Contralateral Noise Degrades Frequency-Coding Accuracy in Normal-Hearing Adults – Preliminary Results

Fuh-Cherng Jeng, Kelley A. Stehura, Breanna N. Hart, and Allison T. Giordano

Communication Sciences and Disorders, Ohio University, Athens, Ohio, USA

INTRODUCTION

- Noise may hinder the listener's ability to extract important acoustic cues in everyday conversation (Helfer & Wilber, 1990; Middelweerd et al., 1990). For example, a listener's ability to identify and follow the envelope and fine-structure cues of human speech is greatly reduced in reverberant (Bidelman & Krishnan, 2010) and noisy (Swaminathan & Heinz, 2012) environments.
- The scalp-recorded, frequency-following response (FFR) is advantageous because it reflects acoustic details of speech stimulation with high fidelity, therefore providing researchers with a method to examine how acoustic signals are processed in the human brain. Early studies have reported adverse effects of noise on the FFR (Li & Jeng, 2011; Song et al., 2011) when noise was added to the ipsilateral side of the ear.
- However, effects of contralateral noise on the FFR remained unclear. Based on the bilateral and communicative pathways of the auditory system (Warr, 1992; Yost, 2013), it was hypothesized that contralateral noise would compromise frequency-coding acuity in the human brain.

METHODS

Participants

- Nine native speakers of English (8 females and 1 male; M age = 27.0, SD = 5.4 years).

Stimulus

- A pre-recorded, monosyllabic, Mandarin speech sound that mimicked the English vowel /i/ (with a rising fundamental frequency [F0] contour ranging from 102-140 Hz) was utilized to elicit FFRs.

Two Experimental Conditions

- Quiet condition: /i²/ (70 dB SPL) to the right ear only
- Noise condition: /i²/ (70 dB SPL) to the right ear + white noise (70 dB SPL) to the left ear

Procedure

- 3 gold-plated surface recording electrodes
  - High forehead, right mastoid, and low forehead
- Participants resting or fast-asleep prior to recording
- 5000 accepted sweeps for each recording

Data Analysis

- Narrow-band, sliding-window, spectrograms were utilized to visualize the response, if any.
- Two objective indices were applied to calculate the pitch-tracking accuracy and phase-locking magnitude for all participants
  - Tracking Accuracy- denotes the overall faithfulness of F0 encoding between the stimulus and response F0 contours
  - Slope Error- indicates the degree to which the shape of the stimulus F0 contour was preserved in the brain waves.

