Auditory modulation transfer functions measured by MEG for modulation rates dominant in speech

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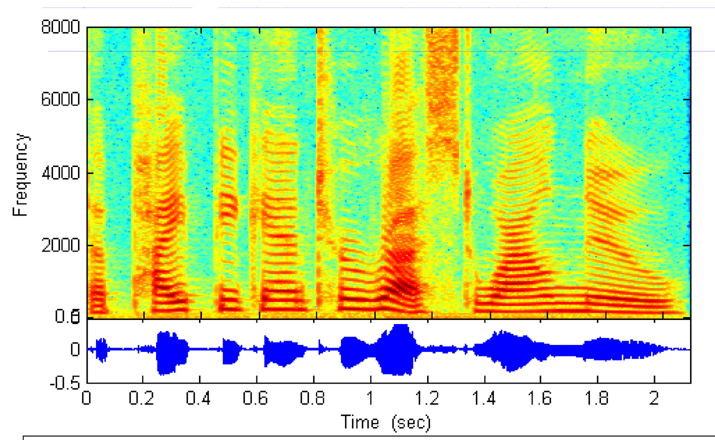
INTRODUCTION

In speech signals, perceptually relevant modulations coexist at different bandwidths and timescales.

Acoustic Constituents of Speech



Narrowband in Frequency ⬍ Broadband in Frequency

Fast Modulation in Time ⬌ Slow Modulation in Time

In this study we investigate the acoustic constituents of speech, idealized as simple sounds of varying bandwidths and varying temporal modulations.

- Modulated Pure Tone
- Modulated 1/3 Octave Noise
- Modulated 2 Octave Noise
- Modulated 5 Octave Noise

METHODS

Recording

- Magnetic signals were recorded using a 160-channel, whole-head axial gradiometer system (KIT, Kanazawa, Japan.).
- Sampling rate 500 Hz, bandpassed between 1 Hz and 200 Hz, with notch at 60 Hz.
- 157 MEG channels denoised with a Block-LMS adaptive filter, using 3 reference channels.
- 14 human subjects (6 men and 8 women).

Stimuli

- 20 different stimuli (2000 ms stimulus duration), each a sinusoidal amplitude modulation of a carrier, with:
  - 5 modulation frequencies: 1.5 Hz, 3.5 Hz, 7.5 Hz 15.5 Hz and 31.5 Hz.
  - 4 carriers: pure tone at 707 Hz ; 1/3, 1, and 5 octave pink noise centered at 707 Hz.
- 50 repetitions per stimulus; interstimulus intervals from 700 to 900 ms; loudness approximately 70 dB SPL.

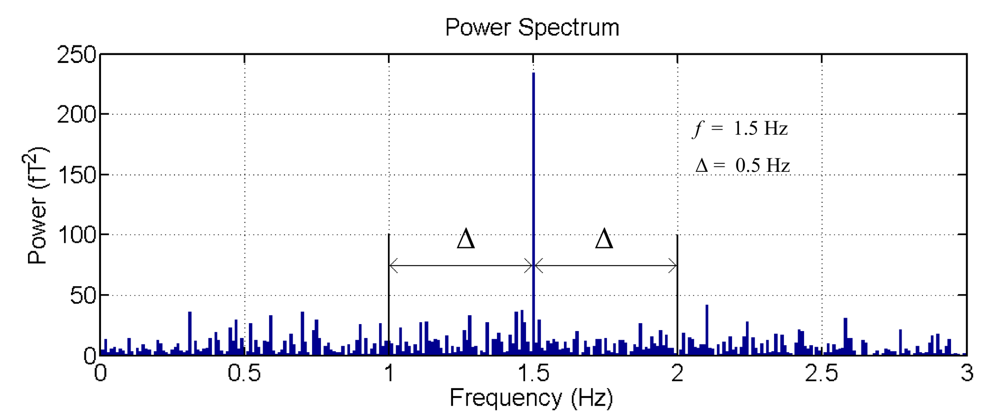
Analysis

- Concatenated responses from 50 to 2050 ms post-stimulus gave 20 total responses (100 s duration) for each channel.
- The Discrete Fourier Transform (DFT) results in 20 frequency responses (0.01 Hz resolution) for each channel.
- The SSR is the DFT's magnitude and phase at the modulation frequency (and harmonic frequencies, if significant).
- The SNR (Signal-to-Noise Ratio) represents the strength of the signal normalized with the noise power.
- $SNR = 10 \cdot \log_{10}(P_{sig}/P_{noise})$, where

