Macaque motor cortex resting state spiking activity is characterized by low correlations and high dimensionality

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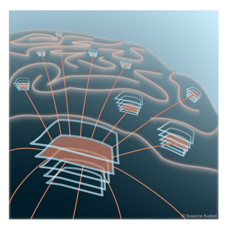


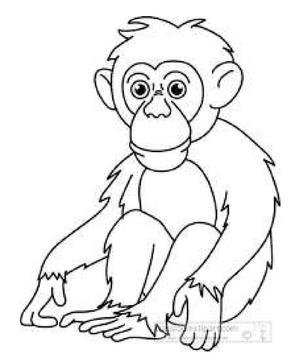
Motivation

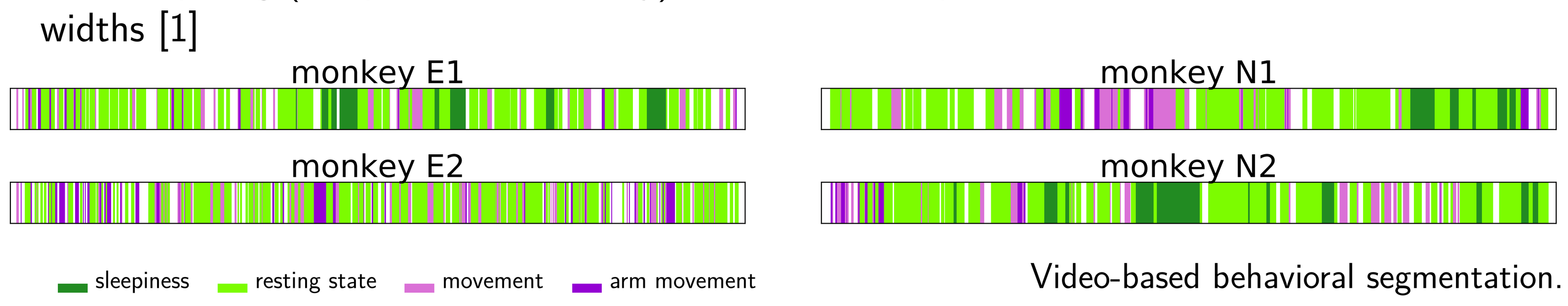
Resting state activity is typically studied with large scale measurements such as fMRI or M/EEG. We investigated the network activity on the level of single units' spiking activity and local field potentials, which is a common approach for active behavioral experiments, but rare in resting state research.

Experimental Resting State Data

Massively parallel spiking data and LFP were recorded from the hand area of macaque pre-/motor cortex. The monkey was at rest, i.e. not involved in any task nor receiving controlled stimuli. The monkey's behavior was video recorded and revealed epochs of resting (RS), sleepiness (RSS), spontaneous body and contralateral arm movements (M, AM).

- 2 macaque monkeys, 2 recordings per monkey
- 4x4 mm^2 10x10 electrodes Utah Array
- approx. layer 3-5 of monkey motor cortex
- 15-20 min measurement accompanied by video recording
- behavioral states derived from the video by visual inspection
- approx. 140 single units (SU) per recording after spike sorting, classified as broad-spiking (**bs**, putative excitatory) or narrow-spiking (**ns**, putative inhibitory) based on their spike widths [1]

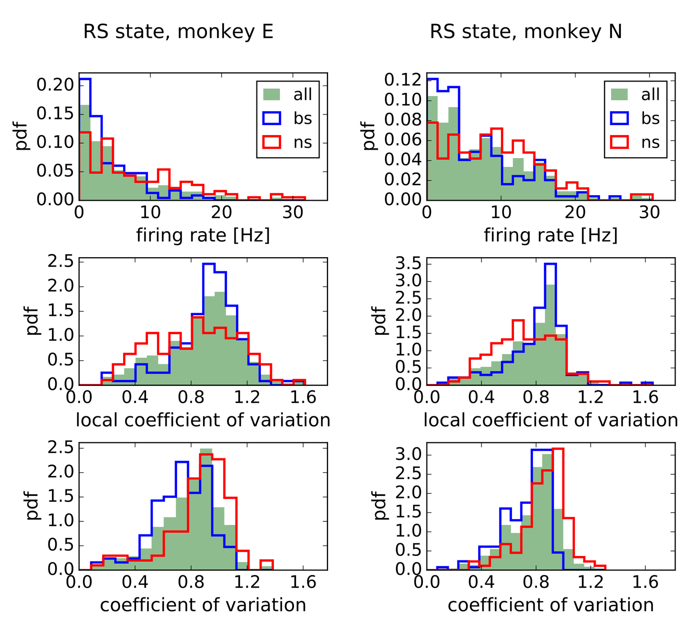




Video-based behavioral segmentation.

