CHARACTERIZATION OF MOTOR CORTEX SPIKING ACTIVITY FOR SPIKING NEURAL NETWORK MODEL VALIDATION

Paulina A. Dąbrowska[1,2], Nicole Voges[1,3], Michael von Papen[1], Junji Ito[1], David Dahmen[1], Alexa Riehle[3,1], Thomas Brochier[3], Sonja Grün[1,4]

[1] Institute of Neuroscience and Medicine (INM-6 & INM-10) and Institute for Advanced Simulation (IAS-6), Jülich Research Centre, Jülich, Germany
[2] RWTH Aachen University, Aachen, Germany
[3] Institut de Neurosciences de la Timone (INT), CNRS - Aix-Marseille Université, Marseille, France
[4] Theoretical Systems Neurobiology, RWTH Aachen University, Aachen, Germany

NEURONUS Forum 2020 | poster **COG_P76** | December 10-11 (Th-Fr) 15:30-16:30 CET | p.dabrowska@fz-juelich.de

Aix*Marseille université

int institut de neurosciences de la timone

RWTH AACHEN UNIVERSITY

JÜLICH Forschungszentrum

Motivation: Model validation with experimental data

Large-scale spiking neural network models

- usually assume "idle" or "resting state" activity
- often validated with data from experiments involving stimulation or behavioural task

How does neuronal activity change during different behaviours?

Ultimate goal: provide a data set suitable for spiking neural network models validation.

Our experimental data

- two macaque monkeys (E & N)
- 4x4 mm^2 10x10 electrodes Utah array implanted in the hand area of M1/PMd
- approx. layer 3-5 of motor cortex
- parallel spiking activity of $\approx$ 120 single units (SUs) and local field potential (LFP)
- 15-20 min long recording sessions
- only SUs with SNR$\geq$ 2.5 and average firing rate $\geq$ 1 spike/s considered in analyses

Details available in a preprint:
Dąbrowska, P. A., Voges, N., Von Papen, M., Ito, J., Dahmen, D., Riehle, A., Brochier, T., Grün, S. (2020). On the complexity of resting state spiking activity in monkey motor cortex. BioRxiv. doi: 10.1101/2020.05.28.121095

Our experimental data

Resting state

- no task, no stimuli
- electrophysiology and video recording
- three behavioural states defined:

resting state (RS)

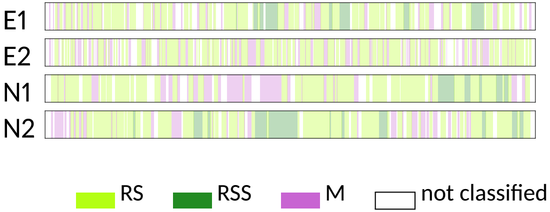
no movements, eyes open

sleepy rest (RSS)

no movements, eyes closed

spontaneous movement (M)

limbs or body movements



Data analysed in **3 s long continuous slices** of single state.

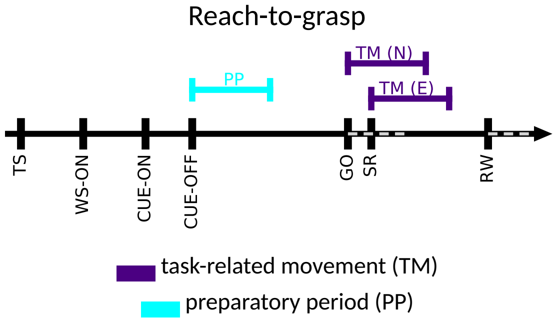
p.dabrowska@fz-juelich.de

Our experimental data

Reach-to-grasp

Task:

- monkey self-initiates a trial (TS)
- a cue relevant to the task is displayed (CUE-ON–CUE-OFF)
- monkey **waits for 1 s** without movements
- second cue (GO) provides missing information about the task
- monkey initiates (SR) a **reaching movement**, grasps an object and holds it to receive a reward (RW)



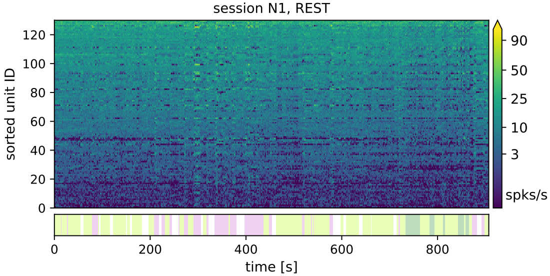
500 ms long data slices, for population-level analyses concatenated into 3 *s* long slices.

