Bimodal distribution of preferred directions to hand movements in visuo-parietal areas

Simon Essink[1,2], Junji Ito[1], Alexa Riehle[3,1], Thomas Brochier[3], Sonja Grün[1,2]

[1] Institute of Neuroscience and Medicine (INM-6), Institute for Advanced Simulation (IAS-6) and JARA Brain Institute I (INM-10), Jülich Research Centre, Jülich, Germany

[2] Theoretical Systems Neurobiology, RWTH Aachen University, Germany

[3] Institute of Neuroscience of la Timone (INT), CNRS - Aix Marseille Université, Marseille, France

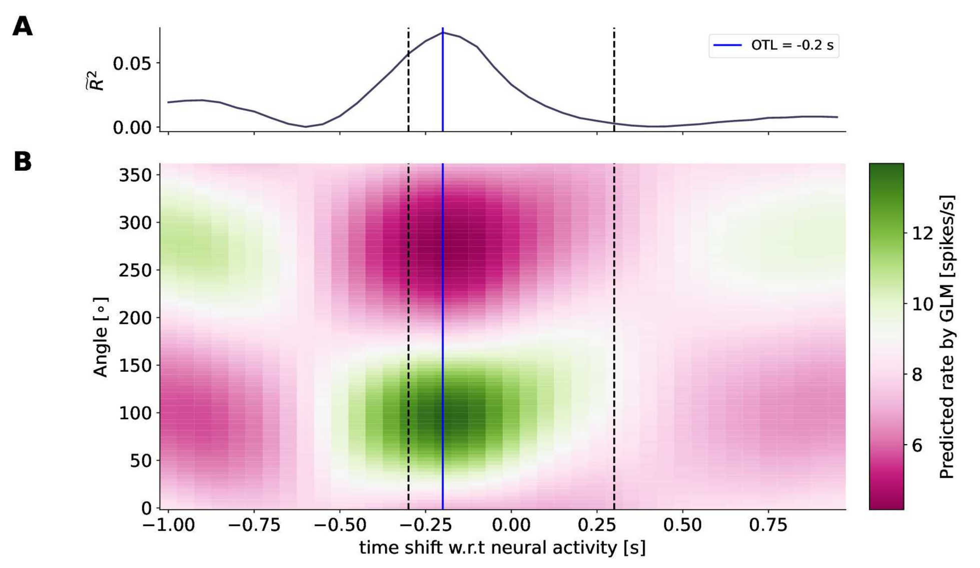
Contact: s.essink@fz-juelich.de

Introduction

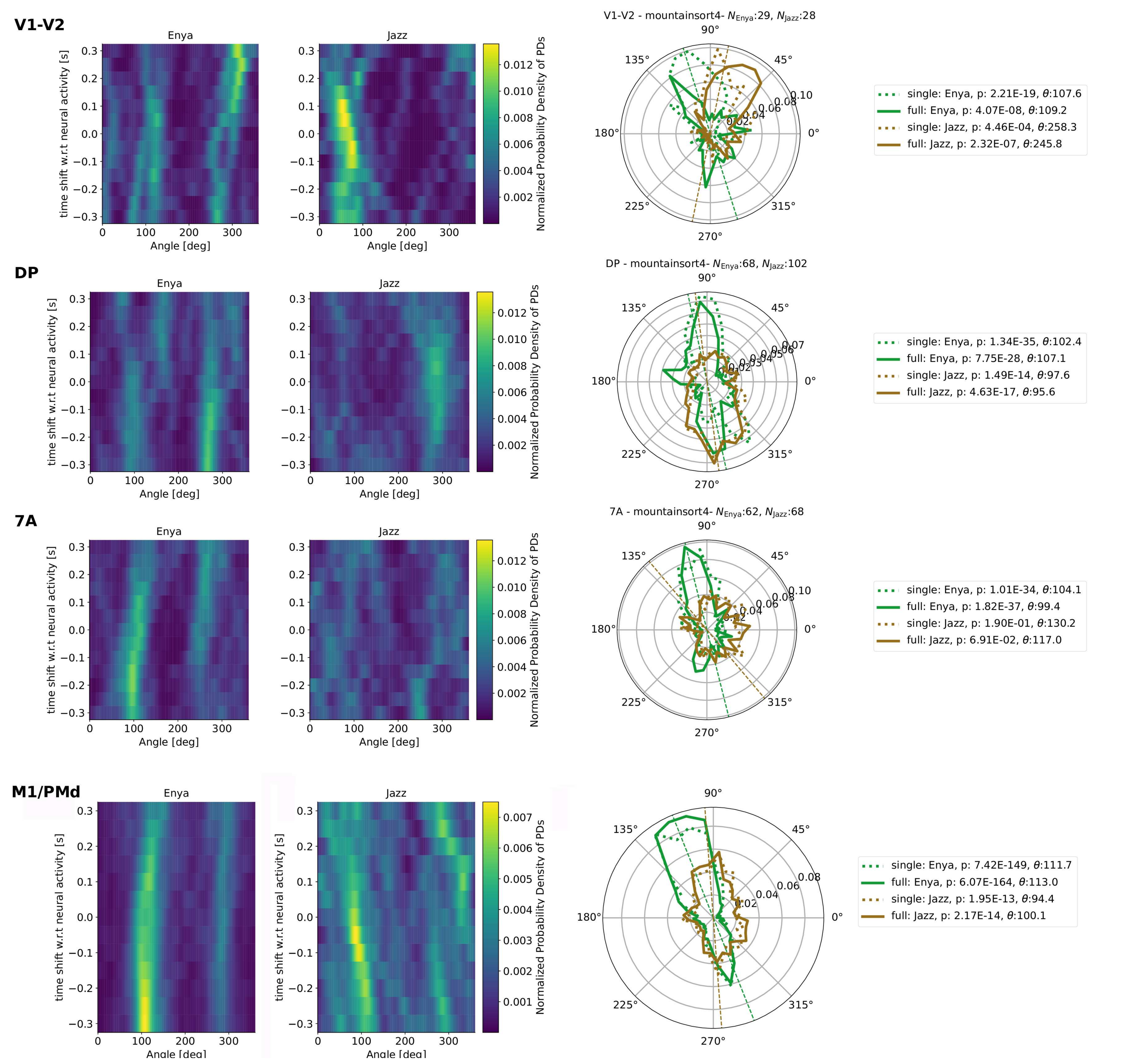
Single neurons in M1 encode the direction of hand movement in their firing rate. The direction of hand movement that leads to maximal firing is termed the preferred direction (PD) [1]. Across many recorded neurons, the distribution of PDs was assumed to be uniform, which could be confirmed for 3D movements [2,3]. However, for movements constrained to 2D, this distribution of PDs showed a systematic bias [4] that could be traced back to the biomechanics of the arm [5,6,7] and is closely related to muscle activity. Unexpectedly, the same bimodality could also be observed in neurons from premotor areas [8]. Given these observations, we ask: Is the bimodality of the distribution of PDs that has been observed in M1 and PMd/PMv also present in the parietal and visual cortex of macaque monkeys that perform a visually guided reaching task in the 2D plane?

