Computational model for the modulation of speech-in-noise comprehension through transcranial electrical stimulation

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Introduction

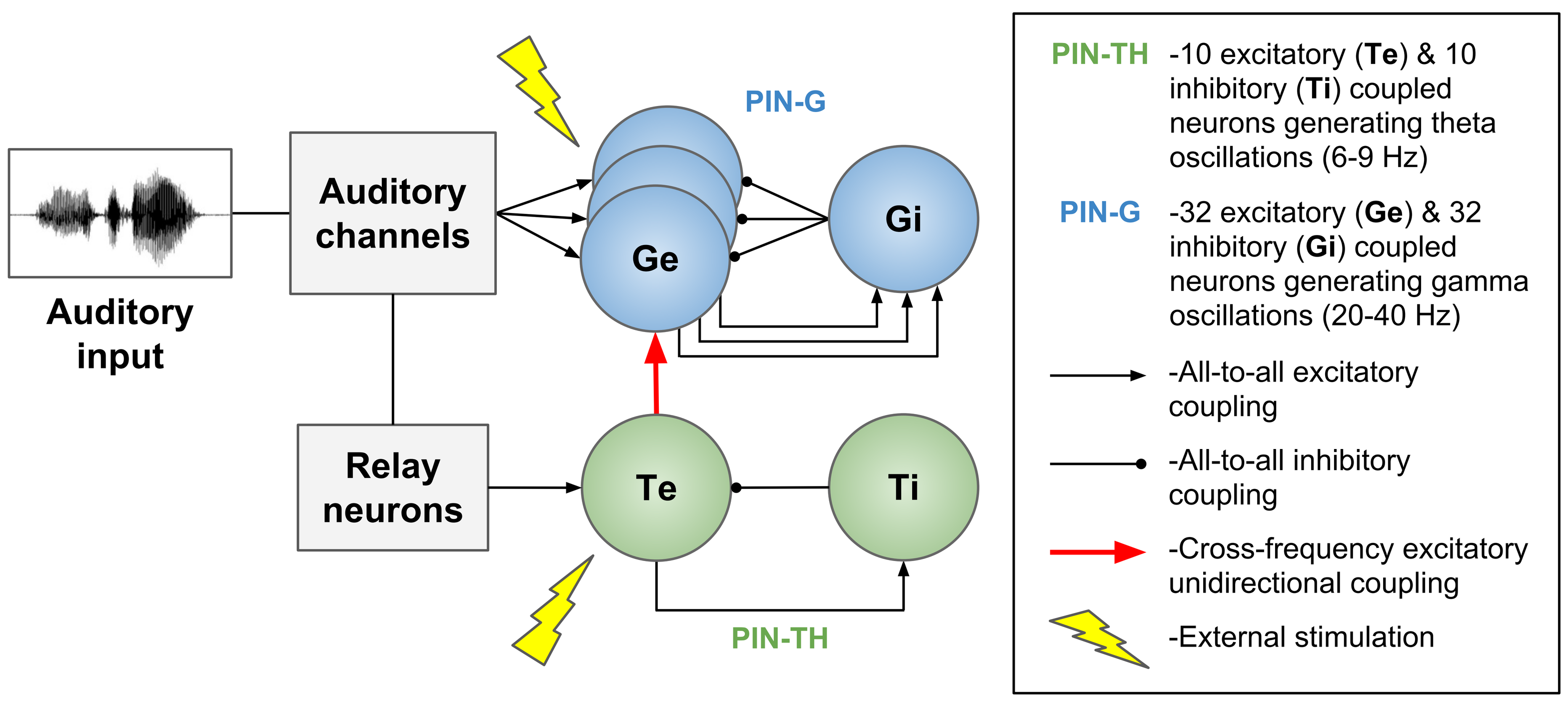
Transcranial electrical stimulation (TES) can non-invasively modulate neuronal activity in humans. Recent studies have shown that TES with an alternating current that follows the envelope of a speech signal can modulate the comprehension of this voice in background noise [Wilsch et al., 2018]. However, how exactly it influences the cortical activity and improves speech comprehension remains poorly understood.

