On the Potential for Artificial Bandwidth Extension of Bone and Tissue Conducted Speech: A Mutual Information Study

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Objectives

- Understanding the relationship between bone-conducted speech and free-air speech for different frequency bands.
- Using that knowledge to enhance the quality of the narrowband bone-conducted speech.
- Improving the experience of communication in noisy environments while wearing communication headsets.

Introduction

New communication headset facilitates communication in noise.

Advantages:

1. Custom mold ⇒ good passive attenuation
2. Equipped with:
   - Outer-Ear Microphone (OEM)
   - In-Ear Microphone (IEM)
   - Digital Signal Processor (DSP)
3. IEM signal less sensitive to environmental noise

Disadvantages:

1. IEM signal bandlimitted to ∼ 2 kHz

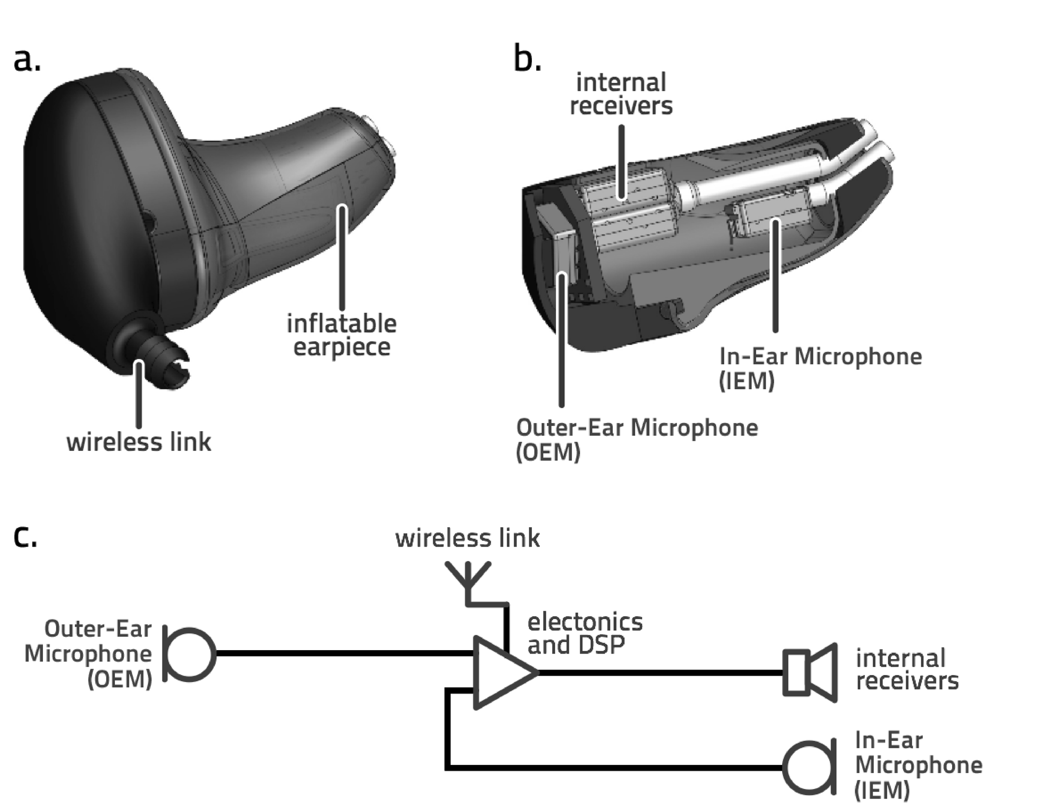

Figure 1: Overview of communication headset (a), its electro-acoustical components (b), and equivalent schematic (c).