Results

Tuning curve of a single unit



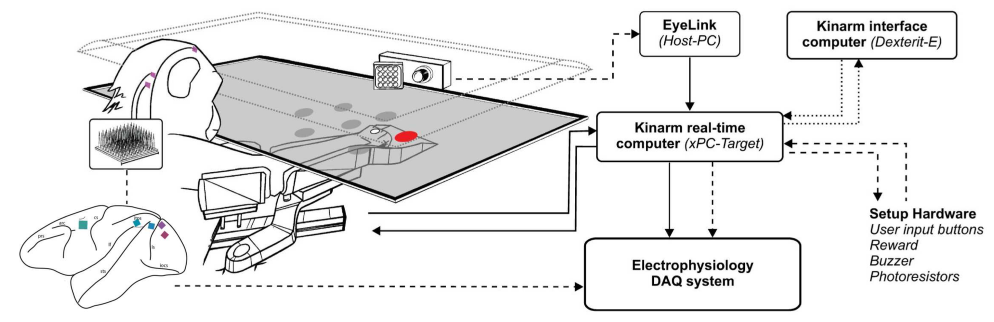
Distribution of PDs across units



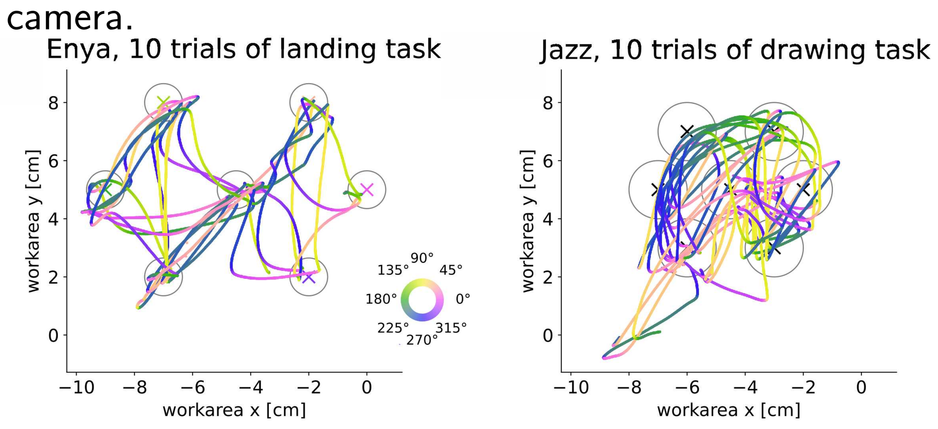
Methods

Experimental Data

Two monkeys (macaca mulatta, female Enya and male Jazz) were trained to perform visually guided motor tasks: a landing task and a drawing task.



Extracellular neural activity was recorded simultaneously with four Utah arrays of 36 electrodes each inserted in V1, V2, DP and area 7A, and one array of 100 electrodes in M1/PMd. To record the monkeys arm and hand movements [9] we employed a two-joint (shoulder and elbow) robotic exoskeleton system (KINARM Exoskeleton Laboratory, BKIN Technologies) that restricted movement to 2D horizontal plane. Eye movements were recorded via the EyeLink system (SR Research; https//www.sr-research.com), an infrared light source and camera.



- rejected channels with cross-correlation and participating in many synchrofacts (see poster by Oberste-Frielinghaus)
- waveform SNR > 2.5, firing rate $\lambda > 1$

Generalized Linear Model (GLM)

- spike count y_t per time bin is Poisson distributed:

$$P(Y = y_t) = \frac{\lambda_t^{y_t} e^{-\lambda_t}}{y_t!}$$

- mean firing rate that is explained by an exponential link function and many regressors grouped into blocks:

$$\lambda_t = \exp\left(\beta_0 + \sum_{i=1}^{N_{\text{visual}}} \beta_i X_{t,i}^{\text{visual}} + \dots + \sum_{i=1}^{N_{\text{movement}}} \beta_i X_{t,i}^{\text{movement}}\right).$$

- regressor blocks: visual, eye position, saccade, hand position, hand movement
- time-shifted copies of regressors included to capture response (~ 1500 regressors)
- Lasso-regularization with $\lambda_{\text{Lasso}} = 0.001$, using Python package statsmodel

As measure for the goodness-of-fit, we use the pseudo-R^2 (between *null model* and *saturated model*):

$$\widetilde{R}^2 = 1 - \frac{\log \mathcal{L}_{\text{saturated}} - \log \mathcal{L}}{\log \mathcal{L}_{\text{saturated}} - \log \mathcal{L}_{\text{null}}} \quad ,$$

The *movement* regressors assumes a von Mises-like functional dependence on the instantaneous movement angle θ:

$$\lambda_t^{\text{movement}} \propto e^{\beta_0 + \sum_\tau \beta_1 \cos\theta_{t-\tau} + \beta_2 \sin\theta_{t-\tau}} \quad ,$$

where τ is the time shift w.r.t. the neural activity.
To integrate out the effect of regressors that do not belong to the movement regressor block, we calculate

$$\lambda_t^{\text{movement}} = \frac{1}{S}\sum^{S} \exp\left(\beta_0 + \sum_{i=1}^{N_{\text{movement}}} \beta_i X_{t,i}^{\text{movement}} + \right. \qquad (1)$$

$$\left. + \dots \text{other regressors shuffled in time} \dots \right) \quad , \qquad (2)$$

