Assessing evoked and oscillatory components in cortical synchronization to music using computational models

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Are rhythms in the brain truly oscillatory?

• Cortical rhythms in auditory cortex reflect the note rate of heard music. (Doelling & Poeppel, 2015)

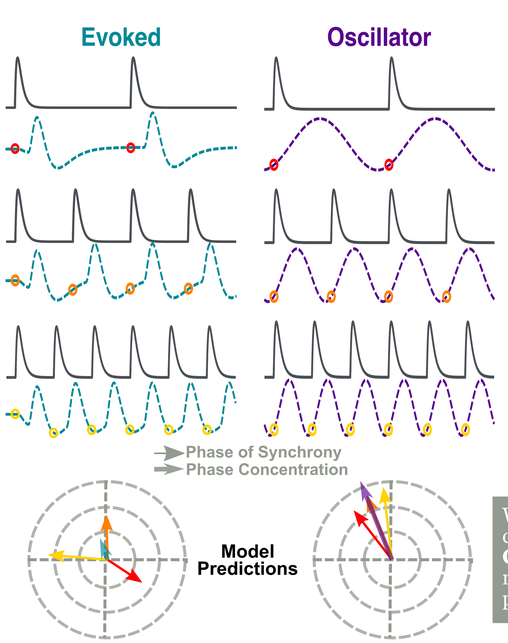
• Are these rhythms truly oscillating or do they simply mirror the rhythmic input?

• Here, we tease apart these two posibilities by studying phase lags at a range of frequencies. The two models should make different predictions which can be borne out in our analysis.

Hypothesis:

The oscillator model will track stimuli at a concentrated phase regardless of frequency. If auditory cortical rhythms are oscillating as well, they should show a similar phase spread.

Models predict distinct time lags and phase relationships



• The two models in practice look very similar. Particularly at higher frequencies.

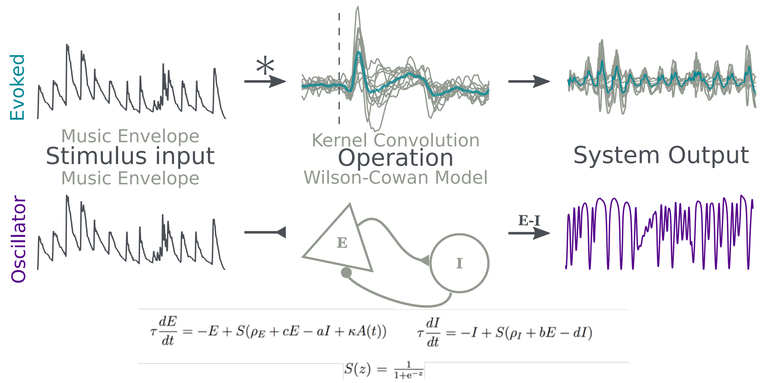
• Oscillator model provides important theoretical benefits (e.g. flexible prediction) that the evoked model cannot.

• Probing the relationship between the phase of sync and the frequency of stimulation will allow for model distinction and to see which model best represents human data.

We summarize this phase consistency using the **Phase Concentraion Metric (PCM)** represented by the teal and purple vectors shown here.

Building models of cortical entrainment to music

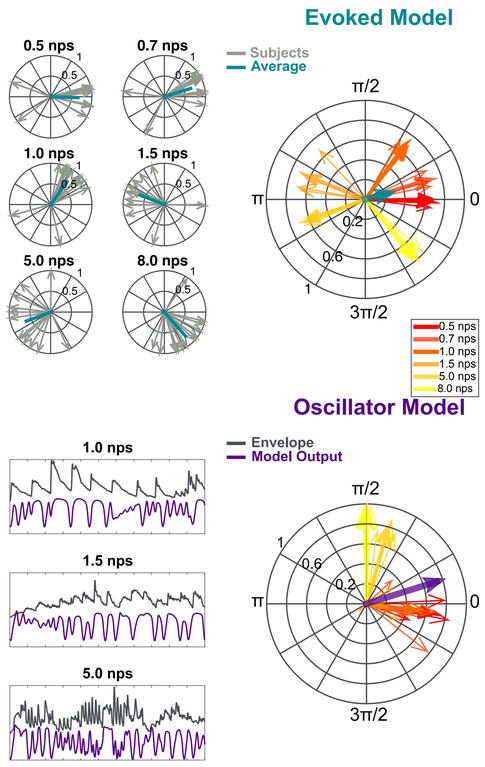
In two previous MEG experiments, participants listened to 3 clips each from 3 songs chosen for their note rate. Exp 1: 0.5, 5 and 8 notes per second (nps). Exp 2: 0.7, 1, and 1.5 nps. Here, we stimulated two models with these same stimulus rates to characterize their phase lag and compare to the previously recorded data.