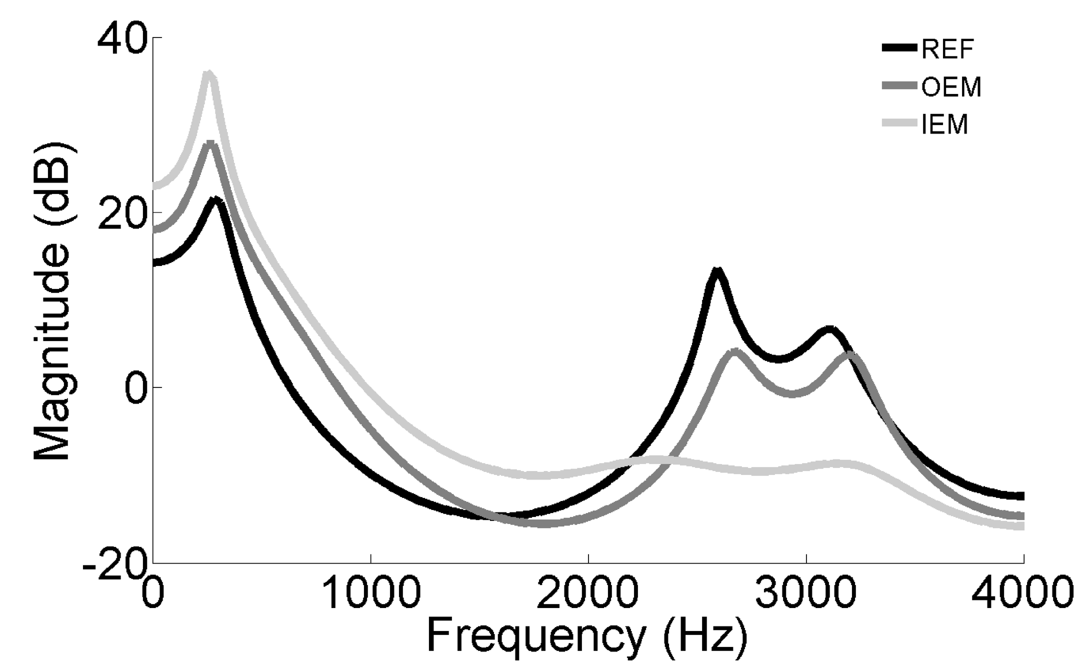

Figure 2: The LPC spectral envelope of the phoneme /i/ recorded with the REF, the OEM and the IEM simultaneously.

Methods

We are interested in the mutual information of the 0-2 kHz and 2-4 kHz sub-bands of the different microphone signals.

Gaussian mixture model PDF:

$$f_{GMM}(x,y) = \sum_{m=1}^{M} \alpha_m f_G(x,y|\theta_m)$$

Mutual Information:

$$\widehat{I(X;Y)} = \frac{1}{N}\sum_{n=1}^{N}\left(\log_2\left(\frac{f_{GMM}(x_n,y_n)}{f_{GMM}(x_n)f_{GMM}(y_n)}\right)\right)$$

Experimental Setup

1. Speech Corpus: first 10 lists of Harvard sentences, female speaker, recorded with OEM, IEM and REF (placed in front of the mouth).
2. Measure the transfer function of the earpiece
3. Compute Mutual Information

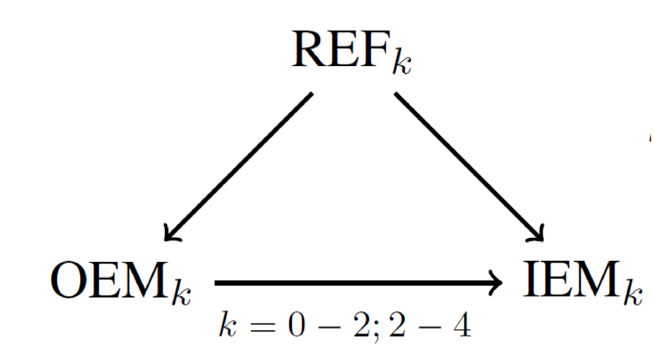

Figure 3: Mutual Information between corresponding frequency bands.

