REDUCTION IN ERRORS OF OMISSION AND SUBSTITUTION WITH LINEAR FREQUENCY TRANSPOSITION

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INTRODUCTION

An alternative to providing sufficient audibility for high-frequency sounds is through frequency lowering (Braida et al 1979). Unfortunately, a dilemma in understanding the efficacy of frequency lowering is being able to explain the mixed findings in the literature (Table 1). One reason is the differing nature of the various techniques. Perhaps of equal importance is how the algorithms are evaluated. Most speech tests used to evaluate frequency lowering are monosyllabic words and sentences which are not high frequency based. It is also well known that phoneme positions also present differing levels of difficulty to the hearing impaired patient. Yet, most tests that were used to examine the efficacy of frequency lowering had consonants in one fixed position only. The "closed set" nature of many of the commercial tests limits the extent of the interpretation one may make on the mechanism through which frequency lowering achieved its objective. By studying the types of errors such as omission or substitution, one may understand how frequency lowering affects audibility and intelligibility. Such interpretations may be possible with the use of a nonsense CVCVC open-set test. The goal of this study was to demonstrate that by using the ORCA-NST (CVCVC format), we can better understand how linear frequency transposition (LFT) achieved an improvement in overall speech understanding score.

Table 1: Tests and results for frequency lowering in 2000-2010, adults data.

Paper	Frequency lowering technique	Speech perception tests	Results
McDermott & Dean (2000)	Linear frequency shifting	Monosyllabic words (CNC)	No significant group improvement
Sakamoto et al (2000)	Nonlinear frequency compression	Sentences recognition	No significant group improvement
McDermott & Knight (2001)	AVR ImpaCt	Monosyllabic words (CNC), consonants (one C per item, closed set), sentences	No significant group improvement
Simpson et al (2005)	Nonlinear frequency compression	Monosyllabic words (CNC)	Significant improvement for 8 out of 17 participants
Simpson et al (2006)	Nonlinear frequency compression	Monosyllabic words (CNC), consonants (VCV, closed set), sentences	No significant group improvement
Robinson et al (2007)	Transposition	Nonsense syllables (VCV, closed set)	Significant group improvement for affricates
Gifford et al (2007)	AVR Nano Xp	Monosyllabic words (CNC), sentences	No significant group improvement
Glista et al (2009)	Nonlinear frequency compression	High frequency words (one C per item, closed set), vowel	Significant group improvement for consonants
Kuk et al (2009)	Linear frequency transposition	ORCA-NST (CVCVC, open set)	Significant group improvement for fricatives in quiet and in noise

METHOD

Participants

- 8 native English speakers, average age 67 years (SD = 18 years).
- 5 of them were experienced HA users and 3 inexperienced; none had worn hearing aids with frequency lowering prior to the study.

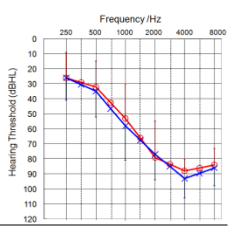

Figure 1: Averaged hearing thresholds for participants: right ear in red and left ear in blue.

Study Hearing Aids

- Widex Mind 440 (model m and 19) BTE hearing aids with linear frequency transposition (LFT), coupled instant occluding earmolds.
- Fitting with sensogram (in-situ thresholds); feedback test was performed; verification with simulated real-ear output on the fitting software.
- "Start frequency" and extra gain for LFT were obtained with a recorded, interrupted /s/ sound presented at 30 dB HL (Kuk et al 2009).

Test Materials and Test Conditions

- ORCA nonsense syllable test, 32-item with female speaker (Kuk et al 2010).
- Each item was in CVCVC format with 3 consonant positions (C1, C2, C3), with stress on second vowel.
- Speech stimuli at 50 dB SPL and 68 dB SPL were delivered via the loudspeaker at 0^0 azimuth, 1 m from the participants; test conditions were counterbalanced. All tests were conducted in sound booth in quiet.
- Test items were randomized for each presentation of the test:
  - A verbal response, either judged as the target sound or a substitution error, was recorded for each word position.
  - No response to a stimulus was counted as an omission error.

