Simultaneous encoding of envelope and fine structure in human auditory cortex

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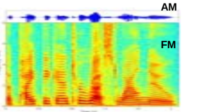
Introduction

Acoustic Envelope and Carrier

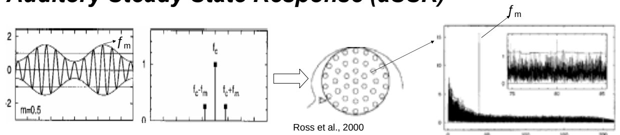


• Dynamically changing envelope and Carrier occurred widely in natural sounds and human speech, which can be characterized as **AM** and **FM**.

• AM and FM are two important physical aspects of communication sounds.

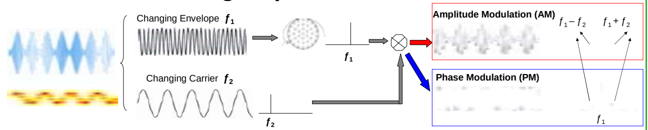
• Responses to pure AM and FM are widely studied in nonhuman species, as well as in humans using different means. However, the mechanism of co-representation of them are still unknown.

Auditory Steady State Response (aSSR)



Here, either only the envelope or the carrier frequency change, and the aSSR at corresponding f_m is a cortical representation of such dynamics. However, when they are modulated simultaneously and independently, how are they represented in human auditory cortex?

Modulation Encoding : a possible mechanism



Our questions

• How does brain co-represent simultaneous modulated envelope (AM) and carrier (FM) stimulus?

(modulation encoding is a possible way by checking sidebands)

• How fast can brain track the carrier dynamics (FM)? *(By using employing different carrier dynamics)*

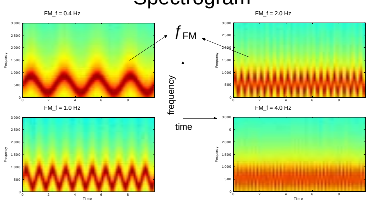
• Is there any coding transition as the rate of carrier dynamics increases?

(temporal coding to rate coding for faster click trains, Lu et al., 2001)

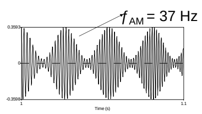
Methods

Stimuli

Spectrogram



Temporal waveform



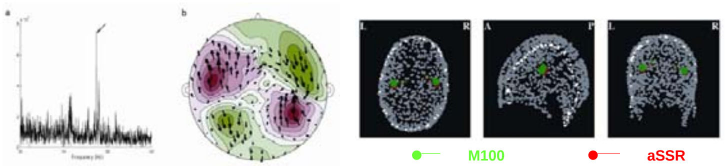
Frequency modulated tones with amplitude modulation of 37Hz
Stimulus duration: 10 sec ; Frequency range: 220-880Hz; f_{AM}(37 Hz);
f_{FM}(0.3, 0.5, 0.8, 1.0, 1.7, 2.1, 3.0, 5.0, 8.0 Hz); 12 subjects

Recording and Analysis

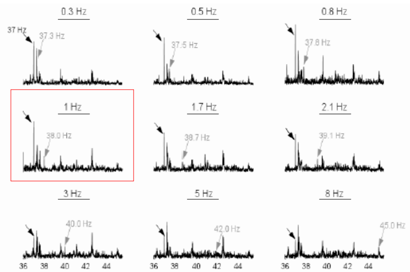
• 160 channel axial gradiometer whole head MEG (KIT system)
• Sampling rate 1000 Hz and on-line anti-aliasing filtering from DC~100Hz
• 9 conditions (9 f_{FM}) and 10 repetitions for each condition
• Channels sorted based on the amplitude of the f_{AM} (37 Hz) frequency and 10 channels with maximum values selected
• Frequency amplitude at 18 (9*2) possible sidebands frequencies ($f_{AM} \pm f_{FM}$) for all channels (157) and all conditions (9) (157 channel * 18 frequency points * 9 conditions) calculated
• Confusion matrix
• Fisher's circular statistical test used to estimate the encoding-type parameter

