MEG Steady State Response to Broadband Sounds

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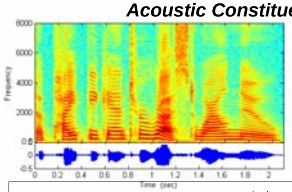
Introduction

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

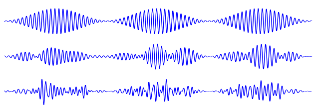
Acoustic Constituents of Speech



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.



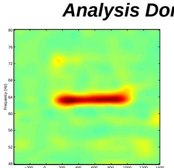
Modulated Pure Tone

Modulated 1/3 Octave Noise

Modulated 2 Octave Noise

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 1000 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.
- Three human subjects (two female) thus far.

Stimuli

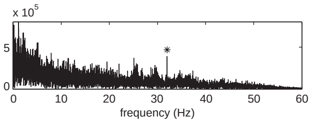
- 12 different stimuli (1000 ms duration), each a sinusoidal modulation of a carrier, with:
  - 4 modulation frequencies: 16 Hz, 32 Hz, 48 Hz and 64 Hz.
  - 3 carriers: pure tone at 400 Hz; 1/3 octave pink noise centered at 400 Hz; 2 octave noise centered at 400 Hz.
- 100 stimulus presentations; interstimulus intervals from 400 to 550 ms; loudness approximately 70 dB SPL.

Analysis

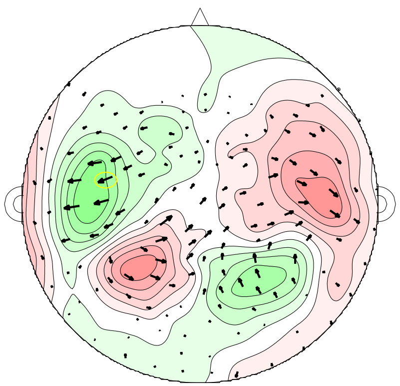
- Concatenated responses from 50 to 1050 ms post-stimulus gave 12 total responses (100 s duration) for each channel.
- The Discrete Fourier Transform (DFT) results in 12 frequency responses (0.01 Hz resolution) for each channel.
- The SSR is the DFT's magnitude and phase at the modulation frequency (and 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.



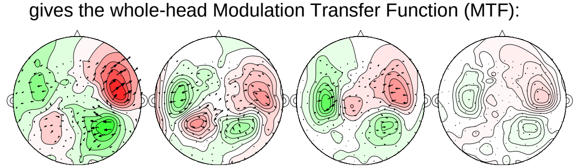
The whole-head SSR for the 32 Hz modulated tone, in magnitude and phase.

Red & Green contours represent the magnetic field strength at the peak of the variance over one modulation cycle.

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.

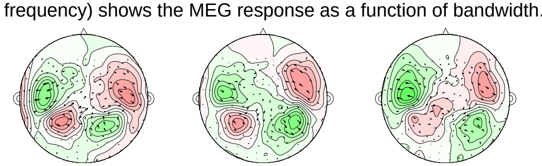
The whole-head SSR for one bandwidth, as a function of modulation frequency, gives the whole-head Modulation Transfer Function (MTF):



16 Hz | 32 Hz | 48 Hz | 64 Hz

The whole-head SSR to modulated tones at the four modulation frequencies 16, 32, 48 and 64 Hz.

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

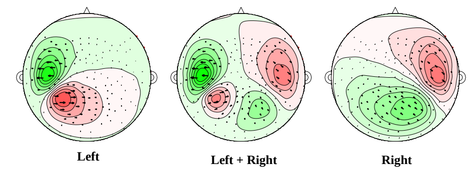


Pure Tone | 1/3 Octave Noise | 2 Octave Noise

Whole-head SSR to modulated pure tone, 1/3 octave noise , and 2 octave noise at modulation frequency 32 Hz.

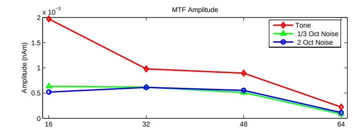
Data Reduction & Equivalent Dipoles

The whole-head SSR is difficult to quantitatively compare across stimuli and subjects. Data reduction, e.g. via the single equivalent-current dipole, allows comparison across stimuli and subjects.

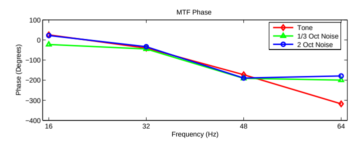


Equivalent dipole fitting of the whole-head 32 Hz modulated tone SSR, in magnitude and phase.

Magnitude and phase of the right hemisphere equivalent dipole give a simple Modulation Transfer Function



Modulation Transfer Function Amplitude across three different bandwidths.



Modulation Transfer Function Phase across three different bandwidths.

Conclusions

- ***New whole-head SSR visual representation: 'Phasor' shows magnitude and phase of MTF across whole head***
- ***Phase of MTF unaffected by stimulus bandwidth except at high frequencies***
- ***Magnitude of MTF decreases with increasing noise bandwidth***
- ***SSR can be measured using 100 instances of 1 second (in contrast to the more commonly used 1 instance of 200 seconds).***

References

- Ross B, Borgmann C, Draganova R, Roberts LE, Pantev C (2000) A high-precision magnetoencephalographic study of human auditory steady-state responses to amplitude-modulated tones. J Acoust Soc Am 108:679-691.
- Schoonhoven, R., Boden, C. J., Verbunt, J. P. and de Munck, J. C. (2003) A whole head MEG study of the amplitude-modulation-following response: phase coherence, group delay and dipole source analysis. Clin Neurophysiol 114, 2096-106.
- Galambos, R., Makeig, S. and Talmachoff, P. J. (1981) A 40-Hz auditory potential recorded from the human scalp. Proc Natl Acad Sci U S A 78, 2643-7.
- Haykin, S. S. (2002). Adaptive filter theory. Upper Saddle River, N.J., Prentice Hall.
- Baillet, S., Mosher, J.C., Leahy, R.M, (2001) Electromagnetic brain mapping, Signal Processing Magazine, IEEE ,18, 14 - 30
- Mosher, J.C., Leahy, R.M., Lewis, P.S., (1999) EEG and MEG: forward solutions for inverse methods. Biomedical Engineering, IEEE Transactions on, 46, 245 - 259