  P_{sig} = Power at the modulation frequency (f)

  P_{noise} = Average power in the frequency band $[f - \Delta, f + \Delta]$; excluding power at f
- $\Delta = 0.5$ Hz was used
- The stimulus set for 31.5 Hz modulation was not used for further analyses, since it does not fall in the range of modulation rates dominant in speech

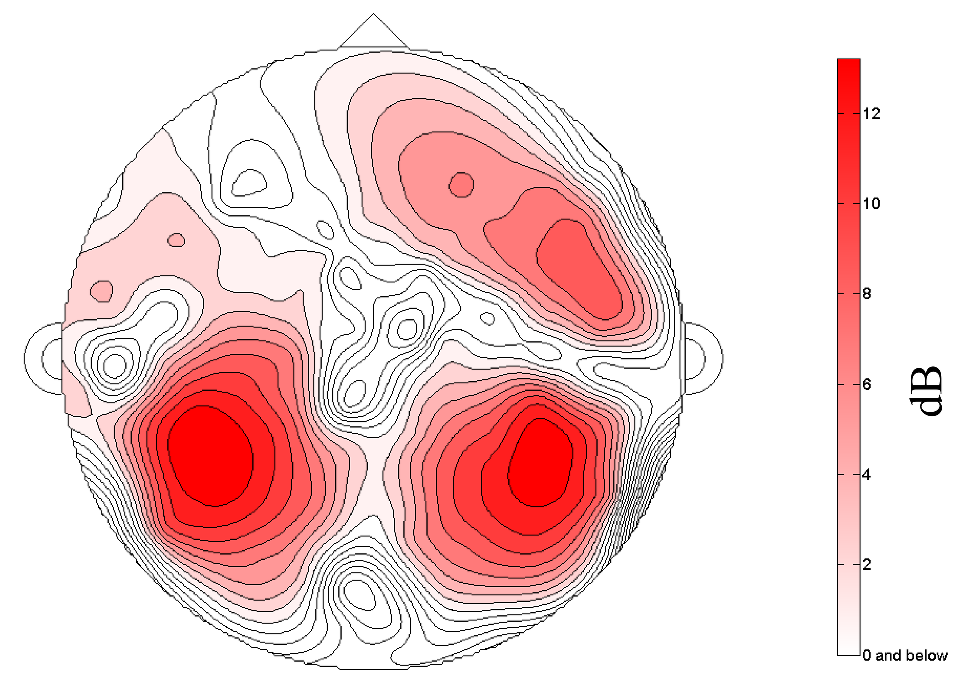
SNR representation



Power spectrum for sensor #87 (left temporal lobe) for subject R0456. Stimulus is a pure tone modulated at 1.5 Hz

Simon et. al. (2005) used a modified source dipole fitting method to evaluate the transfer functions of significant channels. When noise levels are high, the number of significant channels used in this method is low, thus leading to higher uncertainties. We propose that the SNR may be a useful indicator of the encoding strength, since it is normalized with respect to the noise power.

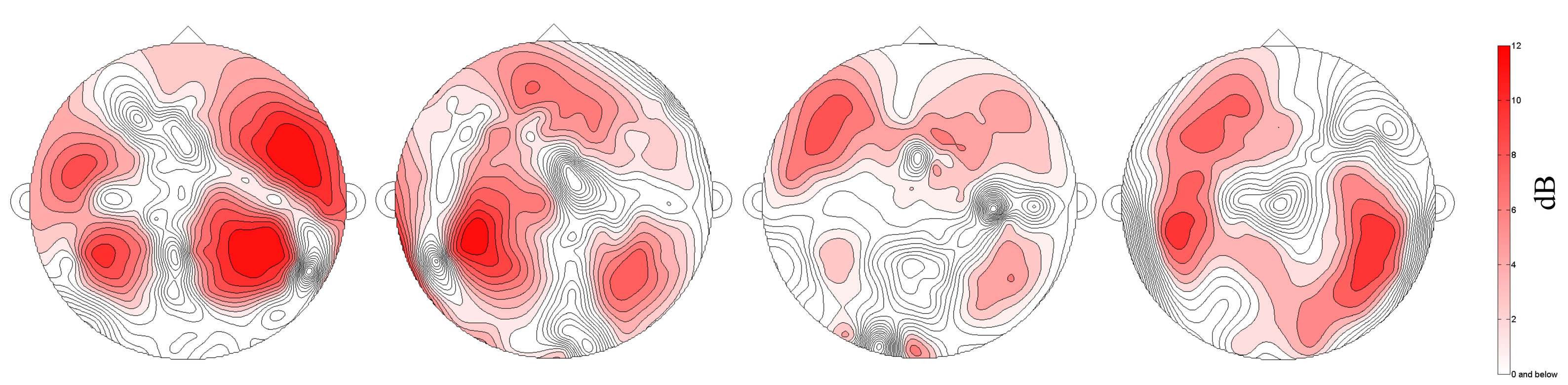
The SNR of a white noise signal is greater than 5 dB with a probability of p = 0.05. We used 20 channels with the top SNRs for further analyses, and they fall above the 5 dB level in most cases. The hypothesis that SNR indicated the encoding strength is supported by plotting the SNRs on a whole-head-map which shows an activation pattern typically seen in auditory responses (The 'butterfly' pattern).