DATA ANALYSIS

Tracking Accuracy

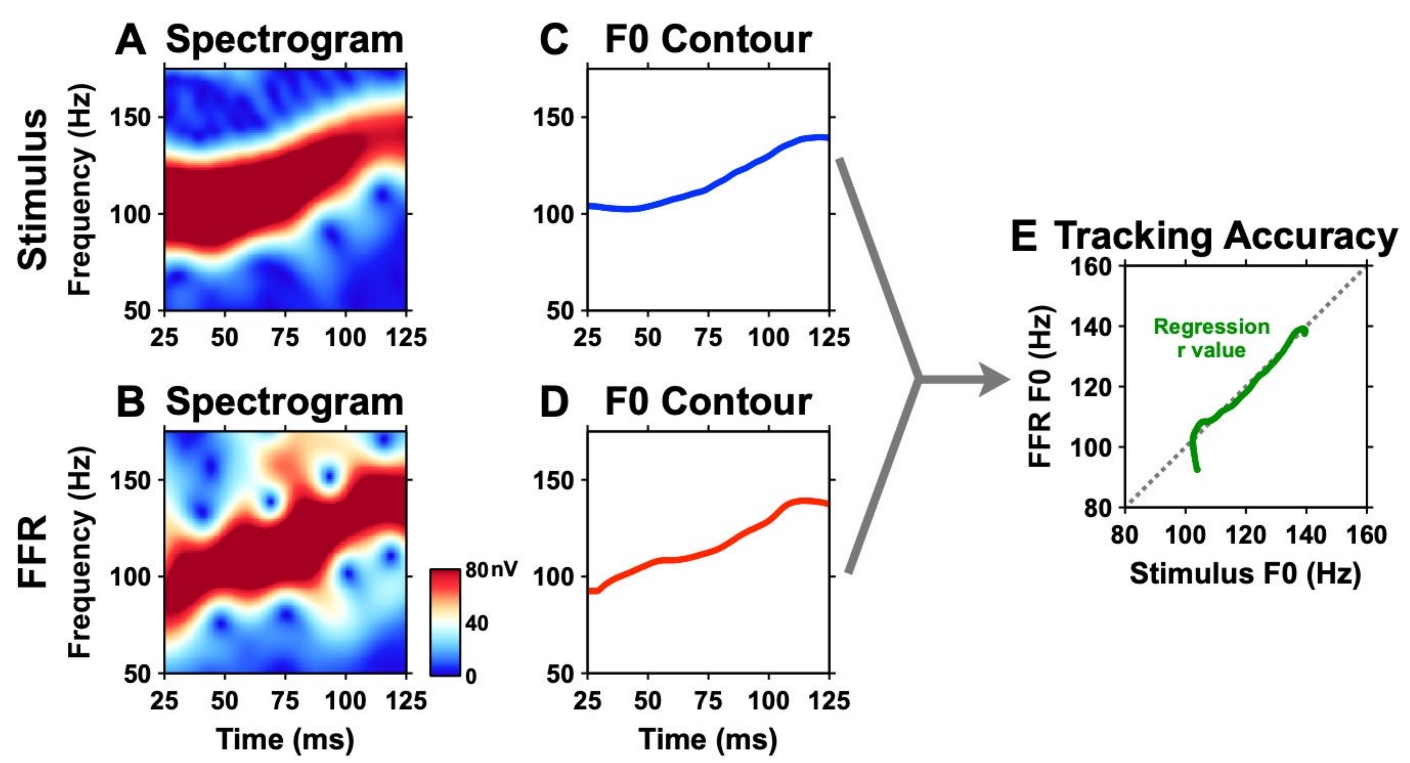

Figure 1. Procedures to compute Tracking Accuracy. ***A***. Amplitude spectrogram of the speech stimulus with a rising F0 contour. ***B***. A typical FFR spectrogram obtained from a normal-hearing participant (subject S005) in the absence of contralateral noise (i.e., the quiet condition). ***C***. F0 contour of the stimulus. ***D***. F0 contour of an FFR recording. ***E***. Tracking Accuracy was defined as the regression r value on a recording-versus-stimulus F0 contours plot.