p.dabrowska@fz-juelich.de

Single unit spiking across behaviours

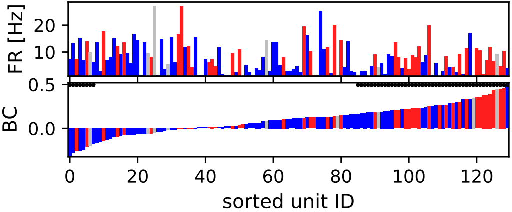
Resting state

$\approx$ 50% SUs significantly change firing rate with monkey's behaviour (Kruskal-Wallis test with $\alpha = 0.001$ and Bonferroni-Holm correction for multiple comparisons)



Behavioural correlation (BC) per SU:

- create state vector: single second resolution; 1 = M, -1 = RS, 0 = other
- correlate with firing rate (1 s bins)

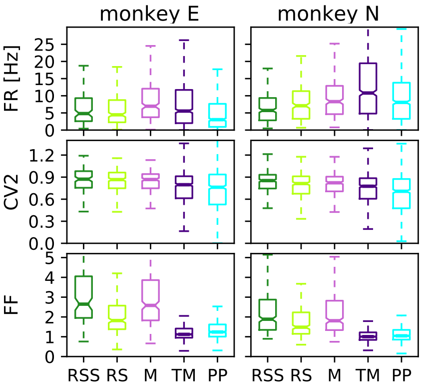


Spearman $r(\mathrm{BC}, \mathrm{FR}) < 0$ and insignificant.

Single unit spiking across behaviours

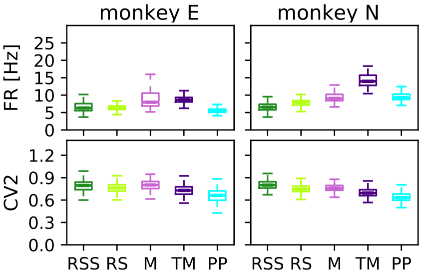
Resting state & Reach-to-grasp

Average over time per SU



FR
firing rate
CV2
coefficient of variation of inter-spike intervals
FF
Fano factor, variability of spike counts across time

Average over SUs per time slice



sleepy resting state (RSS) resting state (RS) spontaneous movement (M) task-related movement (TM) preparatory period (PP)

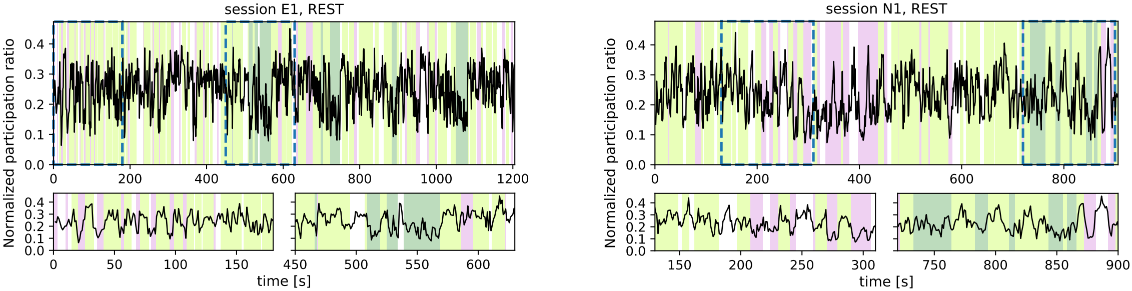
p.dabrowska@fz-juelich.de

Population spiking across behaviours

Dimensionality

Dimensionality quantified as **participation ratio**:

1. Covariance matrix of all spike trains.
2. Eigenvalues λ from eigenvalue decomposition.
3. $\mathrm{PR} = \frac{(\sum_i \lambda_i)^2}{\sum_i \lambda_i^2}$ (normalized by number of SUs per session)