Objectives

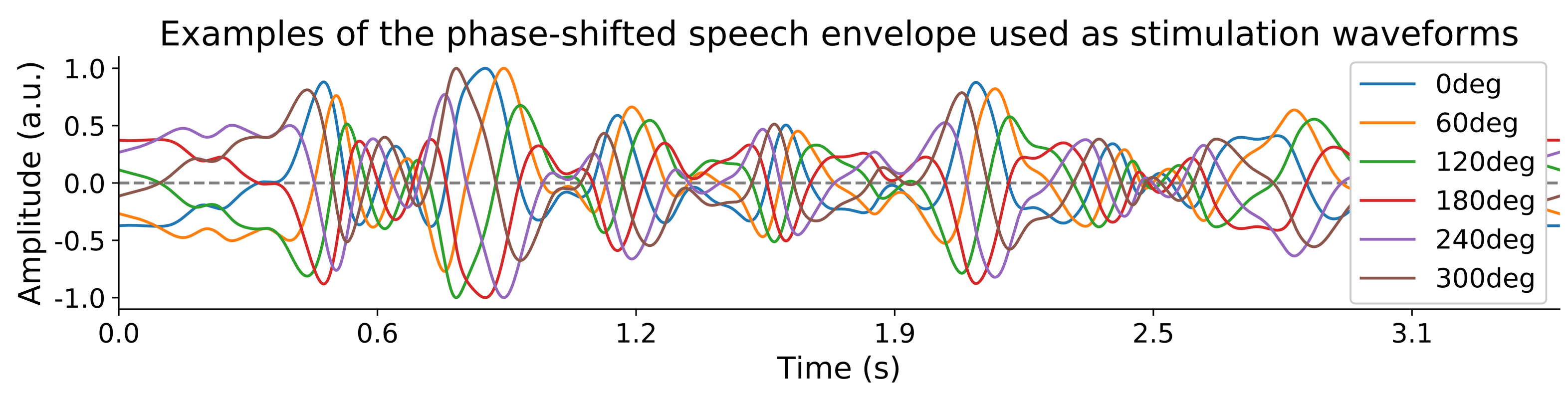
1. Establish a biologically plausible computational model of spiking neural network reflecting natural speech encoding in the auditory cortex.
2. Assess the network's speech-in-noise encoding performance considering different levels of background multi-talker babble noise.
3. Investigate the effect of different external currents on the network dynamics and optimize the stimulation paradigm for the enhancement of natural speech processing.