Slope Error

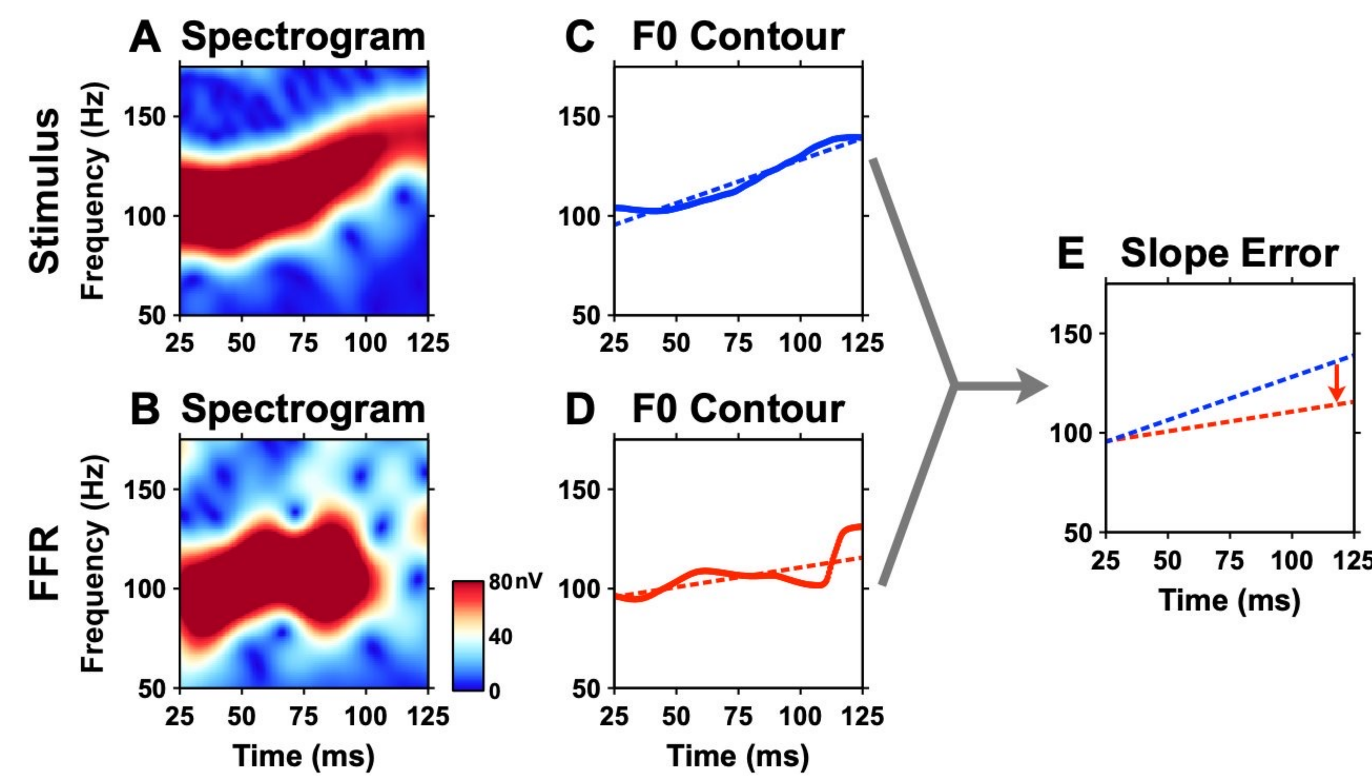

Figure 2. Procedures to compute Slope Error. ***A***. Amplitude spectrogram of the speech stimulus. ***B***. A typical FFR spectrogram obtained from a normal-hearing participant (subject S005) when continuous white noise was delivered to the contralateral ear (i.e., the noise condition). ***C***. Linear regression on the F0 contour of the stimulus. ***D***. Linear regression on the F0 contour of an FFR recording. ***E***. Slope Error was computed by subtracting the regression slope of the stimulus F0 contour from that of the FFR recording.