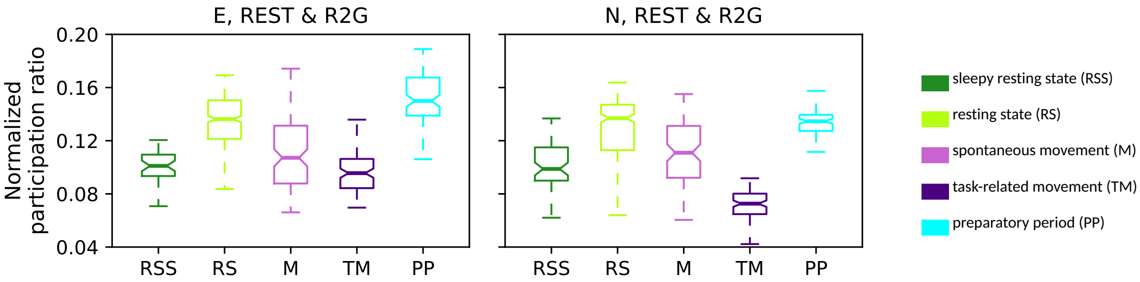
p.dabrowska@fz-juelich.de

Population spiking across behaviours

Dimensionality

Dimensionality quantified as **participation ratio**:

1. Covariance matrix of all spike trains.
2. Eigenvalues λ from eigenvalue decomposition.
3. $\mathrm{PR} = \frac{(\sum_i \lambda_i)^2}{\sum_i \lambda_i^2}$ (normalized by number of SUs per session)

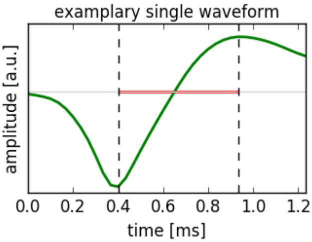


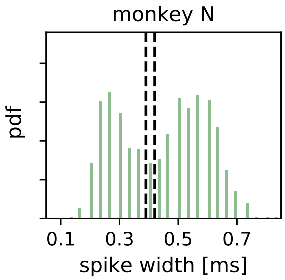
Population spiking across behaviours

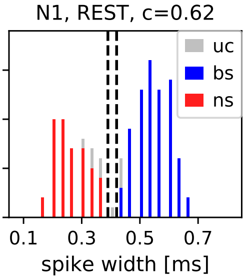
Excitatory-inhibitory balance

Separation of putative excitatory and putative inhibitory neurons:

1. Per monkey take all single waveforms from all recordings, extract their widths.
2. Based on spike widths distribution, set a threshold and apply to average SU waveforms.
3. Calculate consistency: $c_{SU} = \frac{N_{<broad/narrow>}}{N_{single}}$, classify consistent SUs.







p.dabrowska@fz-juelich.de

Population spiking across behaviours

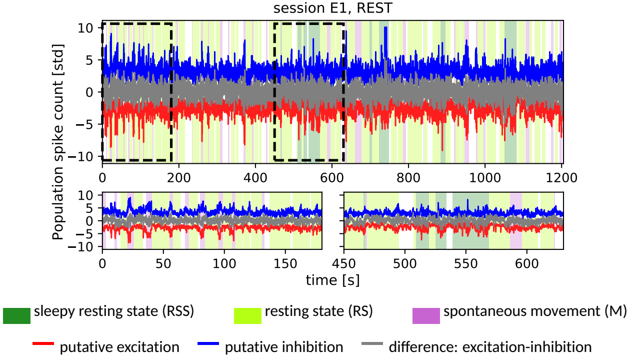
Excitatory-inhibitory balance

Dominance of excitation or inhibition (Δ):

1. In 3 s long slices, bin population activities into 100 ms bins.
2. Z-score with respect to whole-recording mean and std.
3. Subtract inhibitory from excitatory activity.

Instantaneous balance (ρ):

1. In 3 s long slices, bin population activities into 100 ms bins.
2. Calculate Spearman rank correlation between activities.