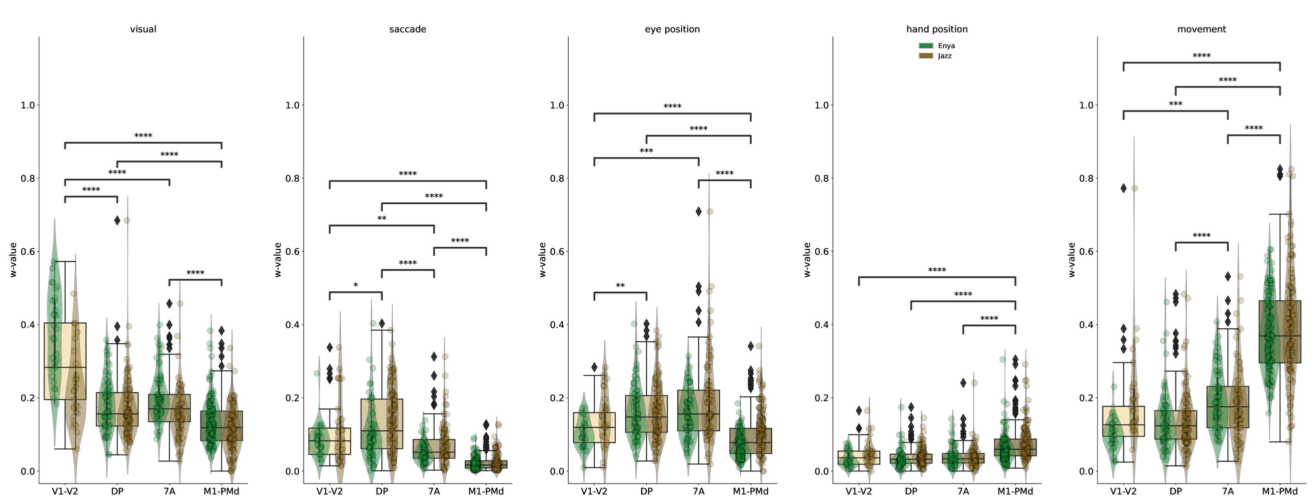
with S being the number of different shuffles [10].

Summary

In this study, we investigated single unit selectivity from simultaneous, multi-area, multi-electrode array recordings along the dorsal visual stream. A GLM framework enables us to disentangle the effect of different behaviors on the single unit activity and isolate the purely movement related activity.
We reproduce the bimodality of the distribution of PDs that has been observed in M1 and PMd/PMv in our dataset.
Furthermore, we are able to answer our original question: We do find significantly bimodal distributions of PDs for hand movement for both monkeys in V1-V2 and DP as well as for monkey Enya also in 7A. In parietal cortex, the dominant orientations are consistent with M1/PMd and across monkeys, suggesting a common low-level movement representation.

Outlook

The GLM framework further allows us to evaluate the importance of different behaviors for the single unit activity [11,12]. In this way, we are able to show the progressive decrease of visual influence and increase of motor signals along the dorsal visual stream.



References

[1] Georgopoulos et al., J. Neurosci. 2, 1527–1537 (1982).
[2] Schwartz et al., J. Neurosci. 8, 2913–2927 (1988).
[3] Caminiti et al., J. Neurosci. 10, 2039–2058 (1990).
[4] Scott et al., Nature 413, 161–165 (2001).
[5] Lillicrap et al., Neuron 77, 168–179 (2013).
[6] Verduzco-Flores et al., eLife 11, e77216 (2022).
[7] Codol et al., https://elifesciences.org/reviewed-preprints/88591v1 (2023)
[8] Suminski et al., Journal of Neurophysiology 113, 2812–2823 (2015).
[9] de Haan et al., Journal of Neurophysiology 120, 539–552 (2018).
[10] Ledergerber et al., Cell Reports 35, 109175 (2021).
[11] Diomedi et al., iScience 23, 101616 (2020).
[12] Vaccari et al., STAR Protocols 2, 100413 (2021).

Acknowledgments: This project has received funding from Research Training Group 2416 MultiSenses-MultiScales (Deutsche Forschungsgemeinschaft) at RWTH Aachen University, Aachen, Germany and from the European Union's Horizon 2020 Framework Programme for Research and Innovation under Specific Grant Agreement No. 785907 (Human Brain Project SGA2).