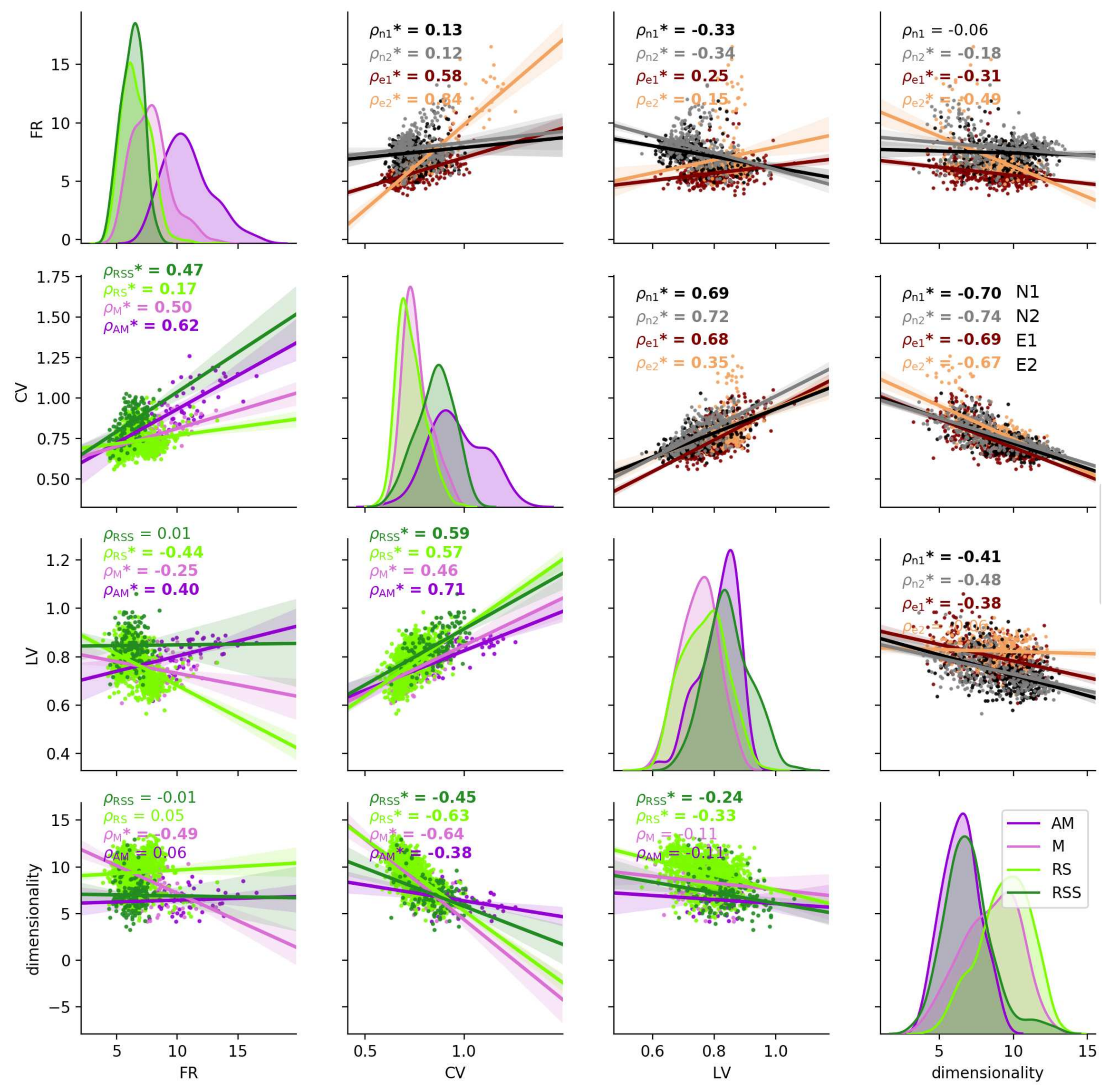
Spiking activity

A basic statistical feature of neuronal spiking activity is firing rate (**FR**) – spike count per unit time. The distributions of average FRs per single unit are shown in top pannels of figures below. Neurons of monkey N tend to fire faster (green), but in both monkeys the difference between bs and ns is pronounced: putative excitatory neurons are characterized by lower FRs.



To quantify the variability of FR in time, the coefficent of variation (**CV**) is calculated (bottom panels). Its local version (**LV**, middle panel) reduces the effect of slow FR changes on the resulting statistics. For both values <1 indicate less variability than in a stationary Poisson process. In both monkeys ns units show higher CVs and lower LVs – an indication of more variable FR over time than in bs.

