An Encoding Transition in the Concurrent Encoding of Frequency and Amplitude Modulation

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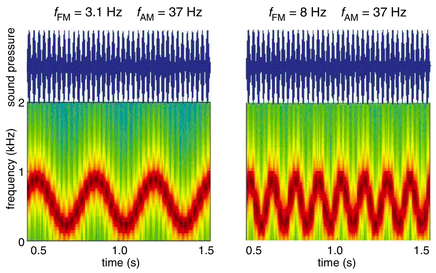
Introduction

How are auditory modulations encoded in auditory cortex?

- Simple Modulations ➡ Simple Cortical Encoding
  - Amplitude Modulation coding for slower modulations
  - Rate coding (invisible to MEG) for faster modulations
- General modulations? AM, FM, etc.
- Amplitude Modulation encoding is easily detectable in Fourier domain: spectral peak at stimulus modulation frequency
- How are compound modulations encoded? Can they be co-encoded, i.e. in a unified representations?

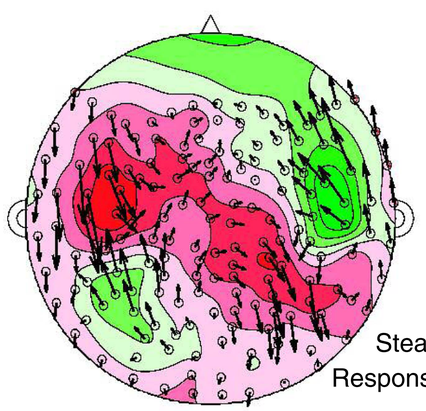
Stimuli



- Two Experiments: Slow-FM & Fast-FM
- 9 Stimuli each with f_{AM} = 37 Hz and varying f_{FM}
- FM between 220 Hz & 880 Hz
- Slow-FM: f_{FM} = [0.3, 0.5, 0.8, 1.0, 1.7, 2.1, 3.0, 5.0, 8.0 Hz]
- Fast-FM: f_{FM} = [2.1, 3.1, 5.1, 8.0, 10.3, 15.1, 20.1, 24.3, 30 Hz]
- AM depth 80%, duration 10 s, 10 repetitions

MEG Recording

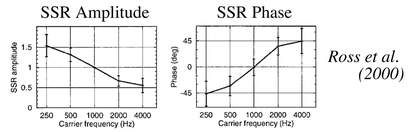
- 157 channel whole-head MEG system
- Two Experiments: 11 & 12 Subjects respectively
- 90 + 36 (Distractor/Target) Stimulus presentations
- f_{Sample} = 1000 Hz, f_{LP} = 100 Hz
- Analysis uses 50/157 channels (with max. amplitude at f_{AM})



MEG Steady-State Response (SSR) at 37 Hz

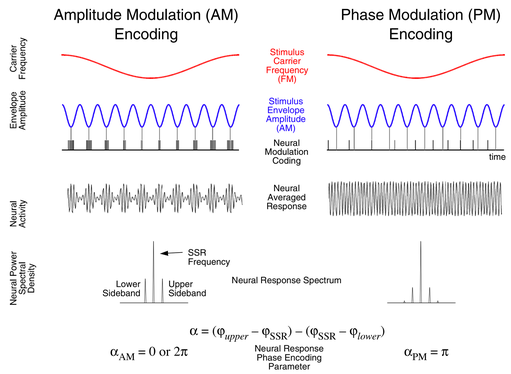
Modulation Encoding

Neural Response Phase & Amplitude depends on Stimulus Carrier Frequency



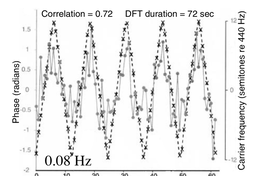
Ross et al. (2000)

Simple Models of Neural Modulation Encoding



Slowest FM rates show Phase Modulation Encoding

Patel & Balaban (2004)

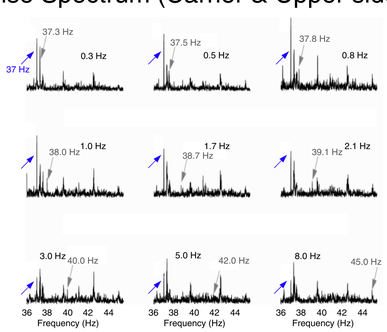


SSR Phase Follows Carrier ⬇ Phase Modulation Encoding

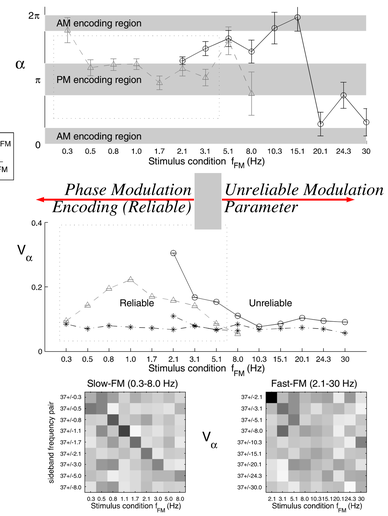
Very Slow FM

No Amplitude Modulation Encoding Observed

Response Spectrum (Carrier & Upper sidebands)

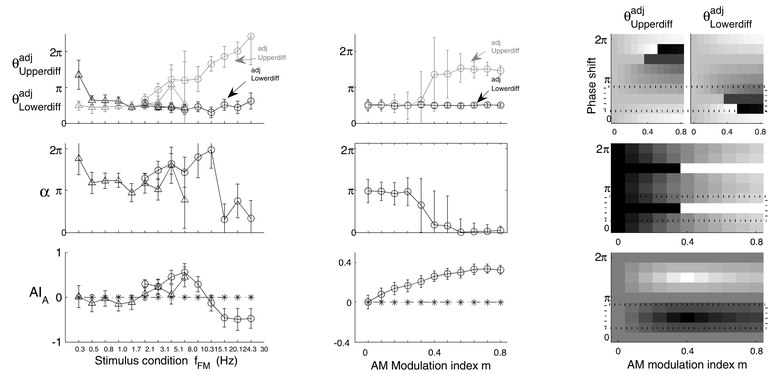


Results



Experimental Results

Model Results



$$S(t) = (1 + m\cos(2\pi f_{FM} t + \theta)) \times \cos(2\pi f_{AM} t + \tfrac{\pi}{8}\cos(2\pi f_{FM} t)) + GWN$$

Amplitude Modulation × *Phase Modulation*

References

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Summary

- MEG can address questions of Neural Coding
  - Modulation encoding gives family of response types
- Combined AM/FM modulations are co-encoded in Auditory Cortex
  - Phase Modulation seen at lowest FM rates
  - Modulation Encoding changes at higher rates
- Single Sideband Modulation unexpected
  - Speculate: Single Modulation Encoding type?
  - Or: Two populations of AM and PM encoding neurons whose phase happens to cancel in lower sideband?

We are grateful to Jeff Walker for his excellent technical assistance. This work was supported by NIH grant R01 DC05660.