RESULTS

Example Spectrograms

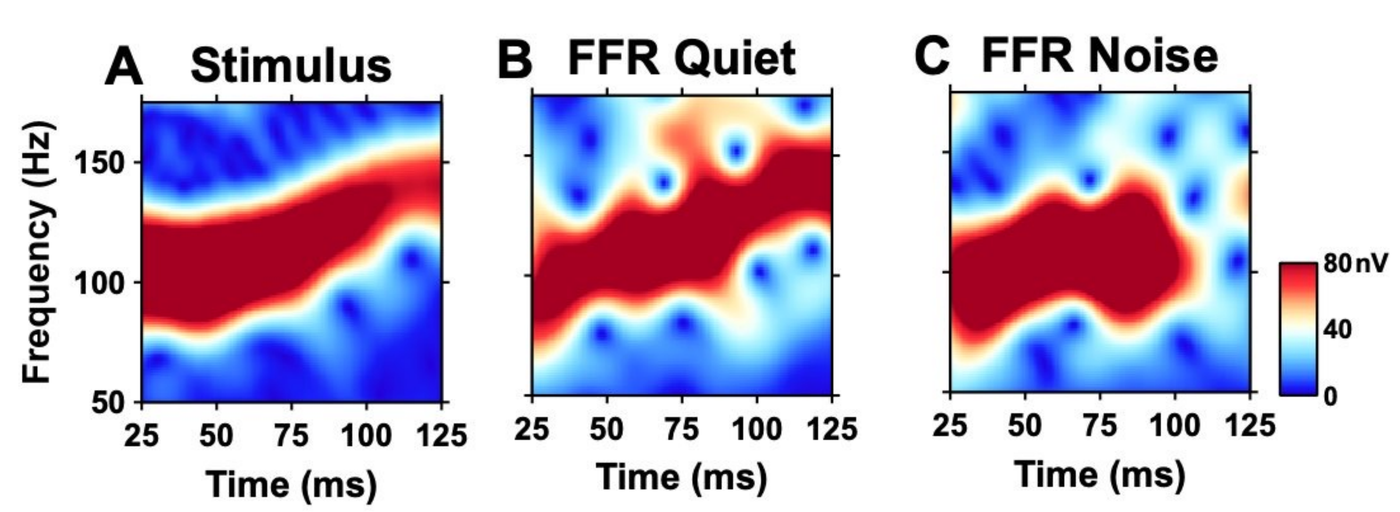

Figure 3. Example spectrograms of the speech stimulus and evoked FFRs. ***A***. Amplitude spectrogram of the speech stimulus with a rising F0 contour. ***B***. A typical FFR spectrogram obtained from a normal-hearing participant (subject S005) in the quiet condition. ***C***. Another FFR spectrogram obtained from the same participant in the noise condition. A gradient scale on the right indicates spectral amplitudes in nV for FFR recordings.