Whole-head SNR representation for a pure tone modulated at 1.5 Hz (Subject R0456)

Whole Head Response Change with Stimulus

The whole-head SNR for pure tone stimulus, at the five modulation frequencies 1.5, 3.5, 7.5 and 15.5 Hz. (Subject R0361)



1.5 Hz | 3.5 Hz | 7.5 Hz | 15.5 Hz

Modulation Transfer Functions

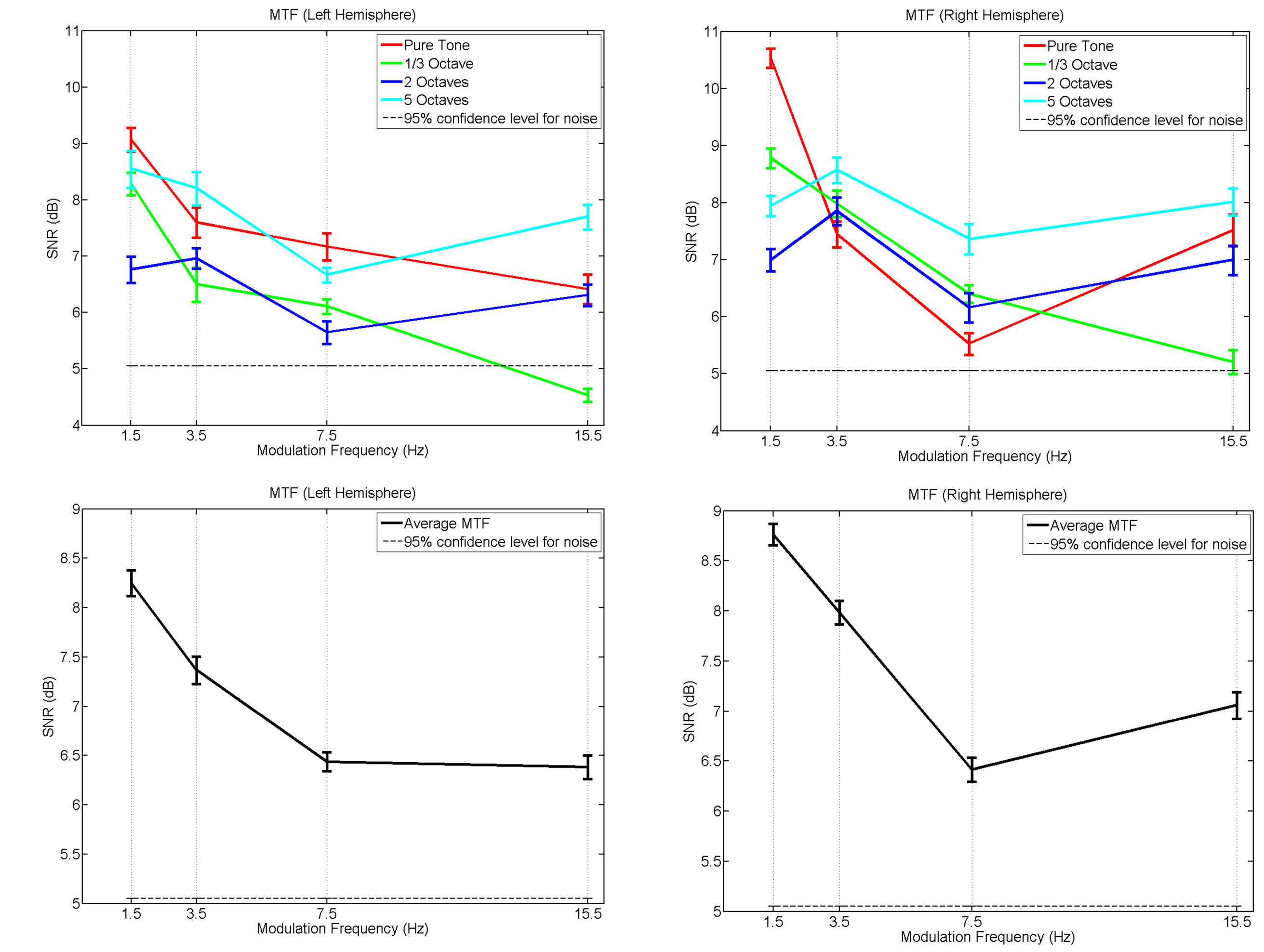
The SNR was averaged across these top 20 channels and across the 14 subjects. The ***Modulation Transfer Function*** (**MTF**) is obtained by plotting the averaged SNR (± s.e.m) against the modulation frequencies.