Auditory Training

- PC-based, self-training program for participants to practice at home in quiet and in noise (Kuk et al 2007).
- "Bottom-up" materials to improve auditory discrimination skills of phonemes (vowels and consonants).
- Target consonants were 3 voiceless plosives /p, t, k/ and 4 voiceless fricatives /s, f, ʃ, θ/.
- Training involved interactive listening activities with immediate feedback.

Procedures

- Visit 1: ORCA-NST evaluation with amplification alone (i.e., non-LFT use); participants were not given study aids to use at home.
- Visit 2: One week after visit 1; ORCA-NST evaluation with LFT; participants were instructed to wear study aids with LFT daily and to complete auditory training at home.
- Visit 3: After one month auditory training (20-30 minutes everyday according to a schedule); ORCA-NST evaluation with LFT; participants were instructed to wear study aids with LFT at home (no auditory training).
- Visit 4: After one month from Visit 3; ORCA-NST evaluation with LFT.

RESULTS

Identification Scores

Figure 2 shows the identification scores obtained at 50 dB SPL (left panel) and 68 dB SPL (right panel).

- 50 dB SPL:
  - Identification scores increased gradually over time for C1, C2, and C3.
  - Identification scores for C1 and C2 were higher than C3.
- 68 dB SPL:
  - Identification scores increased 4% from non-LFT to 2-month LFT for C1.
  - Identification scores dropped from 63% at non-LFT to 57% at initial LFT for C2, then increased to 67% at 2-month LFT.
  - Identification scores increased gradually over time for C3.
  - C1 and C2 had identification scores higher than C3.

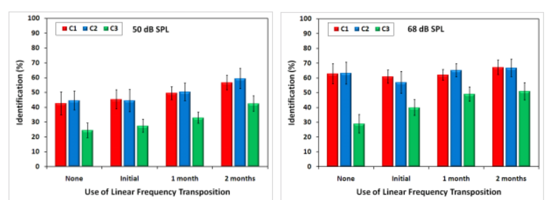

Figure 2: Identification scores for different consonant positions (C1, C2, C3) over time. Error bars are standard errors about the mean.

Errors of substitution and omission

Figure 3 shows the omission errors (unfilled bars) stacked on the substitution errors (filled bars) obtained at 50 dB SPL (left panel) and 68 dB SPL (right panel) for different consonant positions (C1, C2, C3).

- 50 dB SPL:
  - Omission errors were small, < 2% for C1 and C2 at all visits.
  - Omission errors decreased over time for C3 (from 38% to 16%).
  - Substitution errors decreased over time for C1 and C2.
  - Substitution errors were about the same over time for C3.
  - Substitution errors were higher at C1 and C2 than at C3.
- 68 dB SPL:
  - Omission errors were absent (0 %) for C1 and C2 for all visits.
  - Omission errors were decreased over time for C3 (25% to 6%).
  - Substitution errors were higher at C3 than at C1 and C2.
  - Substitution errors were about the same over time for C3.
  - Substitution errors decreased over time for C1 and C2.

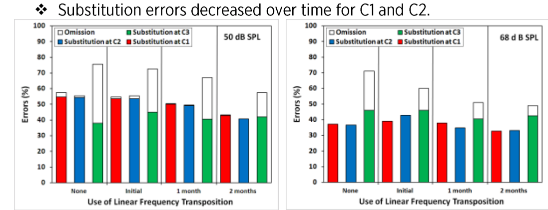

Figure 3: Omission errors (unfilled bars) stacked on substitution errors (filled bars) for different consonant positions (C1, C2, C3) over time.