Statistical Analysis

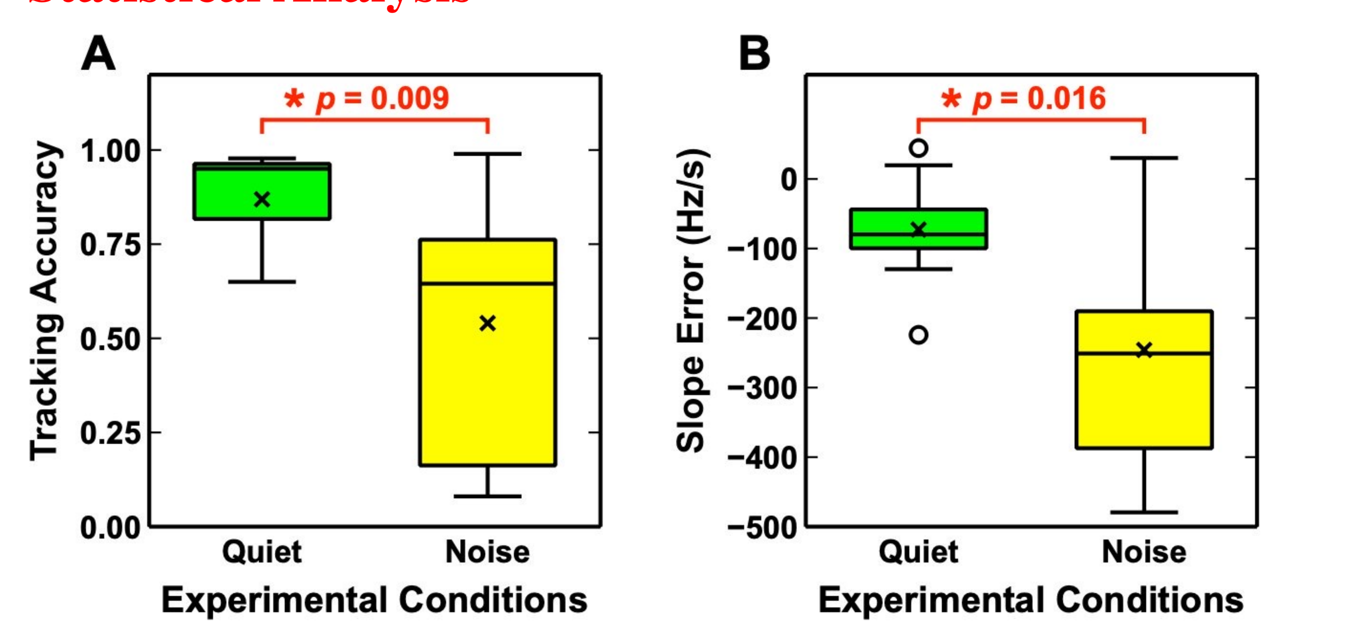

Figure 4. Effects of contralateral noise on frequency-coding acuity. ***A***. Tracking Accuracies obtained in the quiet and noise experimental conditions. ***B***. Slope Errors obtained in the quiet and noise experimental conditions. The data are presented in box plots. The upper and lower boundaries of each box mark the 25th and 75th percentiles, respectively. The solid line within each box represents the median and the cross symbol denotes the mean. Whiskers above and below each box indicate 1.5 interquartile range (IQR) above the 25th percentile and 1.5 IQR below the 75th percentile, respectively. White dots above and below the whiskers are data points that fall outside of the range between (25th percentile + 1.5 IQR) and (75th percentile - 1.5 IQR).

DISCUSSION

- Significant degradations were observed in frequency-coding acuity at the subcortical level when continuous white noise was added to the contralateral ear.
- Specifically, Tracking Accuracy dropped from 0.869 to 0.540 and Slope Error declined from -36 to -123 Hz/s when noise was present in the contralateral ear.
- There are at least two neuronal pathways that may contribute to the effects of contralateral noise on FFR. The first possible pathway is the afferent auditory system, consisting of neurons starting from the superior olivary complex nuclei where the incoming acoustic information first crosses to the opposite side of the brain (Yost, 2013). The second possible pathway is the efferent auditory system that produces mostly regulatory commands. Because the innervation patterns of the efferent system come from both sides of the brain (Warr, 1992), the efferent control of frequency coding in the human brain is bilateral.
- This study presents an overall effect of both pathways combined and thus lays a foundation for researchers to further investigate the relative contributions of the afferent and efferent systems on frequency coding.
- Limitations of this study and future directions
  - Relatively small sample size (N = 9)
  - Integrate behavioral measurements for auditory perception

ACKNOWLEDGMENTS

This study was supported in part by a Student Research Grant (#2610) to K.A.S. from the College of Health Sciences and Professions at Ohio University.

REFERENCES

Bidelman, G. M., & Krishnan, A. (2010). Effects of reverberation on brainstem representation of speech in musicians and non-musicians. Brain Research, 1355, 112–125. https://doi.org/10.1016/j.brainres.2010.07.100

Helfer, K. S., & Wilber, L. A. (1990). Hearing loss, aging, and speech perception in reverberation and noise. Journal of Speech and Hearing Research, 33(1), 149–155. https://doi.org/10.1044/jshr.3301.149

Li, X., & Jeng, F.-C. (2011). Noise tolerance in human frequency-following responses to voice pitch. Journal of the Acoustical Society of America, 129(1), EL21–EL26. https://doi.org/10.1121/1.3528775

Middelweerd, M. J., Festen, J. M., & Plomp, R. (1990). Difficulties with speech intelligibility in noise in spite of a normal pure-tone audiogram. Audiology: Official Organ of the International Society of Audiology, 29(1), 1–7. https://doi.org/10.3109/00206099009081640

Song, J., Skoe, E., Banai, K., & Kraus, N. (2011). Perception of speech in noise: Neural correlates. Journal of Cognitive Neuroscience, 23(9), 2268–2279. https://doi.org/10.1162/jocn.2010.21556

Swaminathan, J., & Heinz, M. G. (2012). Psychophysiological Analyses Demonstrate the Importance of Neural Envelope Coding for Speech Perception in Noise. Journal of Neuroscience, 32(5), 1747–1756. https://doi.org/10.1523/JNEUROSCI.4493-11.2012

Warr, W. B. (1992). Organization of Olivocochlear Efferent Systems in Mammals. In D. B. Webster, A. N. Popper, & R. R. Fay (Eds.), The Mammalian Auditory Pathway: Neuroanatomy (pp. 410–448). Springer. https://doi.org/10.1007/978-1-4612-4416-5_7

Yost, W. (2013). Fundamentals of Hearing: An Introduction (5th ed.). Brill.