with frequency transposition using DSL I/O, RECDs and verified with real-ear measurements. Aided word recognition scores were obtained at 35 dB SL (re: PTA) with the Phonetically Balanced Kindergarten test presented using monitored live voice at fitting and at one month follow-up. Results of conventional hearing aids vs LFT hearing aids were compared using paired t-tests which showed LFT aids performing significantly better than conventional (SD = 15.7, 95% CI = 4–21, p = .006). The children showed a mean improvement of 12.5% in word recognition testing.

Weaknesses in the methodology limit what can be interpreted from the results. Neither the tester nor subject, were blind to the technology, this potentially introduces biases. Baseline measures were made with the children's previous conventional hearing aids. Electroacoustic characteristics of the previous hearing aids compared to the new ones alone could account for the improvement in speech perception seen. The previous hearing aids could have been set inappropriately and therefore only updating the hearing aids could account for the effects seen. The hearing losses were not well matched, making results of a group level analysis difficult to generalize from. There were also large age differences. Therefore, results must be interpreted with caution because of concerns with the methodology and design.

Rees and Velmans (1993) used a single group design to evaluate the effect of transposition on the untrained auditory discrimination of eight children, aged seven to twelve, with congenital high frequency hearing loss. The children were tested using the desk model FRED device coupled to TDH 39 headphones. The FRED device shifts the 4-8 kHz region to the 0-4 kHz region, this device has a traditional amplification channel and a transposition channel. Discrimination was tested with a two-alternative forced choice task, they were asked to pretend two robots could talk, one robot was pointed to while one word was presented, the other robot was pointed to with another word, then one word was repeated and the child had to point to "which robot said it". One list of monosyllabic words was presented under LFT, then two lists under no LFT and then one list under LFT again; repeated procedure using nonsense syllables. Retested between one and seven days after the initial test. Discrimination scores were analyzed using a repeated measures ANOVA with three within-subject factors (transposition vs no transposition, words vs nonsense syllables, test vs retest). The group as a whole had mean scores under the transposition condition that were significantly greater than scores under the no transposition condition (overall improvement of 8.1%). No significant difference is reported between words and nonsense syllables or between test and retest. There were no significant interaction effects. Transposition scores ranged greatly, from 15.6% better to 6.3% worse, 7 out of 8 children were better with LFT.

However, results need to be interpreted carefully due to limitations in the methods used. Hearing losses were not well matched, this makes group level analysis weak, especially with a low number of subjects. The method of testing discrimination has not be validated or proven reliable and there are no norms available. Also, it is not clear if the child's hearing loss is programmed into the FRED device or if there was a default amount of gain provided. A lack of evidence is provided to support findings related to speech perception improvement in children using LFT.

Smith, Dann and Brown (2009) used a single group with repeated measures design to examine the benefits of LFT on six children with sloping high-frequency losses. All the children were oral communicators, spoke English, had no other physical or sensory handicap and were in mainstream classes. They were all fitted with either Widex Inteo IN9 or IN19 (LFT on program and LFT off program) with new molds using an in-situ protocol and allowed to acclimatize for three weeks before testing occurred. Their speech perception abilities were tested using 50 phonetically balanced words with no carrier phrase with monitored live voice at a normal speaking level from one meter in a quiet room. Testing occurred three weeks following fitting and at six week intervals for 24 weeks. Testing was performed using both audio-visual and audition-alone conditions. They were tested with LFT on and off, in each modality. Paired t-tests were performed on the scores for audition-alone word test which showed a significant difference between transposition on and transposition off (t = 3.35, p = 0.01). A paired sample t-test performed on the scores for the audition-alone phoneme test showed a significant difference between transposition on and transposition off (t = 4.65, p = 0.003). Audio-visual tests showed much more variability, these results are not important to the review. Overall a trend of sustained improvements over the 24 week period was observed.

Interpretation of results are limited because of methodological issues. This study consisted of a small sample size and the hearing losses were not well matched, including one asymmetrical loss. The hearing aids used were not set with a well validated prescription such as DSL v5. Testing was done without a soundbooth or audiometer, using live voice and sound level meter. Testing without a soundbooth increases the amount of variables that cannot be accounted for, such as ambient room noise. Testing with monitored live voice is more variable than testing done with a recorded speech signal and harder to compare to previous testing due to this variability. All the children had different teachers and resource teachers, and various amounts of auditory training and lip reading training outside of the study, adding confounds that cannot be accounted for. Double blinding did not occur as the tester was not blinded to whether the hearing aid was in LFT on or conventional processing. Therefore, results must be interpreted with caution because of concerns with the methodology and design.

Conclusion

The evidence provided by these five studies should be interpreted with caution because all of the studies included small sample sizes, ranging from six to sixteen subjects and each study had various methodological concerns that would lead one to question the results. When analyses are completed at the group level and the groups are small and not homogeneous this limits the ability to generalize the findings of the research to the greater population. Although all the studies would suggest a trend that their children benefited from the use of LFT the results could be attributed to various factors, such as developmental effects, training effects and differences in electroacoustic characteristics between baseline and study hearing aids. This testing was primarily done in an acoustically controlled environment which makes it difficult to extrapolate the results to real-world situations. Therefore there is limited evidence to support the beneficial effects of frequency transposition on the speech perception in children.

Future studies should include: larger sample size with well matched hearing losses, group level statistics, controlled acoustic conditions (soundbooth, audiometer, recorded speech sample), multiple valid and reliable outcome measures of speech perception, and use the same hearing aid for baseline measures and the treatment condition. Another option would be to conduct these studies using a case study approach. This is an option because the practice of clinical audiology is done on a case by case basis. Case studies allow for more individualized analysis and interpretation of results.

Clinical Implications

Despite the studies providing relatively weak evidence to support the use of LFT in hearing impaired children improvements were observed in some of the children. For this reason alone, LFT should be utilized clinically. Clinically it should be used on a case by case basis. The use of linear frequency transposition should be tried if the child has a severe to profound high frequency hearing loss with good low and mid frequency hearing and has poor speech perception abilities or struggling with conventional hearing aids. The clinician should use standardized fitting and verification procedures and make the LFT fitting individualized.

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