Perceptions of Nasal Air Emission in Speakers with Cleft Palate

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Abstract

Audible nasal emission (ANE) is a common speech distortion associated with cleft palate or velopharyngeal dysfunction. This study examined the validity and reliability of listener perceptual judgments of ANE using interval scaling and magnitude estimation techniques. Speech samples were collected from 6 adolescents with a history of cleft palate with ANE during speech. Occurrences of ANE in speech samples were identified using visual and auditory inspection. Using an acoustic modification technique, samples were digitally modified to selectively amplify perceived occurrences of ANE +5, +10, and -96dB, to create three stimulus conditions. The original recording of the speech samples served as a control condition. Thirty-one adult listeners performed rating tasks in which they judged the severity of ANE in the speech samples using interval scaling and magnitude estimation without a modulus. Acoustic analysis of ANE was performed using long-term spectral analysis. Statistical analyses included ANOVA, regression and curve-fitting methods according to the procedures of Stevens (1975). Results revealed that magnitude estimation ratings demonstrated stronger evidence of validity and reliability than interval scaling. The curvilinear relationship found between the sets of ratings suggests that ANE is a prothetic or ratio-level perceptual continua that should be scaled using magnitude estimation or other ratio-based methods. In addition, a new model of factors associated with listener perceptions of ANE is supported by evidence that the relative intensity of ANE, the number of occurrences of ANE, and specific acoustic characteristics associated with ANE were all significant predictors of listeners' perceptual judgments of the severity of ANE. With more valid and reliable listener perceptual judgments of ANE, clinicians and researchers can make more accurate clinical diagnoses, measure pre- and post-treatment changes in speech, and compare speech outcomes across studies of persons with cleft palate.

Perceptual Judgments of Speech Characteristics Associated with Cleft Palate

- **Hypernasality:** perception of excessive nasality during the production of vowels and vocalic consonants (Kummer et al., 1992; Whitehill et al., 2002; Kuehn & Moller, 2000).
- **Audible nasal emission (ANE):** perception of "extra noise" in the speech signal, resulting from the escape of turbulent nasal airflow during the production of consonants which require high intra-oral air pressure (Zajac, Mayo, Kataoka, & Kuo, 1996; Peterson-Falzone et al., 2001); Can range from barely perceptible, to loud and "rustling;" also referred to as *nasal turbulence, nasal rustle, nasal snort*, or a variety of other terms (Trost 1981; Kummer et al., 1992; Mason & Grandstaff, 1971; Peterson-Falzone et al., 2001).

Types of Perceptual Continua

- **Metathetic**: varies in quality; are "substitutive" or "exchangeable;" includes position, inclination, pitch, defectiveness of articulation, foreign accent (Stevens, 1957; Stevens and Galanter, 1957; Southwood & Flege, 1999)
  - Interval scaling or DME appropriate rating methods
- **Prothetic**: varies in quantity, strength, magnitude (additive in nature); includes loudness, intelligibility, stuttering severity, speech naturalness, roughness, nasality (Schiavetti et al., 1981, 1983; Southwood, 1996; Toner and Emanuel, 1989; Zraick and Liss, 2000; Whitehill et al., 2000).
  - DME is an appropriate rating method

Common Types of Perceptual Judgments of Speech

- Equal-Appearing Interval (EAI) Scaling (e.g., 0-6 rating scale)
- Direct Magnitude Estimation (DME): scale speech samples relative to each other or a standard stimulus (known as the *modulus*) by assigning a numerical value to each stimulus item relative to the modulus or the first sample heard (*modulus-free* condition).
- Other: Categorical, Visual Analog Scaling, Binary, Rank Order, Paired Comparisons

Recent research suggests that DME permits a more valid rating of perceived nasality and more reliable listener perceptual judgments than interval scaling (Zraick and Liss, 2000; Whitehill et al., 2002; McHenry, 1999). Concerns have been raised regarding the construct validity of interval scaling and the reliability of listener ratings of nasality (Zraick and Liss, 2000; Zraick et al., 2000; Whitehill et al., 2002; Lohmander & Olsson, 2004).

Research Questions

Which rating method demonstrates stronger evidence of construct validity, as assessed using the procedures of Stevens (1975)?

Which method yields ratings with higher inter- and intra-listener reliability?

Which method's ratings demonstrate stronger correlations with factors associated with ANE?

Which of these factors predicts listener judgments of ANE?

Stimulus-related factors? Acoustic factors? Number of occurrences of ANE?

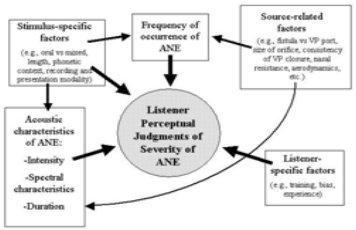

Figure 1. Theoretical model of factors associated with listener perceptual judgments of audible nasal emission.

Method

Speakers

- 6 speakers with ANE (3 males, 3 females; mean age = 13.3 yrs)
- History of cleft lip and palate or submucous cleft palate
- Passed hearing screening at 20dB

Speech Recordings

Stimuli: Novel sentence trios

- Oral-only, loaded with primarily stops or fricatives
- Mixed (oral and nasal sounds)

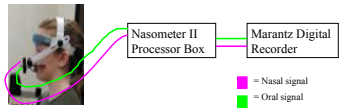

Figure 2. Speech recording instrumentation

Procedures

- Calculated # of occurrences of ANE.
- Significant difference in the number of occurrences of ANE by stimulus type within oral-only stimuli ($p < 0.03$) and by speaker ($p<0.001$). Interjudge reliability: $r = 0.95$.