Results

Steady State Response at f_{AM} (37Hz here)



Steady State Response at Sidebands ($f_{AM} \pm f_{FM}$)

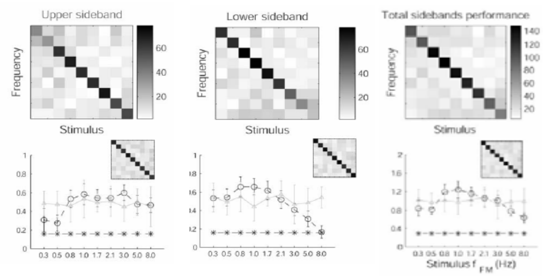


• One example of the spectrum of one representative channel under 9 different stimulus conditions (different f_{FM})

• Sidebands are induced by corresponding stimuli . For example, stimulus with f_{FM} of 1 Hz induces the frequency component at 38 Hz (37+1), the corresponding upper sideband for f_{FM} of 1 Hz, while this frequency is not induced by other stimuli with different f_{FM}

• It indicates employment of modulation encoding for corepresentation of envelope and carrier dynamics.

Confusion Matrix and Sideband Performance

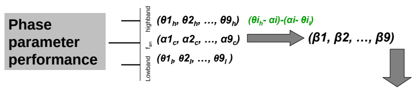


• Confusion matrix is used to check whether the sidebands were really significantly induced by corresponding stimulus

• A simulation using **pure phase modulation** with added noise is run and the resulted confusion matrix and sideband performance can be compared to empirical MEG data.

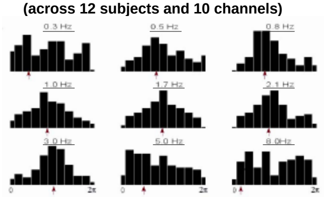
• It confirms that **Modulation Encoding** is used for co-representation

Encoding-type Parameter β Distribution

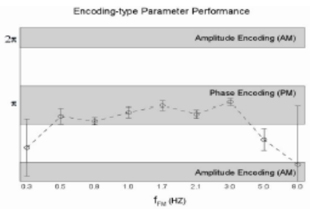


Encoding-type Parameter distribution for different f_{FM}

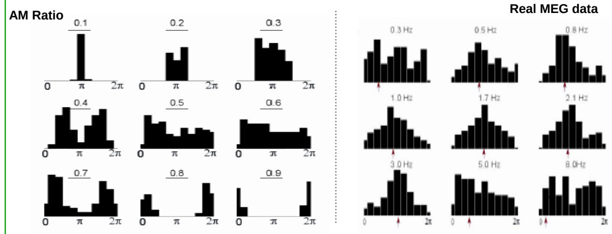
(across 12 subjects and 10 channels)



Summarization across 12 subjects



Encoding-type Parameter Simulations



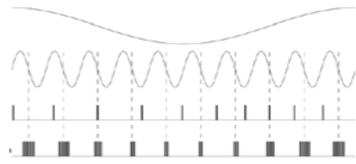
Neural explanations of PM and AM coding

Carrier

Envelope

Phase modulation Encoding **(PM)**

Amplitude modulation Encoding **(AM)**



Conclusions

• ***Modulation Encoding*** is used to encode and co-represent acoustic envelope and carrier dynamics in human auditory cortex.

• ***Phase modulation Encoding*** is used for stimuli with slowly changing carrier (f_{FM} < 5Hz), or to say, the phase of aSSR at f_{AM} (37Hz) tracks the carrier frequency change, which matched with previous studies (Patel and Balaban, 2004)

• For sounds with faster changing carrier (f_{FM} >5Hz), modulation encoding persists, but it is no longer pure phase modulation encoding.

• One possible hypothesis for encoding of sounds with faster carrier change is additional involvement of ***amplitude modulation encoding*** neuron groups, in which the amplitude (rather than the phase) of aSSR at f_{AM} (37Hz) tracks the carrier frequency change.

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This project was supported by NIH R01 DC05660 to DP