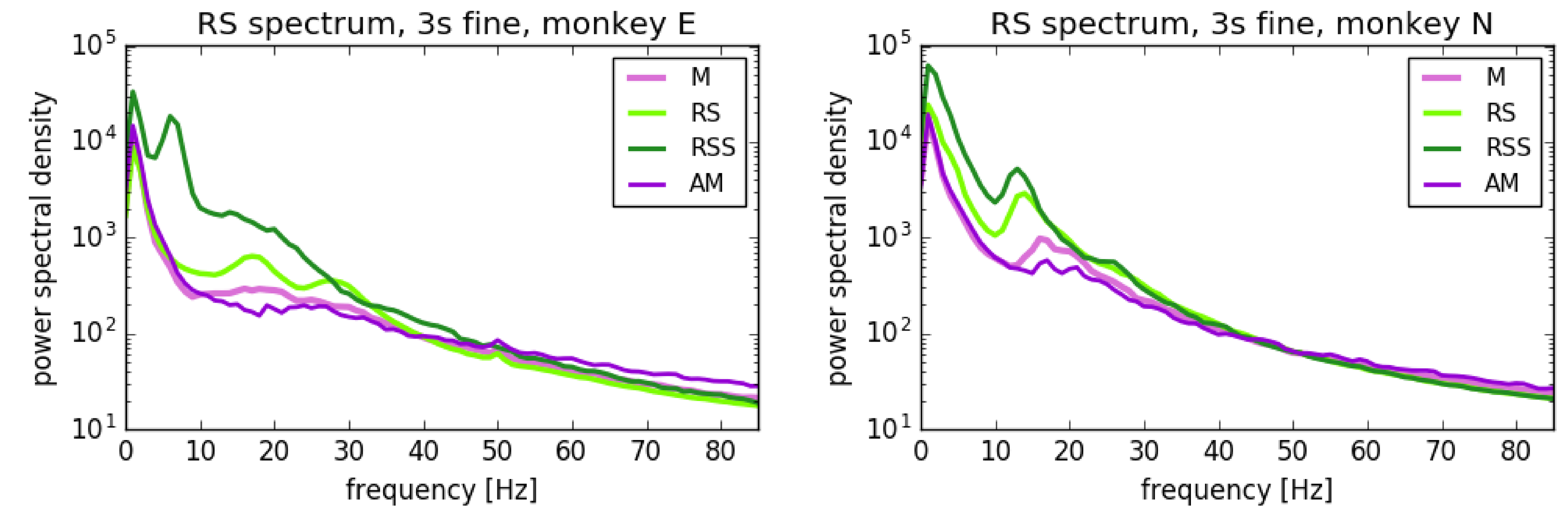
State-resolved comparison of the same statistics pooled across monkeys is shown on the diagonal of figure below. FRs are higher during movements, a common finding in experiments involving active behavior. LV does not show any striking difference between states, but CV divides them into distinctive pairs – the same as the dimensionality does (see below on the right). Off-diagonal plots visualize linear correlationS between respective statistics, state- (bottom triangle) and recording-resolved (upper triangle).



Summary

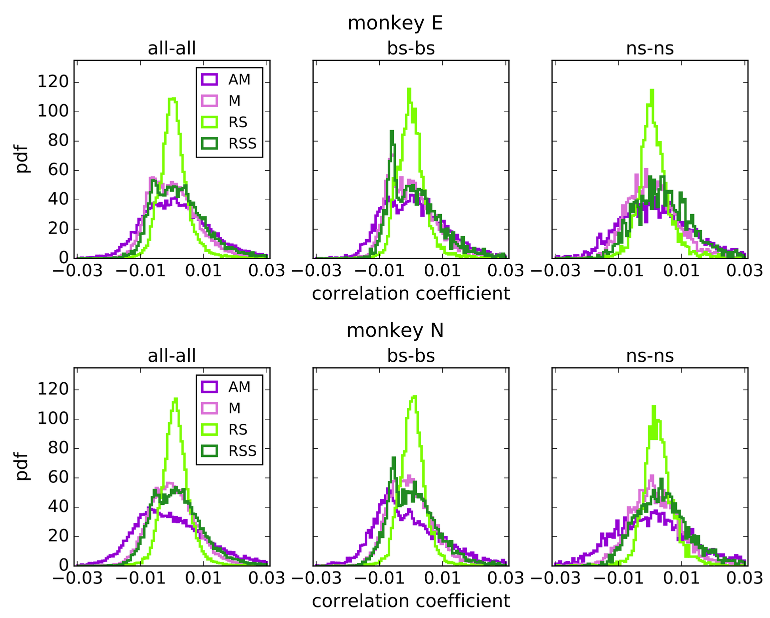
- Combined analysis of spike trains and LFP reveals decreased low frequency (<30 Hz) power and increase of FR and high gamma (>60 Hz) during motor states.
- CV and LV are decreased during RS and M compared to AM and RSS, indicating less non-stationarity in neuronal firing.
- Dimensionality is decreased during AM and RSS and significantly (negatively) correlated to CV and LV.
- CC and COV reach the highest values during AM and the lowest during RS.
- We observe a neuron-type dependent characteristics where putative inhibitory neurons are more strongly correlated and have higher firing rates.

