Auditory Steady State Responses to Broadband Noise in Human Auditory Cortex

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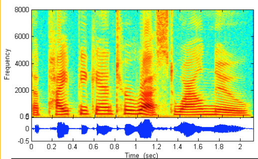
INTRODUCTION

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

Acoustic Constituents of Speech

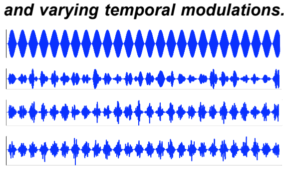


Narrowband in Frequency

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, Jp.).
- 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.
- Eight human subjects (3 men and 5 women).

Stimuli

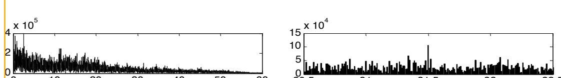
- 20 different stimuli (2000 ms stimulus duration), each a sinusoidal amplitude modulation of a carrier, with:
  - 5 modulation frequencies: 1.5 Hz, 3.5 Hz, 7.5 Hz 15.5 Hz and 31.5 Hz.
  - 4 carriers: pure tone at 707 Hz ; 1/3, 1, and 5 octave pink noise centered at 707 Hz.
- 50 repetitions per stimulus;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

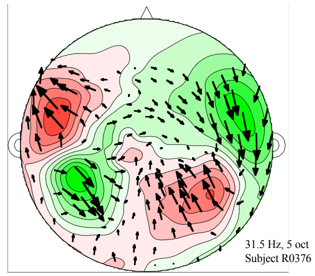
RESULTS

The Fourier transform of each channel's response is the frequency representation of that response. The amplitude and phase, at the modulation frequency, gives the SSR for that stimulus.



Complex Phasor Representation

The Amplitude and Phase at each channel can be shown with a complex vector ("phasor") at each channel, giving a graphical representation of the whole-head SSR.



The whole-head SSR for the 31.5 Hz modulated tone, in magnitude and phase.

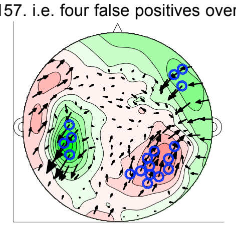
Red & Green intensities represent the complex magnetic field strength after projection onto the maximum-variance phase.

The arrow lengths represent the strength of the magnetic field.

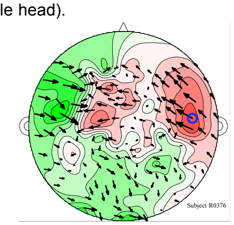
The arrow directions represent the complex phase of the magnetic field (and do not correspond to anatomical directions).

Identifying Statistically Significant Responses

A joint significance test incorporating amplitude (F-test) and phase (Rayleigh's Phase Coherence) identifies only those channels found to be significant (at p = 4/157. i.e. four false positives over the whole head).



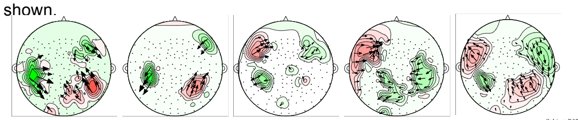
Response at 3.5 Hz for a 3.5 Hz modulated stimulus. 18 significant channels out of a total of 157. The blue circles denote significant channels.



Response at 3.5 Hz for a 1.5 Hz modulated stimulus. The blue circle denotes a 'significant' channel which we interpret as a false positive.

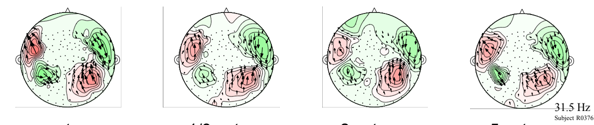
Whole Head Response Change with Stimulus

The whole-head SSR for 5 octave pink noise, at the five modulation frequencies 1.5, 3.5, 7.5, 15.5, and 31.5 Hz. Only significant channels are shown.



1.5 Hz   3.5 Hz   7.5 Hz   15.5 Hz   31.5 Hz

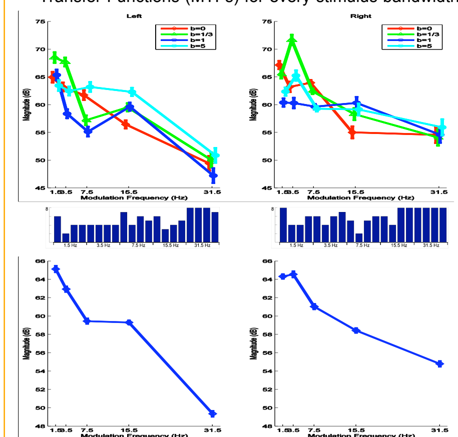
The whole-head SSR, as a function of stimulus bandwidth (for one modulation frequency) shows the MEG response as a function of bandwidth. The clear similarities suggest that there is no strong effect of bandwidth.



pure tone   1/3 octave   2 octave   5 octave

Transfer Functions

Left and right hemisphere complex equivalent dipoles give simple Modulation Transfer Functions (MTFs) for every stimulus bandwidth.



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

The number of the subjects contributing to the MTFs differs as a function of the stimulus and hemisphere.

Average MTF for left and right hemisphere.

CONCLUSIONS

- ***MTF magnitude appears bandwidth independent.***
- ***Strong right hemisphere advantage at highest frequency.***
- ***MTF magnitude strongest below 8 Hz (i.e. low pass).***
- ***Right hemisphere MTF appears to peak near 4 Hz.***

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Acknowledgements

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