Materials and Methods

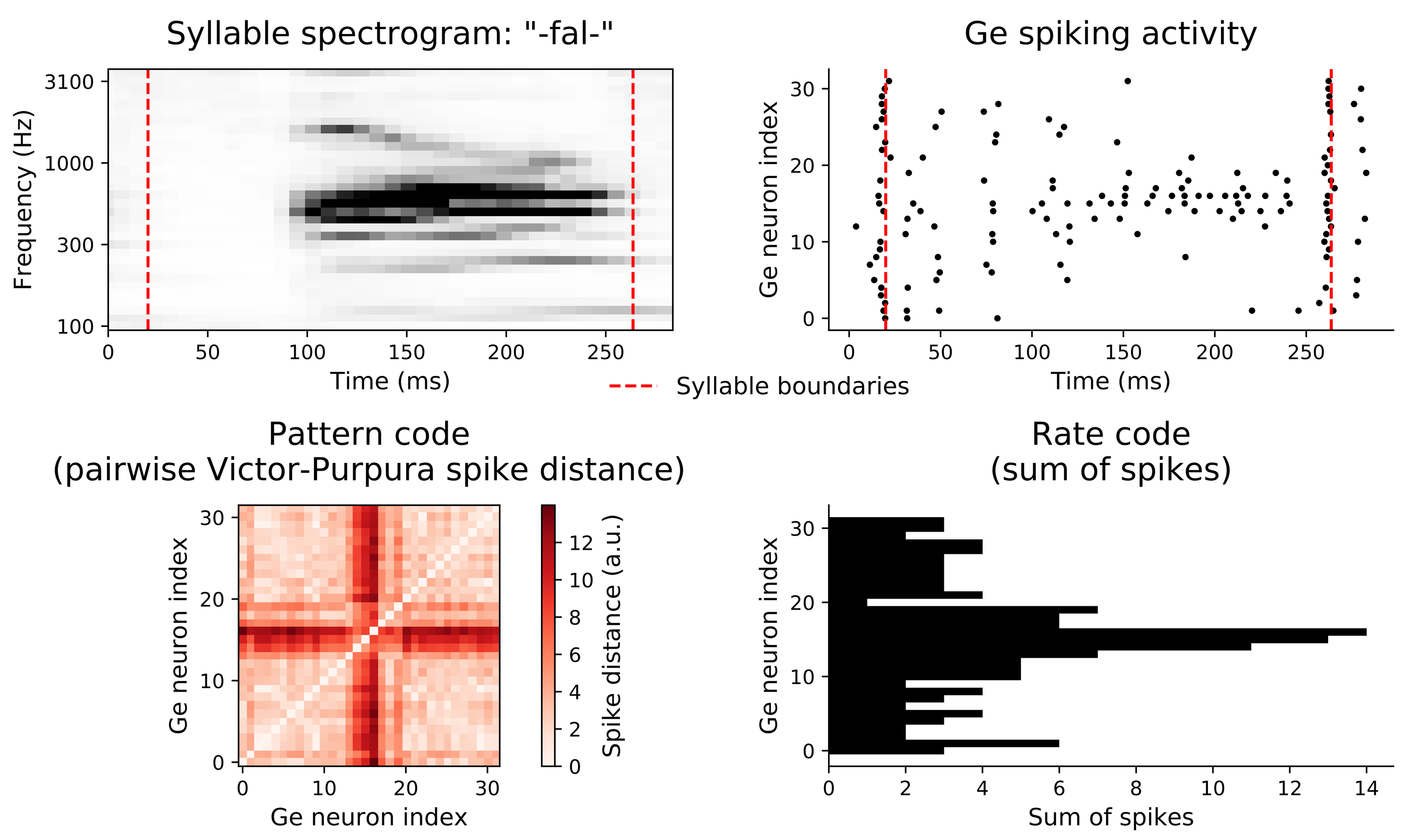
Computational model (adapted from [Hyafil et al., 2015])



- **Auditory channels**: the subcortical auditory processing model [Chi et al., 2005] decomposes auditory input into 32 distinct frequency bands (90-3623 Hz).
- **Relay neurons**: a population of neurons that project the auditory channels with a delay of up to 50 ms and weights that represent the strength of synaptic connections.
- **External stimulation**: tDCS, sine-wave tACS and speech envelope shaped current at different phase lags and intensity levels were delivered to Ge and Te populations.