We found no effect of stimulus bandwidth on the MTF. This supports the findings of Simon et al.. (2005).

RESULTS

Transfer Functions

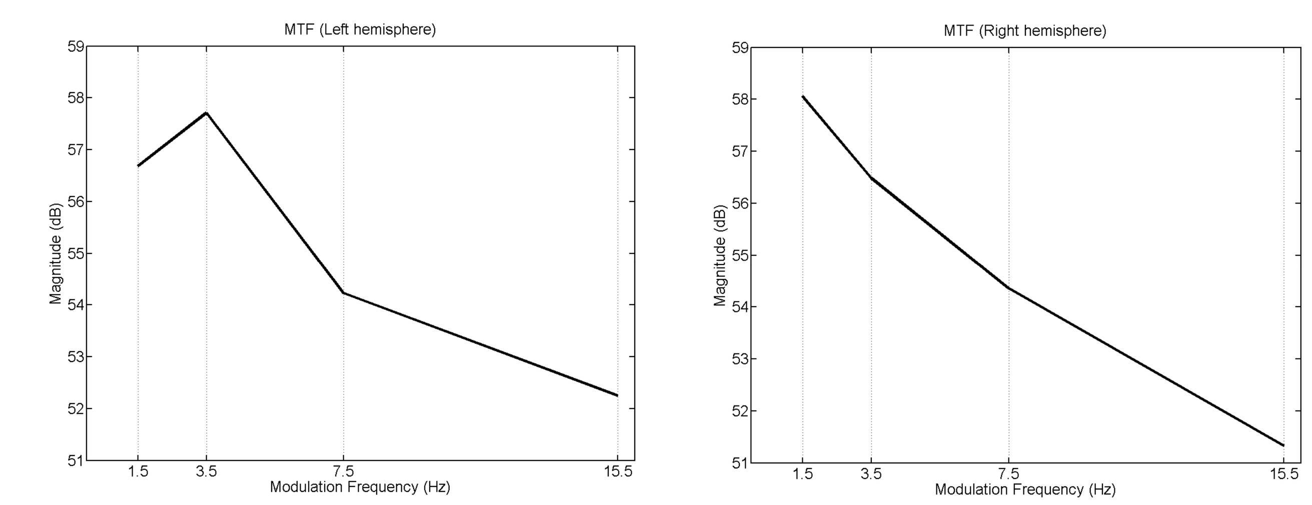
Left and right hemisphere SNR distributions give simple Modulation Transfer Functions (MTFs) for every stimulus bandwidth.



MTF for left and right hemisphere, different color represents different bandwidth.

Average MTF for left and right hemisphere.

These results indicate the same trends in the MTF as found by Simon et al.. (2005), shown below.



Average MTF for left and right hemisphere, *Simon et. al. (2005)*

CONCLUSIONS

- ***MTF magnitude appears bandwidth independent.***
- ***MTF magnitude strongest below 8 Hz (i.e. low pass).***
- ***These results agree with the findings of Simon et al. (2005) using a completely unrelated methodology***

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