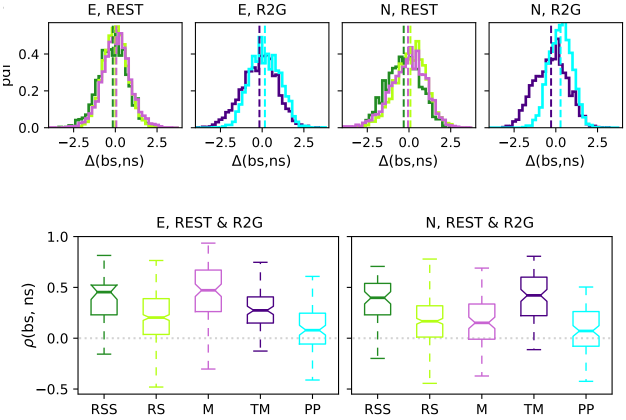
poster **COG_P76** | December 10-11 (Th-Fr) 15:30-16:30 CET
p.dabrowska@fz-juelich.de

Population spiking across behaviours

Excitatory-inhibitory balance

Dominance of excitation or inhibition (Δ):

1. In 3 s long slices, bin population activities into 100 ms bins.
2. Z-score with respect to whole-recording mean and std.
3. Subtract inhibitory from excitatory activity.

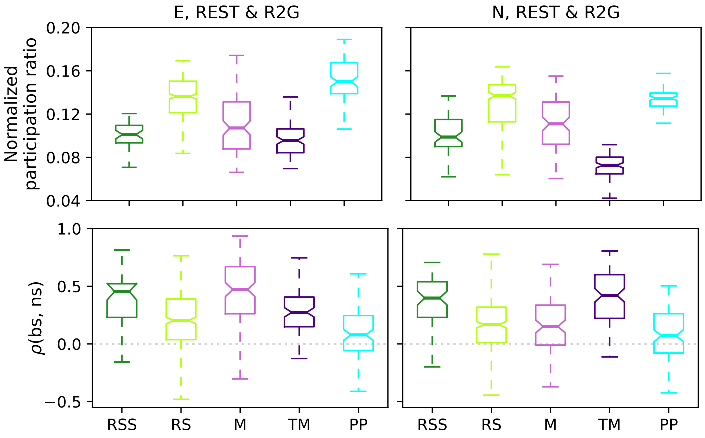


Instantaneous balance (ρ):

1. In 3 s long slices, bin population activities into 100 ms bins.
2. Calculate Spearman rank correlation between activities.

Population spiking across behaviours

Dimensionality and excitatory-inhibitory balance



Spearman rank correlations between dimensionality and instantaneous balance:

	E	N
RSS	-0.31	-0.32
RS	-0.44	-0.21
M	-0.77	-0.42
TM	0.14	-0.33
PP	0.04	-0.08

gray – insignificant

p.dabrowska@fz-juelich.de

Summary

- Resting state spiking activity differs from other behaviours, both task-related and spontaneous.
- $\approx 50\%$ SUs significantly change their firing rate with respect to behaviour.
- Spike times and counts are more variable in time during spontaneous than task-related behaviours.
- Spontaneous behaviours show no domination of excitation or inhibition.
- Non-movement states in the motor cortex are characterized by the highest dimensionality and the lowest instantaneous balance of population activity.

p.dabrowska@fz-juelich.de

Model validation

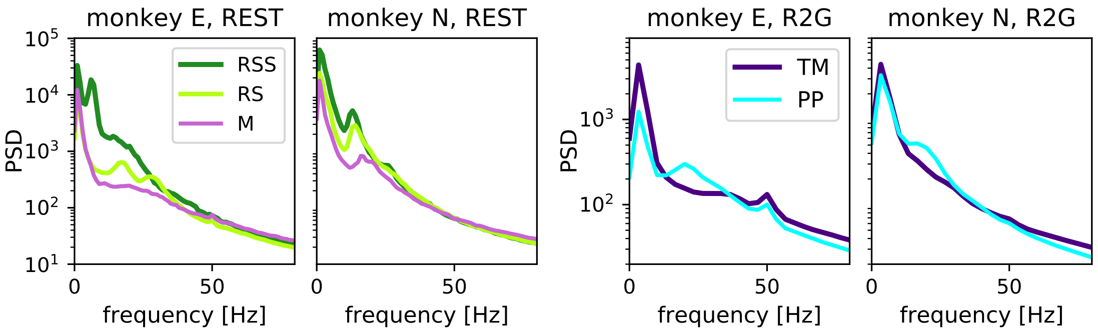
Why is it important to use matching data for model validation?

model assumption	electrophysiological data
stationary states, no transient activations	transient firing rate fluctuations related to behaviour
balance of input excitation and inhibition	*output* activity balanced in spontaneous behaviours
uncorrelated or weakly correlated external inputs	no access to neuronal input, but higher covariance and lower dimensionality of spiking during movements suggests higher correlation in the inputs
parameters defined as distributions and ranges	high heterogeneity of activities