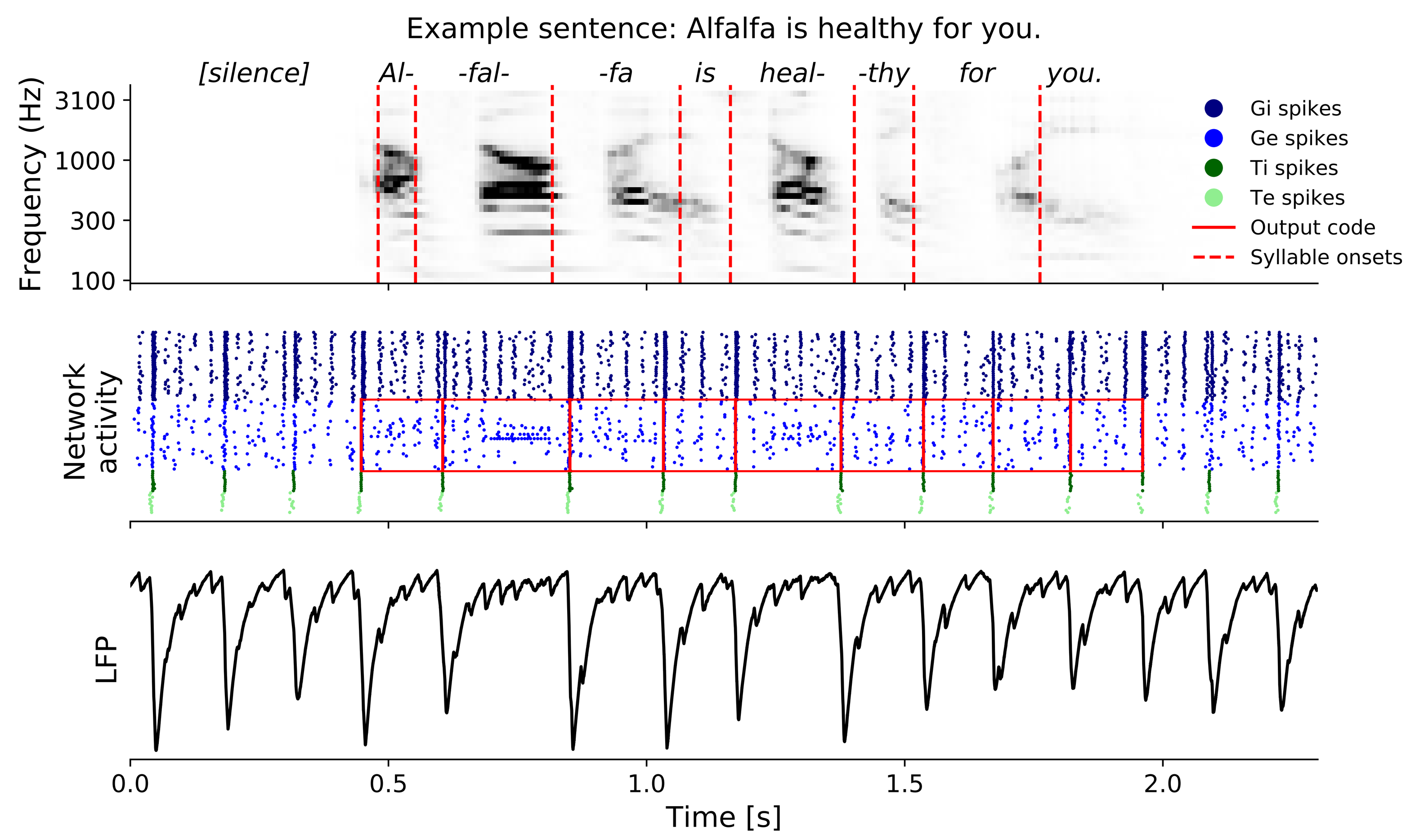
Syllable decoding



- 100 sentences from **TIMIT** database, each preceded by 500-1500 ms of silence, were presented to the model 100 times each. A single **classification trial** was performed using a random subset of **10 syllables** from all the available.
- **Onsets of syllables** were indicated by spike bursts in the PIN-TH network.
- **Nearest centroid algorithm** was used to decode syllables based on **pattern** or **rate code** obtained from the model simulations. To decode syllables from speech-in-noise, the centroids were obtained from the simulations employing the same sentences but **without masking noise**.
- **200 classification trials** were obtained for each of the considered levels of masking **babble noise**.
- To seek for the similarity with normal human performance in speech-in-noise listening task a **sigmoid function** was fitted to all the obtained results to determine at what level of SNR the algorithm yields **50% relative decoding accuracy**.

