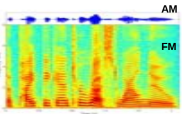
Modulation-encoding and Co-representation of the Acoustic Envelope and Carrier in Human Auditory Cortex

Huan Luo, Yadong Wang, David Poeppel, Jonathan Z. Simon

Neuroscience and Cognitive Science Program, University of Maryland College Park

Introduction

Acoustic Envelope and Carrier

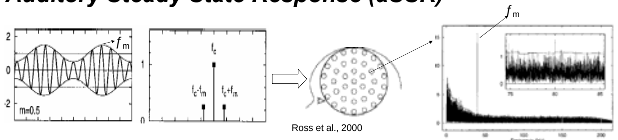


• Dynamically changing envelope and Carrier occurred widely in natural sounds and human speech, which can be characterized as **AM** and **FM**.

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

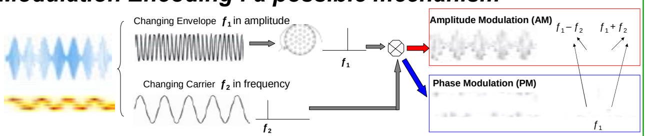
• Responses to pure AM and FM are widely studied in nonhuman species, as well as in humans using different means. However, the mechanism of co-representation of them are still unknown.

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

Previous findings:

• **Modulation encoding** is used by brain to co-represent modulated envelope (AM) and carrier (FM)

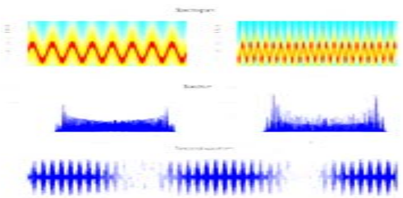
• **Phase modulation encoding** is found for slower carrier dynamics (FM) below 5Hz.

• **Coding transition** (from Phase to Amplitude Modulation encoding) is suggested as the rate of carrier dynamics increases.

We used stimuli with faster carrier dynamics (FM) to test the robustness of the modulation encoding and to explore the possibility of suggested coding transition by our previous experiments.

Methods

Stimuli



Stimulus duration: 10 sec ;
Frequency range: 220 ~ 880 Hz
f_{AM} : 37 Hz
f_{FM} : Low (0.3 ~ 8.0 Hz) previous
High (2.1 ~ 30 Hz)

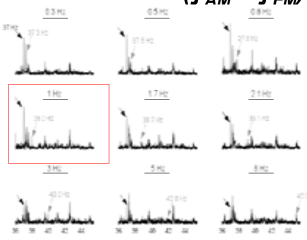
12 subjects for low range
11 subjects for high range

Recording and Analysis

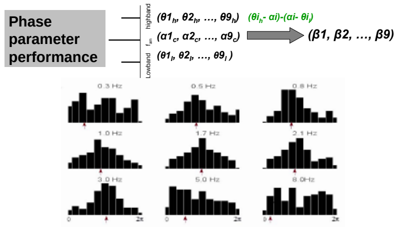
• 160 channel axial gradiometer whole head MEG (KIT system)
• Sampling rate 1000 Hz
• 9 conditions (9 f_{FM}) and 10 repetitions for each condition
• Channels sorted based on the amplitude of the f_{AM} (37 Hz) frequency and 10 channels with maximum values selected
• Frequency amplitude at 18 (9*2) possible 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 Sidebands ($f_{AM} \pm f_{FM}$)

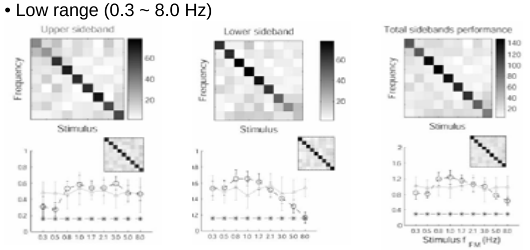


Phase property of two-sideband pattern



Confusion Matrix and Sideband Performance

• Low range (0.3 ~ 8.0 Hz)

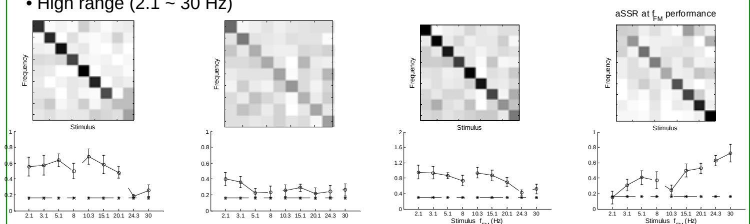


• Confusion matrix is used to check whether the sidebands were really significantly induced by corresponding stimulus

• 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.

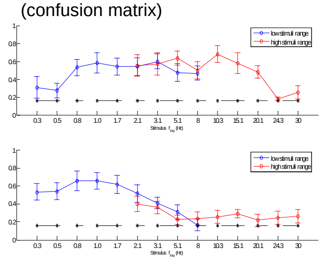
• It confirms that **Modulation Encoding** is used for co-representation

• High range (2.1 ~ 30 Hz)

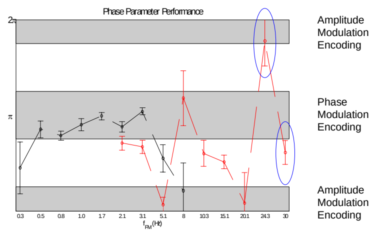


Summarization of low-range and high-range results

• Sideband amplitude (confusion matrix)

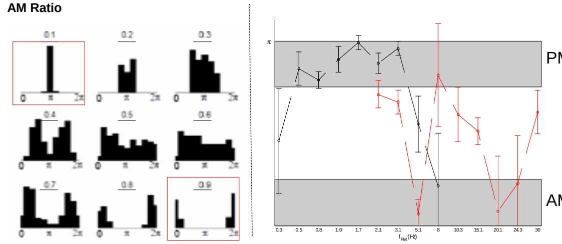


• Encoding-type Parameter (α distribution)



Two sideband --> One sideband

Encoding-type Parameter Simulations



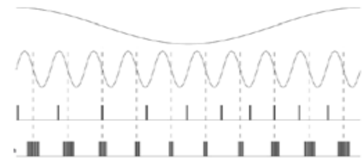
Neural explanations of PM and AM coding

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 for both low and high carrier dynamics up to 20 Hz .

• Dominant ***Phase modulation Encoding*** is used only 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 and there is a two-sideband to single-band transition.

• 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