$$\tau\frac{dE}{dt} = -E + S(\rho_E + cE - aI + \kappa A(t)) \qquad \tau\frac{dI}{dt} = -I + S(\rho_I + bE - dI)$$

$$S(z) = \frac{1}{1+e^{-z}}$$

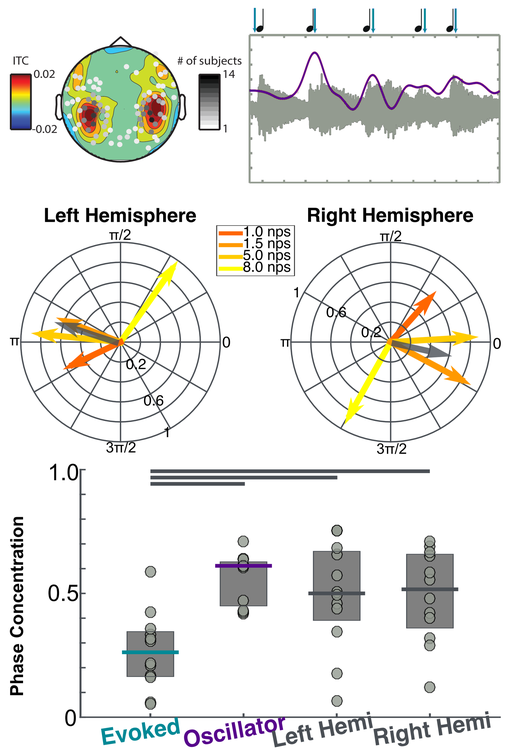
Two models of entrainment show distinct phase lag patterns



The model shows high synchrony to the stimulus but the **phase lag rotates with increasing note rate.** Clips at the same note rate show similar phase, suggesting that the phase is dependent on an interaction between the note rate and likely the peak response of the kernel.

Model output synchrony varies as note rate moves away from the oscillator's resting frequency but the **phase is consistent.** Interesting here is the 5 & 8 nps condition which show high synchrony at a separate phase and may reflect a different mechanism similar to steady-state response.

MEG phase patterns are more consistent with Oscillator



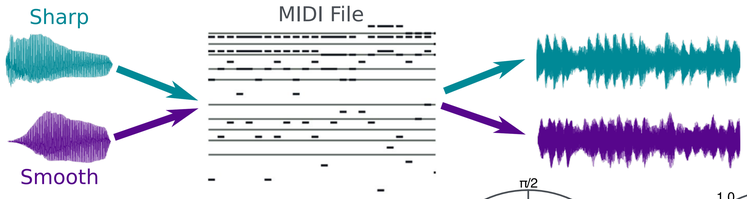
The MEG data shows a phase concentration that is more narrow than predicted by the evoked model.

There is no monotonic relationship between phase lag and note rate.

These features place the data closer to the oscillator model.

We compared PCM across model and individual data and found the **oscillator model better predicts the data from both hemispheres.**

Both oscillatory and evoked components contribute to the auditory response

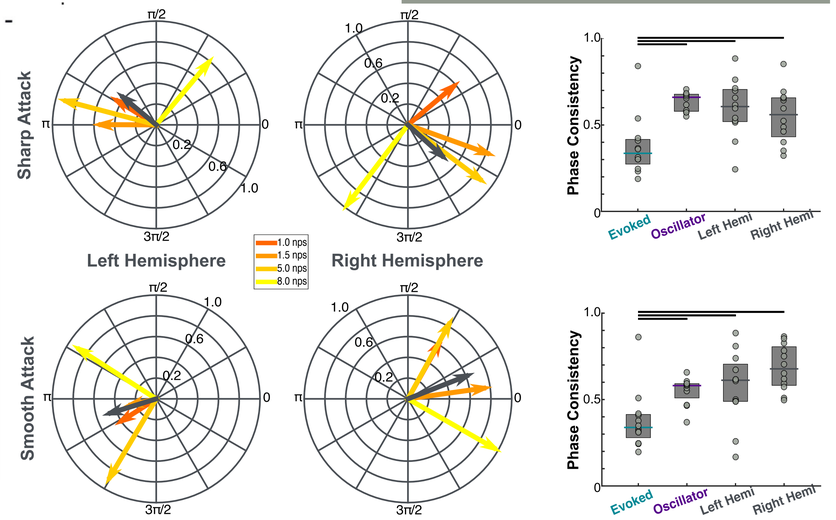


To understand the relationship between evoked and oscillator components of the underlying signal we created stimuli which modulate the evoked response by changing the attack of each note.

Smoothing the attack of the note narrows the phase concentration further in the right hemisphere, consistent with a reduction in the evoked response.

The result suggests the underlying signal contains two separate components, a transient bottom-up response and an oscillatory component determined by the neural circuitry.

By smoothing the attack we better approximate the true PCM of the oscillator component in auditory cortex.



Entrainment is oscillatory

• The two models, evoked and oscillator, show two distinct phase patterns: spread around the circle vs phase consistency.

• The MEG data shows more phase consistency as predicted by the wilson-cowan model.

• The auditory signal contains both evoked and oscillator components. These presumably can work together to handle both surprising and predictable inputs.

References

1. Doelling, K.B. & Poeppel, D. (2015) Cortical entrainment to music and its modulation by expertise. PNAS, 112 (45) E6233-42.

2. Wilson, H.R. & Cowan, J. (1972). Excitatory and Inhibitory interactions in localized populations of model neurons. Biophysical Journal, 12 (1) 1-24.