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FREQUENCY-MODULATION VOWEL MAPS IN NORMAL-HEARING AND HEARING-IMPAIRED LISTENERS

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INTRODUCTION

Sound emitted by most natural vibrating sources is not steady in pitch but contains frequency fluctuations over time during which the harmonicity of the frequency components is typically preserved, as for instance in the vibrato of human singing voices (e.g., McAdams, 1984; Maher and Beauchamp, 1990). This coherent frequency modulation (CFM) has been shown to enhance the audibility of the formant structure of the source's sound-frequency components (Sundberg, 1994), with implications for the ability of listeners to recognize and segregate vowels (e.g., McAdams, 1985; Demany and Semal, 1990; Divenyi et al., 1997). There is compelling evidence that sensorineural hearing loss is in addition to a loss of sensibility, often accompanied by a deterioration of frequency discrimination and of the ability to detect frequency changes over time, as reflected by elevated frequency-modulation detection limens (FM-DSLs) (e.g., Zurek and Formby, 1981; Moore and Gerschenson, 2002). Such deterioration, argued due to a loss of resolution in the representation of tonotopic activity, temporal phase-locked information, or both, may thus have consequences for the perception of vocal activity, and thereby vowel quality and identification, in hearing-impaired (HI) listeners. The present study investigated the ability of HI listeners to perceive a sung vowel based on the addition of CFM to a steady complex tone, compared to a group of normal-hearing (NH) listeners. This was achieved by obtaining "vowel maps" in the two groups as a function of the two primary acoustic parameters of vowel rate and FM excursion.

RESEARCH QUESTIONS

- What is the effect of the vowel map in HI listeners along the FM-rate and FM-excitation dimensions?
- Is such a map affected by hearing impairment, and if so, along which dimensions?

METHODS

Stimulus configuration

Harmonic complex tone with first 8 harmonics of vowel /o/.
- CFM applied by adding the same frequency shift M (cents) to all N components:
  \[ f(n) = f_0 \left(1 + \frac{M}{1200}\right) \]
  \( f_0 = \text{harmonic number}; f(n) = \text{fundamental frequency} \)
- shimmer and flatter added for better simulation of natural vocal vibration.
- Three temporal segments with "on-off-then-hear" (Bregman and Ahad, 1986) such that adding CFM leads to the fusion of all components into a singing voice (Fig. 1).

Procedure

- Tracking of the "sweet spot" area for which a singing voice emerges in the third segment stimulus as a function of FM rate and FM excursion [Fig. 2].
- One FM parameter was kept constant while the other was adjusted in a 1-interval 2-ARC yes-no task with a 1-up, 1-down paradigm.
- Thresholds were approached from outside the sweet spot (unnatural vibrato) at FM rates of [3, 4, 5, 6, 7, 8] Hz and FM excursions of [21, 35, 49, 63, 77, 91] cents.
- 6 reversals, step sizes of [3.5, 4.5] Hz (FM rate) and [4.5] cents (FM excursion).
- 5 repetitions per segment for each of the 24 conditions.

RESULTS

Subjects

- 14 NH listeners (8 musicians, 6 non-musicians).
- 12 HI listeners (7 musicians, 5 non-musicians).

Effects of hearing impairment and musical experience

- Broader excursion in HI listeners, shifting towards higher FM excursions and lower FM rates compared to NH listeners [Figs. 3, 4, 5].
- No ANOVA on mean FM rates and square-root transformed mean FM excursions for each boundary, with hearing loss and musical experience as factors [Fig. 5].
- Significant variance of hearing loss for all sweet spot boundaries except upper FM rate.
- Significant effect of musical experience for lower FM boundary only.
- No correlation of mean FM parameter thresholds with HF-HL or ERB for any boundary.
- Correlation of mean thresholds with LF-HL for lower FM boundary excursion only (p=0.08).
- Large individual differences [Fig. 4] not explained by audibility or frequency selectivity at FL.

CONCLUSIONS

- NH listeners, adding CFM to an unmodulated complex tone was sufficient to evoke the perception of a sung voice for FM rates between 4.1 and 7.5 Hz and FM excursions between 17 and 83 cents on average.
- These values may provide some guidelines when constructing synthetic/simulated stimuli for which a realistic sung vibrato is desired.
- Hitting loss was found to cotact the perception of a sung voiced based on FM-rate and FM-excitation cues.
- Further work is needed to clarify the role of deficits in detection or discrimination of FM parameters, temporal fine-structure processing, and the ability to follow the rate of frequency changes, for the perception of vocal vibrato and vowel quality in HI listeners.

REFERENCES

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