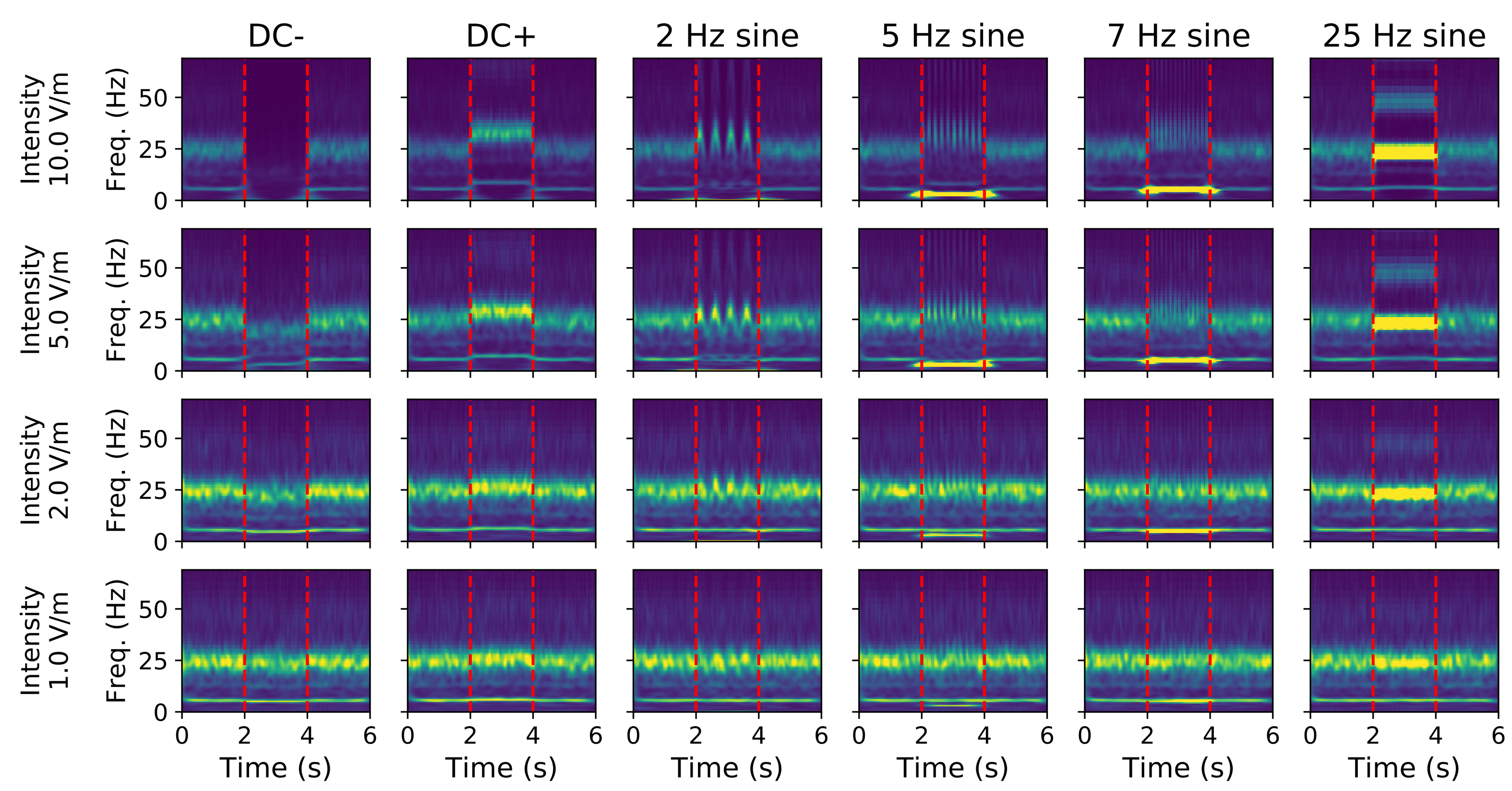
Results

Network's behavior (without external stimulation)



