Theta-band Cortical Tracking of the Speech Envelope Shows the Linear Phase Property

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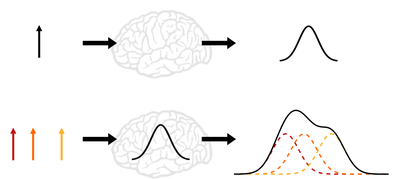
electronic version

Introduction

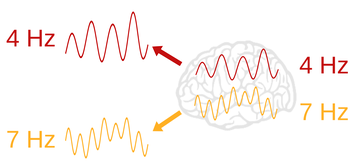
When listening to speech, low-frequency cortical activity tracks the speech envelope. It remains controversial, however, **whether such envelope-tracking activity reflects superposition of transient responses evoked by sound features or entrainment of neural oscillations**.

Evoked response hypothesis



Response to multiple stimuli is superposition of responses evoked by each stimulus

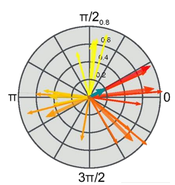
Oscillation hypothesis



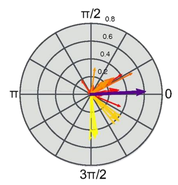
Response is generated by phase-resetting of intrinsic neural oscillations

Phase lag of music response

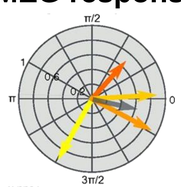
Evoked model

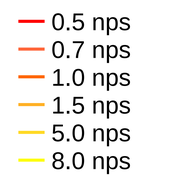


Oscillator model



MEG response





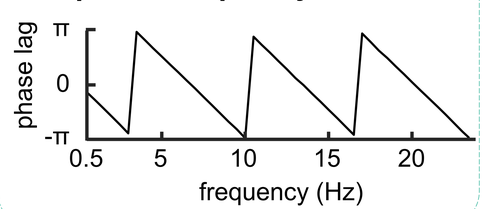
Delta-band envelope-tracking to music is better explained by the oscillator model (Doelling et al., 2019)

Simulated phase properties for speech tracking response

Evoked model (A system with 0.15 s delay)

$$r(t) = \int_0^{\tau} \delta(\tau - 0.15) A(t-\tau) d\tau$$

phase-frequency curve



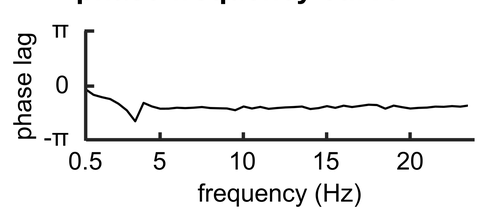
phase lag linearly changes

Oscillator model (Doelling et al., 2019)

$$\tau \frac{dI(t)}{dt} = -I(t) + S(\rho_I + bE(t) - dI(t))$$

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

phase-frequency curve

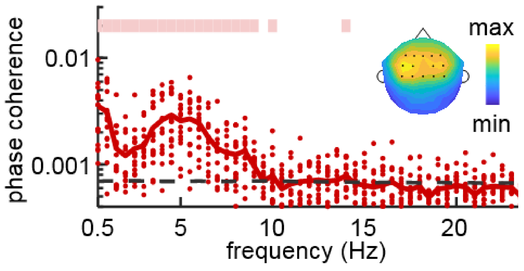


phase lag changes in a limited range

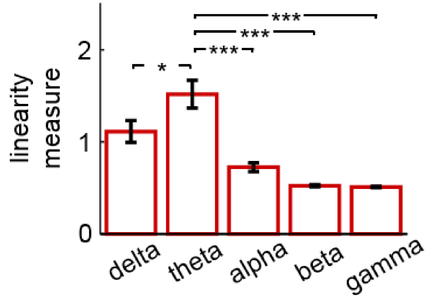
Exp$_1$ Phase properties of EEG response in healthy participants

- **Procedure:** Passive listening to a one-hour Mandarin story (repeated twice).
- **Participants:** Fifteen native Mandarin listeners.

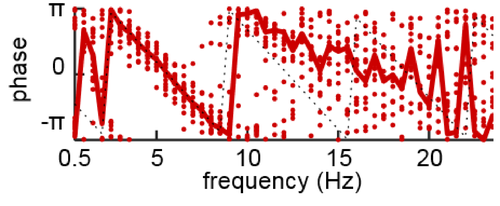
response tracks the envelope below 10 Hz



linearity measure of phase lag peak in the theta band



phase lag linearly changes with frequency

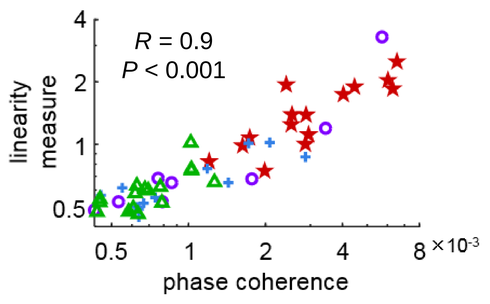


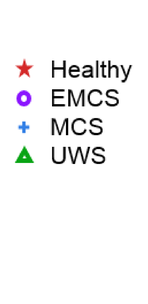
The phase lag is approximately a linear function of frequency in the theta band, which can be easily explained by the evoked response model and therefore does not require more sophisticated nonlinear oscillator models.

Exp$_2$ Influence of consciousness state on phase property

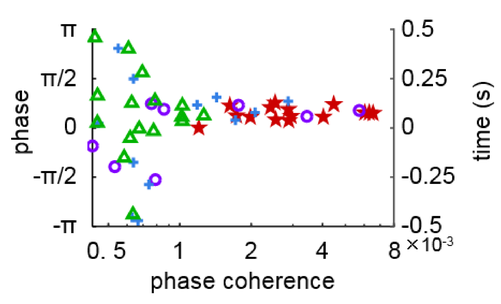
- **Participants:** Patients with disorder of consciousness (DoC), which are categorized into 3 groups, i.e., emerged from a minimally conscious state (**EMCS**), minimal conscious state (**MCS**), and unresponsive wakefulness syndrome (**UWS**)

phase coherence vs phase linearity





phase coherence vs group delay



Regardless of the consciousness state, the phase lag changes linearly and the group delay is consistent for both healthy individuals and patients who show reliable envelope tracking.

Conclusions

Theta-band envelope-tracking activity shows the linear phase property, which is not strongly modulated by consciousness states and can be explained by the evoked model.