MEG Steady State Responses To Auditory Stimuli Of Varying Complexity

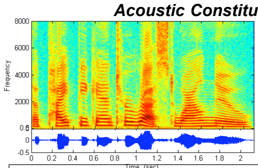
Simon JZ[1,3,5] Wang Y[2], Poeppel D[2,3,4,5], Xiang J[1], Ahmar N[1]

[1]Department of Electrical & Computer Engineering, [2]Cognitive Neuroscience of Language Laboratory,
[3]Neuroscience and Cognitive Science Program,[4]Department of Linguistics, [5]Department of Biology
University of Maryland College Park

Introduction

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

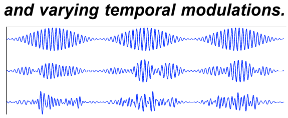
Acoustic Constituents of Speech



Narrowband in Frequency ⬍ Broadband in Frequency

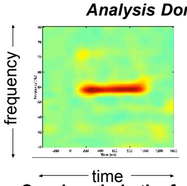
Fast Modulation in Time ⬌ Slow Modulation in Time

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



Physiological data (e.g. MEG) can be analyzed in the *time* domain, the *frequency* domain, or *jointly* in both time and frequency.

Analysis Domains and Methods



- Time
  - *e.g. Evoked Field*
- Time Frequency
  - *e.g. Induced/Evoked Oscillation*
- Frequency
  - *e.g. Modulation Transfer Function*

- ***Our domain is the frequency domain***
- ***Our methodology is the Steady State Response (SSR)***
- ***For a stimulus of any bandwidth, we measure the Modulation Transfer Function (MTF): the response amplitude and phase at each modulation frequency.***

Methods

Recording

- Magnetic signals 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 neural channels denoised with a Block-LMS adaptive filter, with the 3 reference channels.
- Five human subjects thus far.

Stimuli

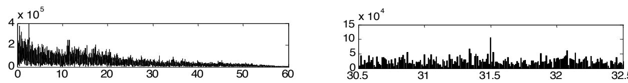
- 20 different stimuli (2000 ms duration), each a sinusoidal amplitude modulation of a carrier, with:
  - 5 modulation frequencies: 1.5 Hz, 3.5 Hz, 7.5 Hz 15.5 Hz and 31.5 Hz.
  - 4 carriers: pure tone at 707 Hz ; 1/3, 1, and 5 octave pink noise centered at 707 Hz.
- 50 stimulus presentations; interstimulus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

Analysis

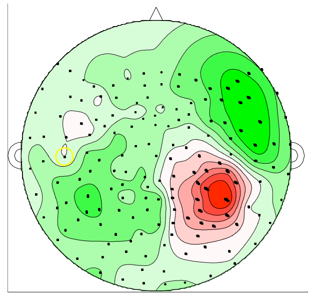
- Concatenated responses from 50 to 2050 ms post-stimulus gave 20 total responses (100 s duration) for each channel.
- The Discrete Fourier Transform (DFT) results in 20 frequency responses (0.01 Hz resolution) for each channel.
- The SSR is the DFT's magnitude and phase at the modulation frequency (and 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.



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.



31.5 Hz, 5 oct
Subject R0289

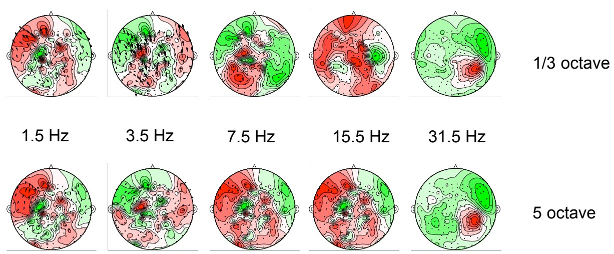
The whole-head SSR for the 31.5 Hz modulated tone, in magnitude and phase.

Red & Green contours represent the magnetic field strength projected onto the real line.

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

The arrow with the yellow circle (left hemisphere) corresponds to the channel whose frequency response is shown above.

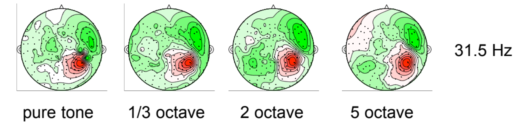
The whole-head SSR for one bandwidth, as a function of modulation frequency, gives the whole-head Modulation Transfer Function (MTF):



The whole-head SSR for 1/3 and 5 octave pink noise, at the five modulation frequencies 1.5, 3.5, 7.5, 15.5, and 31.5 Hz. Note the strong similarity of the complex magnetic field patterns for stimuli with the same modulation frequency.

Subject R0289

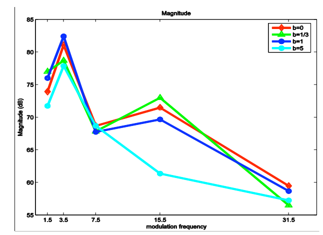
The whole-head SSR, as a function of stimulus bandwidth (for one modulation frequency) shows the MEG response as a function of bandwidth.



The whole-head SSR to 31.5 Hz modulations, at the four bandwidths 0 (pure tone), 1/3, 2, and 5 octaves. The strong similarities are clear.

Transfer Functions

Right hemisphere equivalent dipoles give simple Modulation Transfer Functions for every bandwidth (*N* = 5).



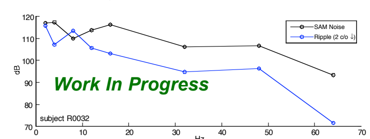
The Transfer Function is independent of bandwidth, and has the shape of a lowpass filter except for a peak near 4 Hz.

Conclusions

- ***New whole-head SSR visual representation: 'Phasor' shows magnitude and phase of MTF across whole head***
- ***Magnitude of MTF unaffected by stimulus bandwidth***
- ***MTF acts as lowpass filter but additional peak near 4 Hz***
- ***SSR can be measured using 50 instances of 2 seconds (in contrast to the more commonly used 1 instance of 200 seconds).***

References

- Ross et al. (2000) A high-precision magnetoencephalographic study of human auditory steady-state responses to amplitude-modulated tones. J Acoust Soc Am 108, 679-691.
- Schoonhoven et al. (2003) A whole head MEG study of the amplitude-modulation-following response: phase coherence, group delay and dipole source analysis. Clin Neurophysiol 114, 2096-2106.
- Baillet et al. (2001) Electromagnetic brain mapping, Signal Processing Magazine, IEEE ,18, 14-30.
- Mosher et al. (1999) EEG and MEG: forward solutions for inverse methods. Biomedical Engineering, IEEE Transactions on, 46, 245-259
- Haykin (2002). Adaptive filter theory. Upper Saddle River, N.J., Prentice Hall.
- Liegeois-Chauvel et al. (2004) Temporal Envelope Processing in the Human Left and Right Auditory Cortices. Cerebral Cortex 14, 731-740.



Acknowledgements

Thanks to Kensuke Sekihara for help. YW and DP are supported by NIH R01DC05660. DP is a fellow at the Wissenschaftskolleg zu Berlin and the American Academy Berlin.