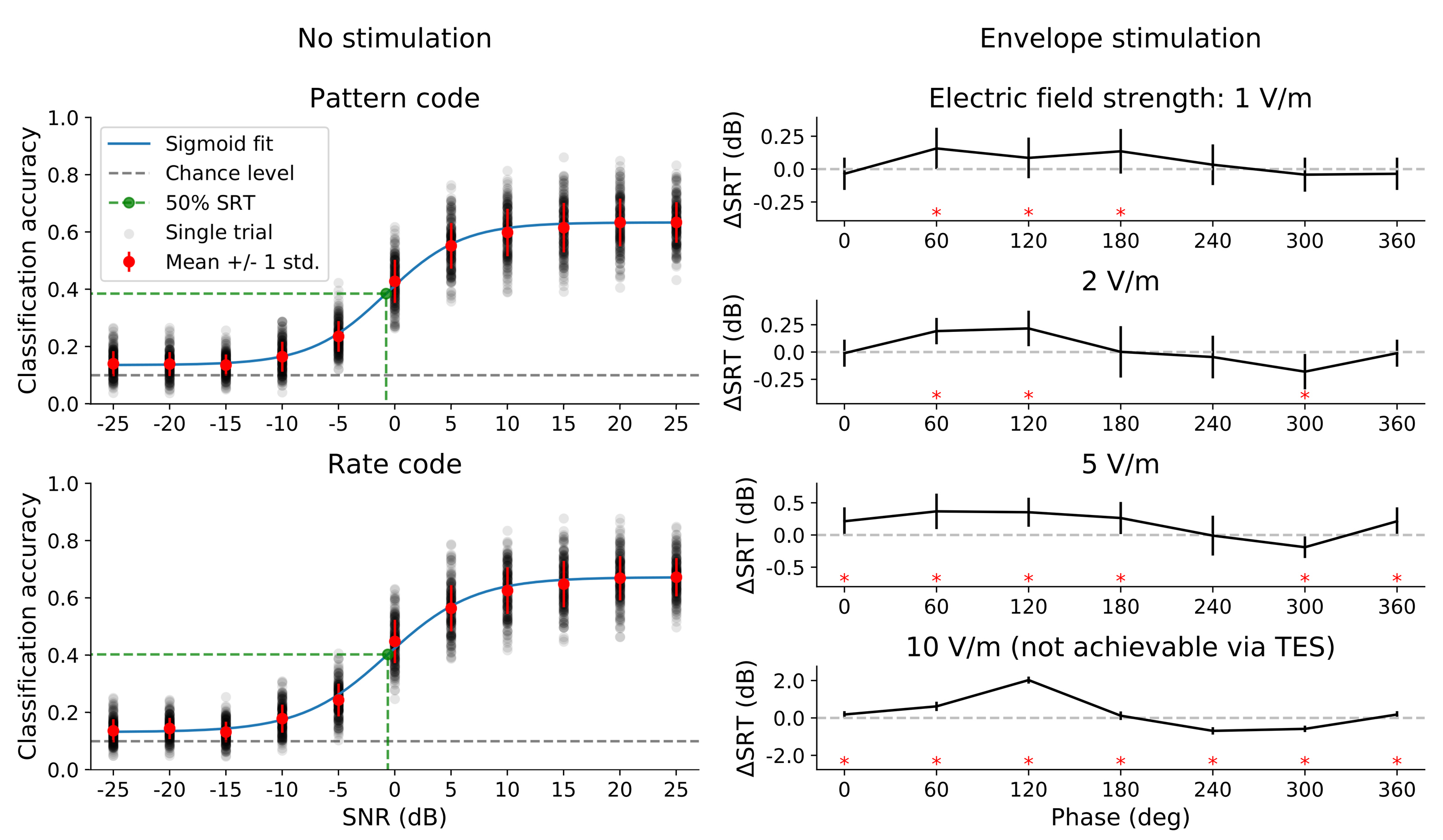
The cross-frequency coupling provides strong modulation of the gamma activity by theta oscillations (middle and bottom panels). Spike bursts in PIN-TH network (green) are entrained to syllable onsets (red, dashed) and determine time-windows for the fast gamma activity (red, solid).

The effects of TES on LFP of the decoupled network at rest



The red dashed lines indicate the onsets and offsets of stimulation. For low-frequency TES (2-7 Hz), the gamma activity (20-40 Hz) was temporally modulated while the theta (6-9 Hz) was entrained to the stimulation frequency. The high-frequency TES almost exclusively affected the gamma activity.

Speech-in-noise syllable decoding



In agreement with the 50% speech reception threshold (SRT) in normal hearing population, 50% of the relative decoding accuracy, with no stimulation applied, was identified at -1 dB. The syllable decoding performance, measured as a shift of the 50% SRT from the 'no stimulation' case (left), was significantly ($p<0.05$, red asterisk) modulated by certain phases of the envelope stimulation.

Acknowledgements

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References

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