Position effect on identification scores and errors

2-way repeated-measures ANOVA analyses for the effect of LFT use (non-LFT, initial-LFT, 1-month LFT, 2-month LFT) and consonant position (C1, C2, C3) on identification scores, substitution errors, and omission errors were conducted. Post-hoc 1-way repeated-measures ANOVA analyses for the effect of LFT use on identification scores, substitution errors, and omission errors were conducted for individual consonant positions. Table 2 shows the statistical results for the effect of LFT use. A check mark "✓" indicates the effect of LFT use to be significant (p < 0.05).

Table 2: Effect of LFT use on identification scores, omission errors and substitution errors for different consonant positions (C1, C2, C3) at 50 dB SPL and 68 dB SPL. A check mark shows the effect was significant (p<0.05).

Effect of LFT use	50 dB SPL				68 dB SPL			
	All positions	C1	C2	C3	All positions	C1	C2	C3
Identification Scores	✓		✓	✓	✓		✓	✓
Omission Errors	✓			✓				
Substitution Errors			✓				✓	

- Identification scores: Significantly improved over time for combined position effect and individual positions C2 and C3, tested at both intensity levels.
- Omission errors: Significantly reduced over time for combined position effect and C3, tested at 50 dB SPL.
- Substitution errors: Significantly reduced over time for C2, tested at both intensity levels.

Reduction of omission errors at low input level

- For discussion, consonants with omission errors >25% when tested at non-LFT were considered as "frequently omitted" sounds.
- These frequently omitted consonants were grouped according to whether their reduction in omission errors ("O") >25%, reduction in substitution errors ("S") >25%, and increase in identification scores ("I") >25% between no-LFT and 2-month LFT use (Figure 4):
- ***Group 1:*** *Reduction in "O" and "S" <25%; Increase in "I" <25%*
  - /k/, /t/, /l/ tested at 50 dB SPL; /t/, /l/ at 68 dB SPL
- ***Group 2:*** *Reduction in "O" >25%; Reduction in "S" <25%; Increase in "I" <25%*
  - /f/, /θ/, /ð/, /tʃ/ tested at 50 dB SPL; /θ/ at 68 dB SPL
- ***Group 3:*** *Reduction in "O" >25%; Reduction in "S" <25%; Increase in "I" >25%*
  - /s/, /ʒ/ tested at both 50 dB SPL and 68 dB SPL
- ***Group 4:*** *Reduction in "O" <25%; Reduction in "S" >25%, Increase in "I" >25%*
  - /ʃ/ tested at both 50 dB SPL and 68 dB SPL

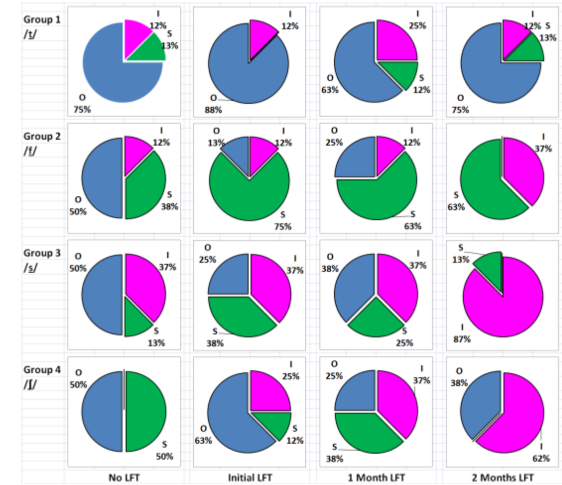

Figure 4: Pie charts to show the distribution of identification scores ("I"), omission errors ("O"), and substitution errors ("S") for the frequently omitted target consonants (with "O" >25% initially) in different visits. Only one consonant is shown for each group; grouping is according to whether reduction in "O" and "S" >25%, and whether increase in "I" >25% between non-LFT and 2-month LFT use.

CONCLUSIONS

- Significant improvement of LFT was found for identification of consonants at CV and at VC positions.
- Improvement of LFT at CV position is mainly a result of correcting substitution errors.
- Improvement of LFT at VC position is a result of reducing omission errors and a result of correcting substitution errors.

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