Perceptual importance of the voice source spectrum from the second harmonic to 2kHz.

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Introduction

- This poster examines the perceptual importance of the source spectral slope from the second harmonic (H2) to 2 kHz.
- Part of an overall effort to devise a model of voice quality comprising perceptually-valid acoustic attributes (a psychoacoustic model).
- Two sections:
  - Acoustic and perceptual analyses of the spectral slope from H2-H4 and from H4-2 kHz.
  - Data on the importance of spectral components in perception of voice quality contrasts in Hmong.
Part I: Describing the source spectrum and assessing perceptual importance of H2-H4/H4-2 kHz

- Based on previous work, we assume that perceptually-important variability in the harmonic source can be characterized by 4 acoustic parameters: the spectral slope from H1-H2, H2-H4, H4-2 kHz, and 2 kHz-5 kHz.

- Question: Do these parameters covary freely, or are there characteristic spectral shapes that tend to co-occur?

- Classical view: Spectra roll off smoothly at 12 dB/octave.
Acoustic analyses

- 49 voices
  - 18 male, 31 female
  - Randomly selected
  - Assorted vocal pathologies plus normal
  - Sustained /a/

- Source spectrum modeled using inverse filtering followed by analysis by synthesis

- 4 source spectral slope features (Fig. 1)
  - H1-H2, H2-H4, H4-2 kHz, 2 kHz-5 kHz
Figure 1. Natural (red) and synthetic (blue) voice spectra and the corresponding synthetic source spectrum.
Results: Patterns of spectral roll off

- Slopes of the 4 segments were uncorrelated, as expected.
- The majority of spectra were characterized by slopes that increasingly flattened (as a function of frequency) with increasing frequency* (Fig. 2a).
- Elbows occurred in this basic curve, with likelihood of occurrence and the size of the change in slope decreasing with increasing frequency (Fig. 2 b-d; F(2, 17) = 8.48, p < 0.01).
- Spectral shapes from H2-2k range from moderately concave to moderately convex.

* Same result when scaled in dB/octave or dB/Hz.
Figure 2

A. N=29/49

B. N=12/49

C. N=5/49

D. N=3/49
Preliminary perceptual evaluation

- Four voices (2 male, 2 female)
- H2-H4 and H4-2 kHz were varied in steps of 2 dB by altering the amplitude of H4 (Fig. 3).
- Other harmonic amplitudes were adjusted to maintain smooth slopes.
- H1-H2, 2 kHz-5 kHz and all other synthesizer parameters remained constant.
- One expert listener; same-different (A/X) task
Original spectrum

H4 decreased by 6 dB

H4 increased by 6 dB
Results

- JNDs for H4 amplitude (and associated spectral slopes) ranged from 2-4 dB for both increases and decreases in amplitude. Interactions with other spectral attributes remain to be investigated.

- Range of variability in H2-H4 across voices ≈ 10.4 dB; JND/range ≈ 0.29

- Range of variability in H4-2kHz across voices ≈ 18.3 dB; JND/range ≈ 0.16

- *Consistent with the perceptual importance of these spectral features.*

- Part II investigates this possibility in more detail.
Part II: Perception of H1-H2 and H2-H4 in speakers of Hmong

- We tested the model on listeners of White Hmong.
- Hmong has two tones (–g vs. –j) that differ primarily in voice quality.
  - Cf. breathy *tag* [tâ] and modal *taj* [tâ]
- 15 Hmong speakers were presented with a forced choice task (breathy vs. modal word).
Spectral manipulations

- Synthesis modeled on a sustained /a/ vowel uttered by a healthy female speaker
  - The vowel was then shortened to a normal length for /ta/ in Hmong (about 300 ms)
  - The pitch was set to a high-falling contour starting at 280 Hz, typical for a female speaker
  - A token of onset /t/ was spliced onto the synthesized vowel.

- Controlled for factors like F0 and NHR; only spectral components were manipulated
Spectral manipulations

- 18 stimuli were created in five conditions:
  - Condition 1: H1-H2 varied between -2 and 15 dB (H1 manipulated; all other components held constant)
  - Condition 2: As H1-H2 increased from -2 to 15 dB, H2-H4 decreased linearly (H2 manipulated).
  - Condition 3: As H2-H4 increased from 5 to 22 dB, H4-2k decreased linearly (H4 manipulated; H1-H2 constant at 8dB)
  - Condition 4: As H4-2K increased from 10 to 27 dB, 2k-5k decreased linearly (harmonic nearest 2 kHz manipulated; H1-H2 and H2-H4 held at 8 and 22dB, respectively)
  - Condition 5: 2k-5k varied between 0 and 17 dB (highest harmonic manipulated)
Example of manipulations:
Changing the amplitude of H2

\[ H_1 - H_2 = -2 \text{ dB}; \quad H_2 - H_4 = 22 \text{ dB} \]

\[ H_1 - H_2 = 3 \text{ dB}; \quad H_2 - H_4 = 17 \text{ dB} \]
Results

- We ran a logistic mixed-effects regression model
  - Breathy vs. modal response was the dependent variable
  - Each component was a fixed effect
  - Subject as random effect

- Each model component contributed significantly to perception of phonemic breathiness, but H1-H2 and H2-H4 (independently) contribute most significantly to model fit ($z > 10$ $p<0.0001$; cf. $z = -2.2$, $p<0.05$ for H4-2 kHz, $z = -3.4$, $p<0.001$ for 2 kHz-5 kHz).
Results (continued)

- Increase in H1-H2 and/or H2-H4 > more “breathy” responses.

- When they covary (as in Condition 2), the two components can cancel each other out:
  - High H1-H2 but low H2-H4 $\rightarrow$ modal
  - Low H1-H2 but high H2-H4 $\rightarrow$ modal
Proportion of 'breathy' responses as a function of H1-H2

H1-H2 varying

H1-H2 and H2-H4 covarying

R² = 0.8637

R² = 0.0846
Proportion 'breathy' responses as a function of H2-H4

- H1-H2 and H2-H4 covarying
- H2-H4 and H4-2kHz covarying

R² = 0.0846

R² = 0.8093
Conclusions

- A model of the source spectrum comprising only four components (H1-H2, H2-H4, H4-2kHz, and 2kHz-5kHz) can adequately model a range of pathological and healthy voices.
- Most deviations from continuous source spectral rolloff occur in the lower frequency range (below 2kHz).
- Each of the components is perceptually useful, with H1-H2 and H2-H4 both independently responsible for determining perception of linguistically breathy voice quality.
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