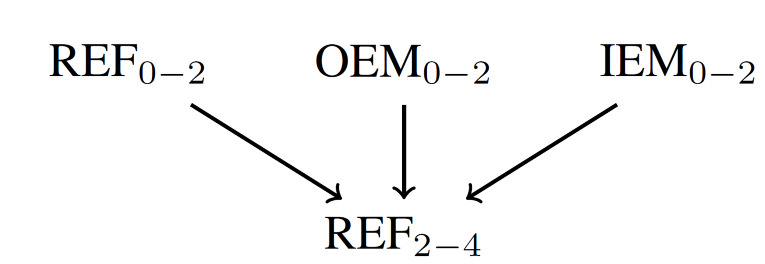

Figure 4: Mutual Information between high band of the REF and low bands.

Conclusions

1. **In quiet:** OEM and REF signals share mutual information in the 2-4 kHz
2. **All SNRs:** IEM and REF signals share information in the 0-2 kHz
3. High-band of the OEM signal or the low-band of the IEM can be used to artificially extend the bandwidth of the IEM signal
4. Creating a better quality/intelligibility signal that is less prone to environmental factors

Results

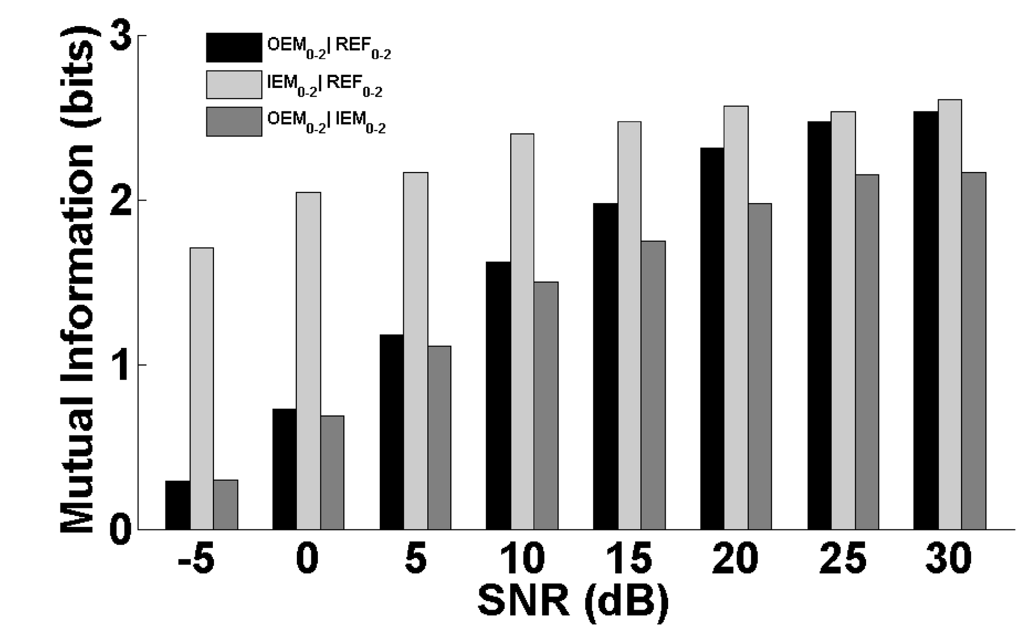

Figure 5: Mutual information of the low-band between the REF, OEM and IEM signals.