Digital Manipulation of ANE

Occurrences of ANE in the nasal signal were either amplified or attenuated to create 4 stimulus conditions: 1 control condition, 3 amplification conditions including +5, +10, and -96dB (the "no ANE" condition)

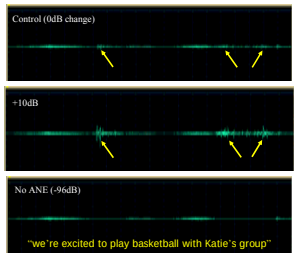

Figure 3. Example of digital manipulation of ANE in the nasal signal resulting in a control (0 dB change) condition, +10 dB condition, and -96 dB ("no ANE") condition. Arrows denote occurrences of ANE.

Listeners

31 trained adult listeners (SLP graduate students)

- Completed coursework in cleft palate
- Stimuli presented over headphones to listener while seated in a soundbooth.

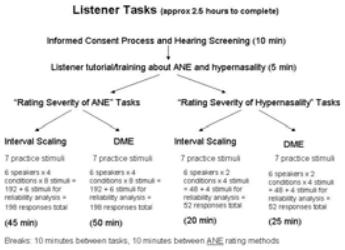

Figure 4. Flowchart illustrating listener perceptual judgments tasks for this study.

Data Analysis (per Lane et al., 1961; Engen, 1971; Stevens, 1975)

- The arithmetic mean of the interval scale ratings and the geometric mean of the modulus-equalized DME ratings were calculated. The means were plotted against each other.
- Progressively higher order polynomials were fit to the data until a nonsignificant improvement in was fit obtained.
- The strength of the relationship between factors associated with ANE and each method's ratings were examined using correlation coefficients, regression analysis.
- Inter- and intra-listener reliability was calculated using % exact agreement, Pearson's, Spearman's, and intra-class correlation coefficients.

Results

Validity

ANOVA for interval scale ratings regressed on magnitude estimation ratings shows a statistically significant F ratio (F [2, 189] = 1893.38, $p < 0.0001$). The curvilinear (quadratic) model accounts for significantly more variance ($r^2 = 0.95$) in predicting listener ratings of ANE than a linear model. **A curvilinear** relationship was found to best fit the data for the full set of ANE stimuli ratings. This suggests that ANE is a **prothetic** continua and **DME** is the rating method with stronger validity.

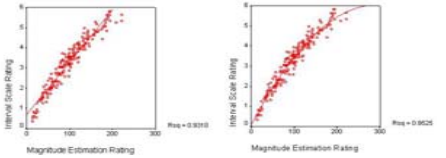

Figure 5. Direct magnitude estimation ratings plotted as a function of interval scale ratings.

Reliability

DME ratings demonstrated consistently higher intra- and inter-listener reliability than interval scale ratings.

- Intralistener: Interval scaling Spearman's ρ= 0.59; DME Pearson's r = 0.80
- Interlistener: Interval scaling ICC r=0.53; DME ICC r =0.79

Relationship between Listener Ratings and Factors Associated with ANE

The **relative intensity (amplification condition)** of ANE was found to be significantly correlated with listener ratings of the severity of ANE for both rating methods (DME $p<.01$, $\rho=.62$; Interval scaling $p<.01$, $\rho = .65$). Louder occurrences of ANE were perceived to be more severe.

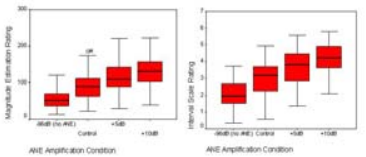

Figure 6. Boxplots illustrating that listeners perceived an increase in the severity of ANE as the intensity of ANE was digitally manipulated within the speech samples, for both rating methods.

The **# of occurrences of ANE** was found to be significantly correlated with listener ratings of the severity of ANE for both rating methods (Interval Scale Ratings: $p<0.01$, $\rho = 0.49$; DME Ratings: $P<0.01$, $\rho = 0.51$). Samples with more frequent ANE were rated as more severe.

An exploratory analysis of the **acoustic characteristics of ANE** was conducted. LTAS analysis suggested that ANE is associated with an increase in energy in the highest frequency regions of the spectrum. Correlations between perceptual judgments of ANE and spectral slope were significant (Interval Scale: $p<0.01$, $\rho = -0.61$; DME: $p<0.01$, $\rho = -0.51$).

Predictors of Listener Judgments of Severity of ANE

Regression results were similar for interval scaling and DME.

Significant predictors (all $p<0.001$): intensity of ANE (amplification condition), number of occurrences of ANE, and spectral slope.

Overall, correlation and regression analyses suggest that either method results in perceptual judgments of ANE that are sensitive and responsive to these factors found to influence listener perceptions of ANE.

Discussion

- Similar to findings for other speech phenomena, the results of this study support that ANE is a prothetic perceptual dimension.
- Direct magnitude estimation demonstrates stronger evidence of validity and reliability compared to interval scaling for listener judgments of ANE.
- There are multiple factors associated with listener perceptions of the severity of ANE including, but not limited to, intensity, frequency of occurrence, and spectral characteristics.
- Contrary to expectations, stimulus type did not result in significant differences in listener perceptions of ANE.
- Other factors to be explored: source of ANE (e.g., location of orifice, size, shape), other acoustic characteristics (e.g., duration, timing of ANE), aeromechanical factors (e.g., magnitude of nasal airflow), etc.

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