Local Field Potentials



LFP is often compared to EEG or ECoG even though its origin is much more local. Still, several behavior-related features of all of these signals are known, e.g. dominance of low-frequency oscillations in non-active states and increase in high frequencies related to movements [2].
In our data this phenomenon is clearly visible: the power in low frequencies (<30 Hz) is higher during rest than during movements, and particularly high during sleepiness. During movements, however, power above 60 Hz is enhanced in comparison to RS and RSS.

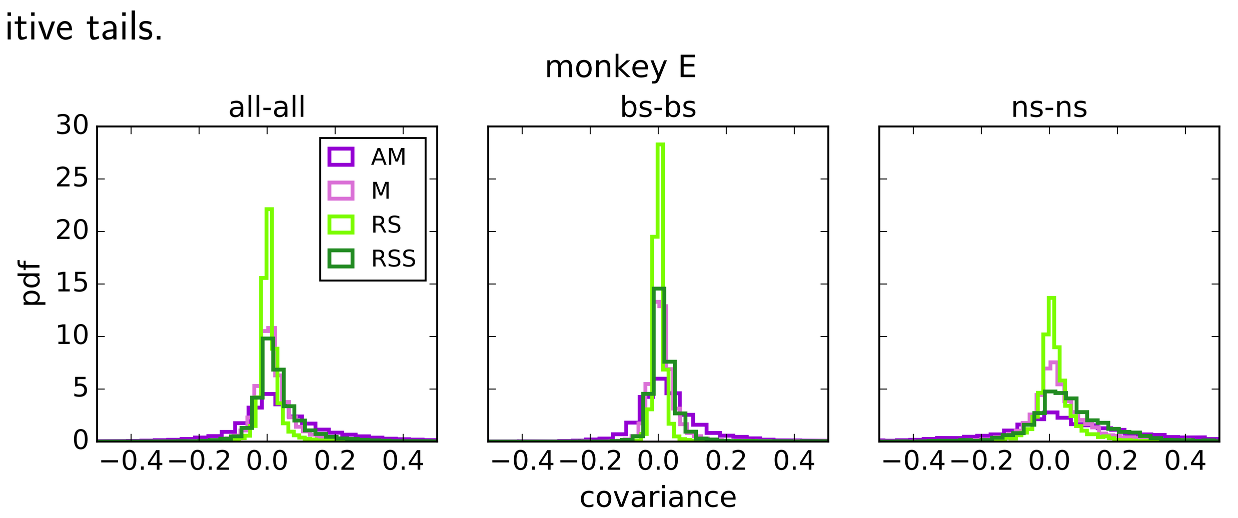
Pairwise Fine Correlations



Pairwise fine temporal correlation (**CC**) between single units can be used to estimate synchrony in the data. Spike trains are binned into 3 ms bins, a scale characteristic for single action potentials. Therefore only coincidential spikes contribute to the resulting statistics.
The left plots show that absolute values for RS are lower than for any other state, indicating less synchronous activity of single units. Ns-ns pairs show higher correlations than bs-bs independently of behavior.

Pairwise Covariances

Pairwise cross-covariances (**COV**) calculated with 100 ms bins reveal comodulation of firing rates between spike trains. Non-stationarities, e.g. changes of FR, can lead to asymmetric COV distributions with large positive tails.



Similarly to CC, COV distribution is the narrowest in RS – values are the closest to zero. The opposite is observed during AM. Absolute values are the highest among all states, with a positive tail, pointing to quickly changing and covarying firing rates. Putative inhibitory pairs have the largest variances. These results are observed for both monkeys.

Dimensionality

The dimensionality of neural activity [3]:

$$d = \frac{(\sum \lambda_i)^2}{\sum \lambda_i^2}$$

is obtained from Eigenvalue decomposition of the covariance matrix. The dimensionality is low when there is a small number of large eigenvalues, i.e. a small number of components explains most of the variance in the data. As shown in the figure to the left, the dimensionality is strongly decreased during AM and RSS (see also [4]).

References

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