Simultaneous encoding of envelope and fine structure in human auditory cortex

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Introduction

How does the human brain encode incoming auditory signals?

- First an initial short-term Fourier transform at the inner ear
- Separate streams for envelope (e.g. the Hilbert transform) and fine structure processing (see, e.g. Smith et al., Picton et al.) and both AM and FM are very important in speech processing (Zeng et al.)
- Auditory steady state response (aSSR) studies by Ross et al (2000) provide evidence for the deconvolution of sound **envelopes** in the human auditory cortex. Patel & Balaban (2004) suggest that the **phase** of the aSSR can track carrier frequency

Our questions

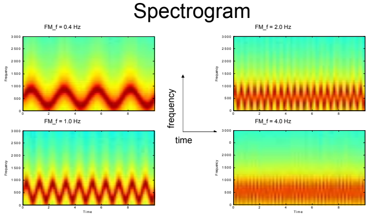
- How does the brain represent different dynamics in fine structure?
- Is there any threshold in encoding fine structure dynamics?
- Is there any transition in encoding from slow changing to fast changing fine structure?

To investigate the issue, using a high time resolution technique to record from human auditory cortex (MEG), we use AM-FM auditory stimuli, which have both simple dynamic envelope and simple dynamic fine structure properties.

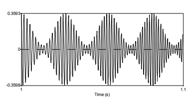
Methods

Stimuli

Spectrogram



Temporal waveform



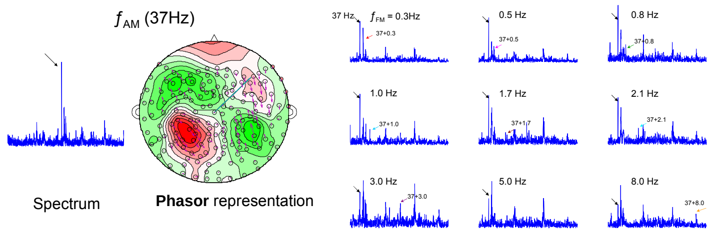
Frequency modulated tones with amplitude modulation of 37Hz
Stimulus duration: 10 sec ; Frequency range: 220-880Hz; f_{AM}(37 Hz);
f_{FM}(0.3, 0.5, 0.8, 1.0, 1.7, 2.1, 3.0, 5.0, 8.0 Hz)
12 subjects

Recording and Analysis

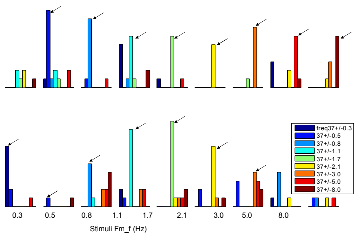
- 160 channel axial gradiometer whole head MEG (KIT system)
- Sampling rate 1000 Hz and on-line anti-aliasing filtering from DC~100Hz
- 9 conditions (9 f_{FM}) and 10 repetitions for each condition
- Single-trial data for identical conditions (same f_{FM}) concatenated (10 epochs in total, 100 sec)
- DFT of the epoch data calculated
- Channels sorted based on the amplitude of the f_{AM} (37 Hz) frequency and 10 channels with maximum values selected
- Frequency amplitude at 18 (9*2) sidebands f_{AM} + f_{FM} and f_{AM} - f_{FM} frequency for all channels (157) and all conditions (9) (157 channel * 18 frequency points * 9 conditions) calculated
- For each channel data, at single frequency points, the condition (stimulus) that evoked the maximum amplitude at this frequency selected (157*18*9 -> 157*18) and the 10-channel maximum stimulus distribution was drawn
- Fisher's circular statistical test used to estimate the phase parameter for different stimuli

Results

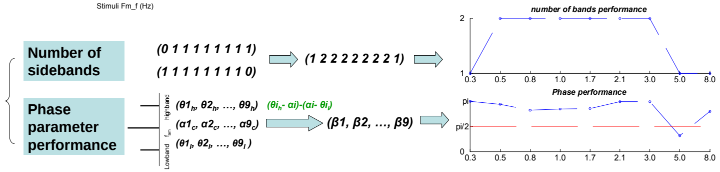
Steady State Response



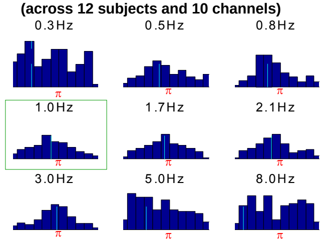
Summarization across 10 channels



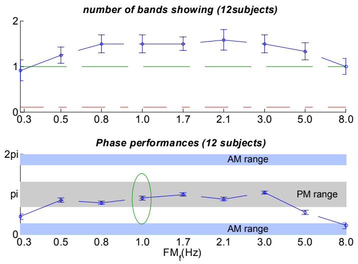
- To detect the aSSR at sidebands from noise, for each sideband frequency (f_{AM} + f_{FM}, f_{AM} - f_{FM}), the power when there is a corresponding driving stimulus compared with the power when there is no corresponding driving stimulus (other f_{FM})
- Maximum sideband frequency for each stimuli selected
- 1 or 0 used to represent sideband performance for each stimuli separately for highband and lowband
- The high and low band performance combined
- Same method used to detect steady state response at f_{FM}



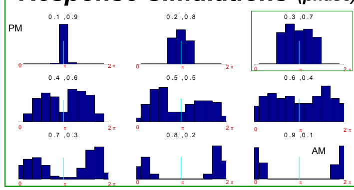
Phase parameter distribution for different f_{FM} (across 12 subjects and 10 channels)



Summarization across 12 subjects

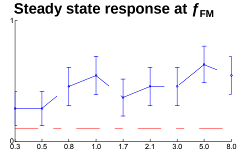


Response Simulations (phase)



Different combination of AM and PM
(ratio$_{AM}$, ratio$_{PM}$)

Steady state response at f_{FM}



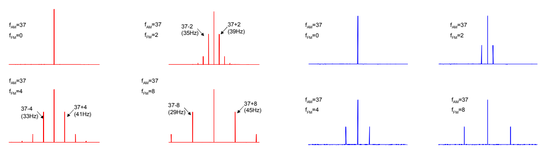
Response Simulations (Spectrum)

Phase Modulation

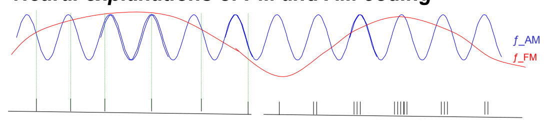
sin(2*pi*f_{AM}*t+sin(2*pi*f_{FM}*t+ø)+θ)

Amplitude Modulation

(1+m*sin(2*pi*f_{FM}*t+θ))*sin(2*pi*f_{AM}*t+ø)



Neural explanations of PM and AM coding



Conclusions

- Steady state response were found for co-modulated acoustic signal at amplitude modulation frequency (f_{AM}), at frequency modulation frequencies (f_{FM})
- We also found steady state response at sidebands (f_{AM}+ f_{FM}, f_{AM}- f_{FM}).
- For f_{FM} up to 3 Hz, steady state response phase tracks the carrier frequency. This generalizes Patel & Balaban's observed phase tracking at f_{FM} < 0.1Hz
- Tracking can be observed up to 8 Hz
- For f_{FM} greater than 3 Hz, pure phase modulation not observed. Possible explanations are of coding transition (see e.g. Lu et al.) or that the data become too noisy to be analyzed.

References

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