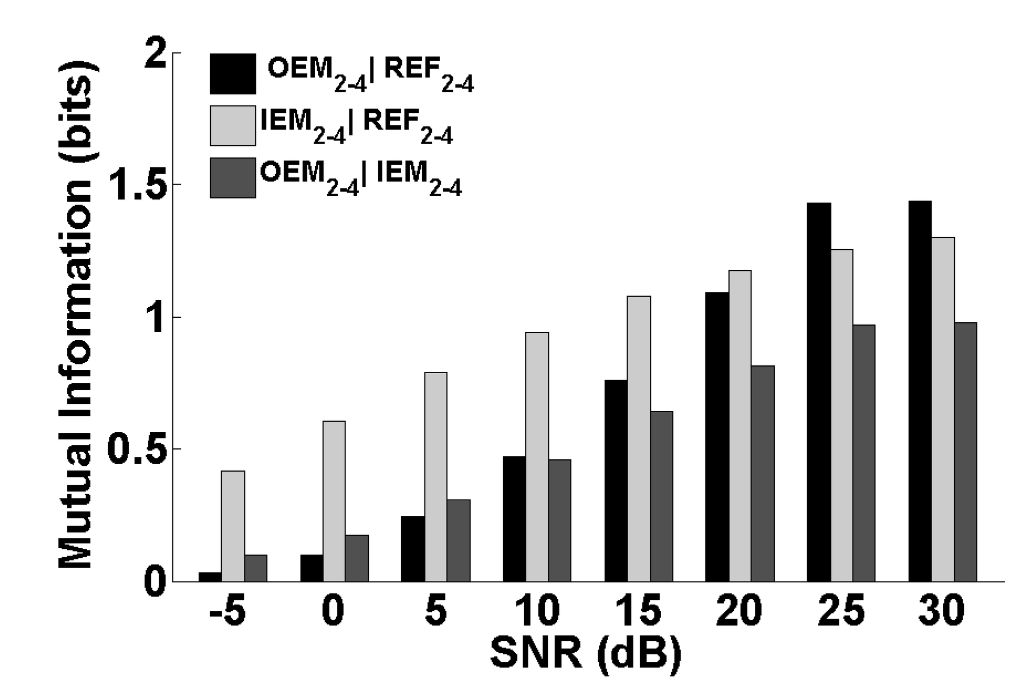

Figure 6: Mutual information of the high-band between the REF, OEM and IEM signals.

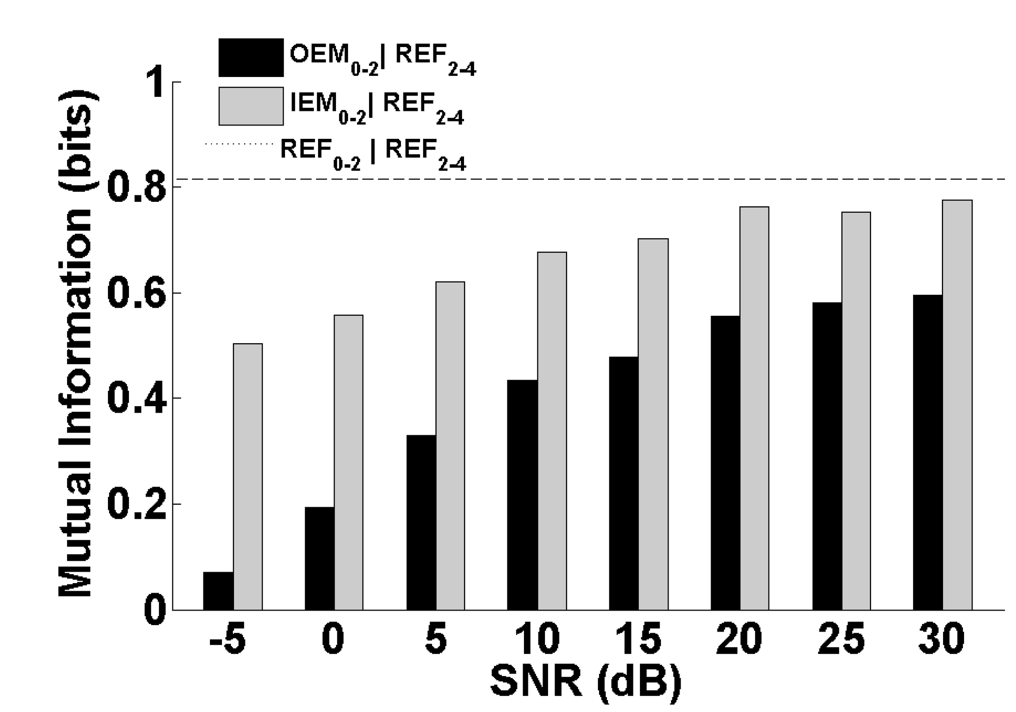

Figure 7: Cross-band mutual information between the OEM, IEM and REF signals compared with the average cross-band mutual information within the REF signal.

Funding Acknowledgements

CRITIAS
MUSAE LAB
CIRMMT Centre for Interdisciplinary Research in Music Media and Technology
NSERC CRSNG

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