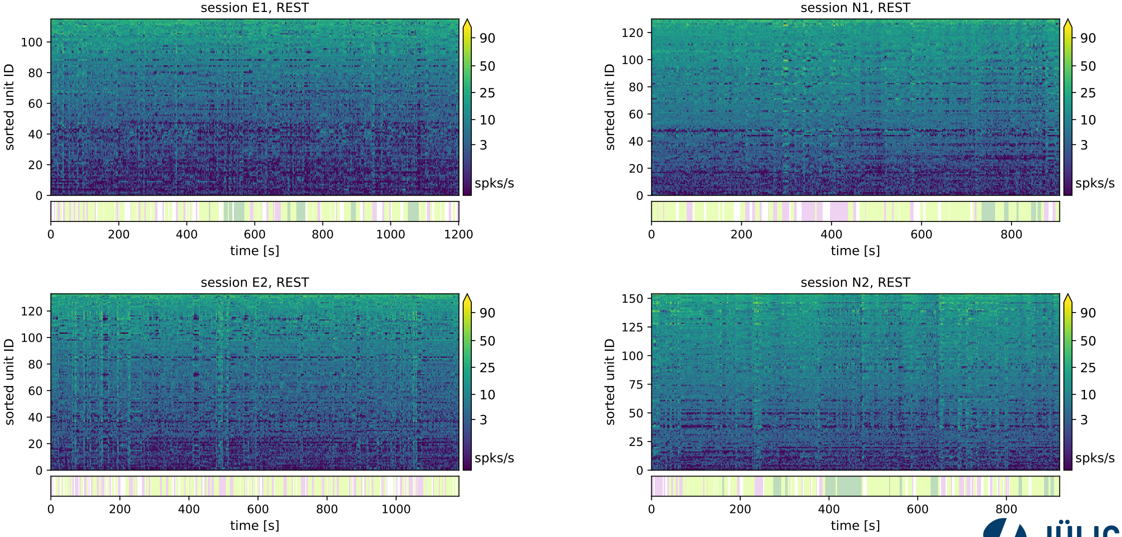
poster **COG_P76** | December 10-11 (Th-Fr) 15:30-16:30 CET
p.dabrowska@fz-juelich.de

Additional materials

Local field potentials

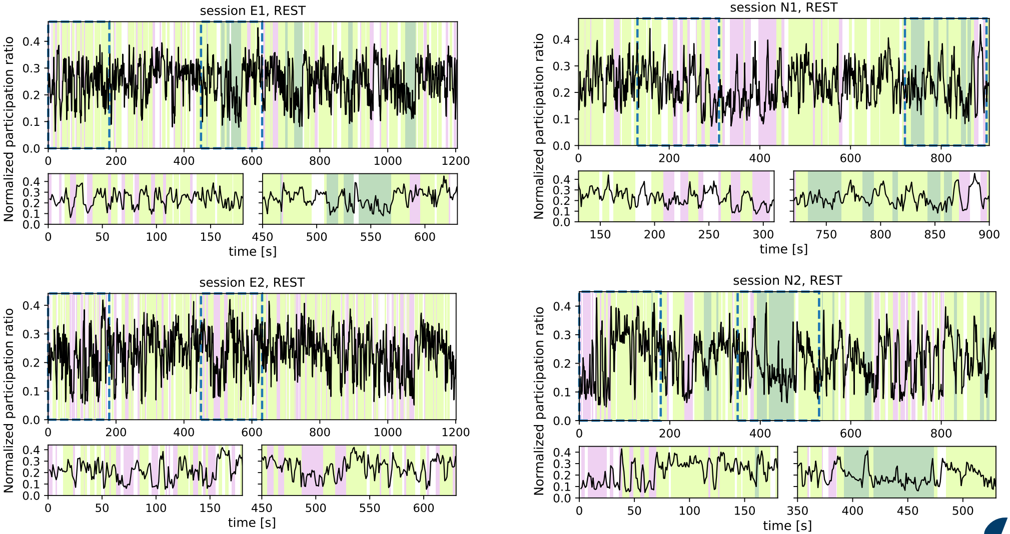


Time-resolved single units firing



p.dabrowska@fz-juelich.de

Time-resolved dimensionality



Time-resolved balance