Breaking Down the Cortical Representations of Speech in LFP and MUA

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How are auditory stimuli represented in LFP and MUA?

Local field potential (LFP), the low frequency component of extracellular recordings, is closely related to neural measures commonly available for human subjects, such as EEG and MEG. Therefore, the LFP provides a valuable bridge between single-unit animal and non-invasive human neurophysiology. Here, we characterize the spectro-temporal tuning of LFP and multi-unit activity (MUA) recorded from ferret primary auditory cortex (A1) using natural stimuli and compare in particular their spontaneous versus stimulus-evoked dynamics.

Stimuli, Neural Recording, and Terminology
Stimuli: 30 three-second duration sentences from the TIMIT speech database, presented contralaterally to the recording site.

Electrophysiological activity was recorded from primary auditory cortex (A1) of awake, passively listening, adult ferrets (11 animals, 477 recording sites) using high-impedance tungsten electrodes (1-4 MΩ). MUA was defined as the time-varying power of neural recording between 600 and 3000 Hz, and LFP was analyzed in several bands below 300 Hz. Spectro-temporal receptive fields (STRFs) were estimated from the speech response by boosting (David et al., 2007).

The evoked response is the neural activity over trials (i.e. presentations of the same stimulus). The response variance is its variance over trials. The response variance is also called the induced power, i.e. the power of induced activity, which is the difference between the response in single trials and the evoked response. Mathematically, for a neural response \( X(t) \), the evoked response is \( E(X(t)) \) and the induced response is \( X(t) - E(X(t)) \), where \( E() \) denotes the expectation or mean operation. The variance of \( X(t) \) is exactly the power of the induced response, i.e. \( \text{Var}(X(t)) = E[(X(t) - E(X(t)))^2] \). A BST

LFP Response to Speech: Spectral Properties

The stimulus reduces the inter-trial variance of low-frequency LFP (<14 Hz) but increases the inter-trial variance of high-frequency LFP (>40 Hz). The anti-correlated increase in evoked response and reduction of response variance observed in low-frequency LFP channels is evidence in support of a phase resetting theory: the stimulus-driven LFP response is at least partly converted from ongoing spontaneous LFP.

Auditory stimuli do not only evoke phase-locked LFP responses but also reduce the variance of ongoing low-frequency LFP activity.

STRFs for MUA and Evoked LFP
Examples of STRFs for MUA (upper) and evoked LFP (lower).

The STRF temporal response is the sum of the STRF over frequency. The averaged MUA temporal response is dominated by a single excitatory peak, while that of the evoked LFP oscillates through 3 peaks (P1-P4) and lasts for more than 200 ms. The first peak of LFP STRF has a BF and bandwidth similar to the MUA STRF.

The predictive power is the correlation between STRF predicted response and actual response, calculated using cross-validation. The predictive power of MUA and LFP STRFs is moderately correlated across recording sites (\( R = 0.43 \)).

STRFs for LFP Response Variance
STRFs were also estimated based on the variance of the neural response in different frequency bands.

The variance based STRF is excitatory for LFP >70 Hz, but inhibitory for LFP <20 Hz.

The latency of the MUA STRF is similar to the STRF latency for LFP >150 Hz, but much shorter than the latency of the inhibitory STRF observed for LFP <70 Hz.

The BF of the MUA STRF is also similar to the STRF BF for LFP >150 Hz.

The spectro-temporal tuning of high-frequency LFP (>150 Hz) and MUA is similar. The decrease in variance for low frequency LFP (<40 Hz) reflects suppression with different tuning than the MUA.

A Schematic Model for “Phase Resetting”

The stimulus-related reduction of response variance is evidence for a phase resetting theory. In the following, however, we show that phenomenological phase resetting may not indicate a direct relationship between stimulus-driven and spontaneous activity.

In this model, the neural response is a linear summation of spontaneous activity and stimulus-driven activity, which are here independent of each other. However, due to the limited dynamic range of neuronal circuits, characterized by a static compressive nonlinearity, the summed response appears as what is predicted by the phase resetting theory.

Conclusions
MUA signals are strongly correlated with short-latency evoked LFP and high-frequency LFP responses variance. The remaining components of the LFP must be explained by network dynamics other than local spiking.

References:

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