Population decoding of visual motion direction in V1 marmoset monkey : effect of uncertainty.

Alexandre Lainé *1, Sophie Denève [1], Nicholas J. Priebe [2], Guillaume S. Masson [1] and Laurent U. Perrinet [1]

1. Institut de Neurosciences de la Timone, UMR 7289, CNRS and Aix-Marseille Université, Marseille, France.
2. Section of Neurobiology, School of Biological Sciences, University of Texas at Austin, Austin, TX, USA.

* Correspondence : alexandre.laine@univ-amu.fr

Introduction

Studying the **internal representation** of natural features (fig. 1) in the primary visual cortex (V1), like direction or spatial frequency, is crucial to understand how we perceive the external world. Research on 2D motion direction in **non-human primates** [1, 2] in particular when displaying **naturalistic stimuli** like MotionClouds [3] reveals substantial diversity and multiple mechanisms within the neuronal population [4] (fig. 2). The aim of this project is to examine how a large population of V1 neurons encodes stimulus direction and how this representation is modulated by the uncertainty using **decoding methods**.

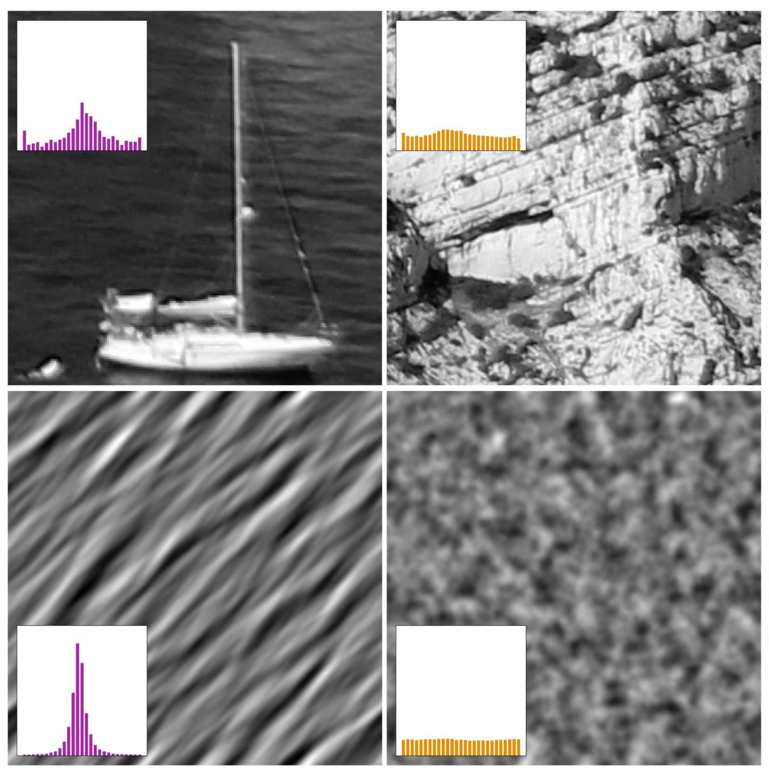


Figure 1 : Uncertainty in natural images and Motion Clouds

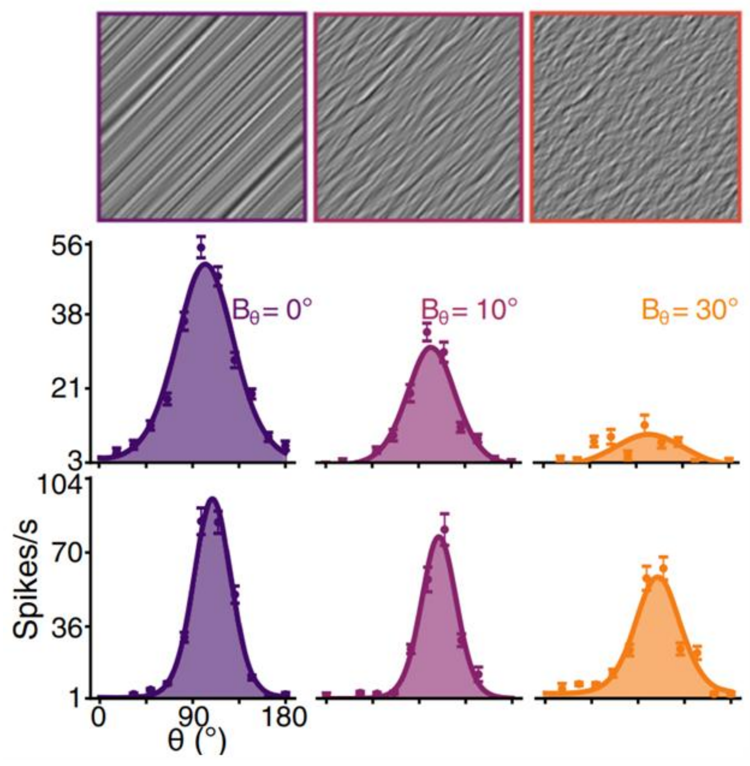


Figure 2 : Two subpopulation in cats area 17 (from [4])

Methods

Activity of 130 neurons was recorded in area V1 of an anesthetized marmoset monkey using Neuropixel technology [5] during the presentation of MotionsClouds in eight directions (θ) and two precision levels (B_θ). Single neuron tuning curves has been fitted for each precision level with the following equation. The orientation selectivity index (OI) [6] is computed on the output of the fitting part.

$$\mathrm{fr}(\boldsymbol{\theta}) = R_0 + (R_{max} - R_0) \times \exp\left(\kappa_\theta\left(\cos\left(2 \times (\boldsymbol{\theta} - \theta_0)\right) - 1\right) + \kappa_\phi\left(\cos(\boldsymbol{\theta} - \theta_0) - 1\right)\right)$$

The decoding method (fig. 3), allow us to analyze the representation of motion direction in the marmoset V1, focusing on the effects of uncertainty on the population code. Our decoder optimizes the weights of a logistic regression to achieve optimal decoding accuracy on a training set. Training is conducted in two different manner (1) on a broad time window at beginning and the end of the stimulus presentation, or (2) by applying temporal generalization [7]. The optimized weights are analyzed by two different reduction dimension methods (PCA and dPCA [8]) in order to project them into a new neuronal space.

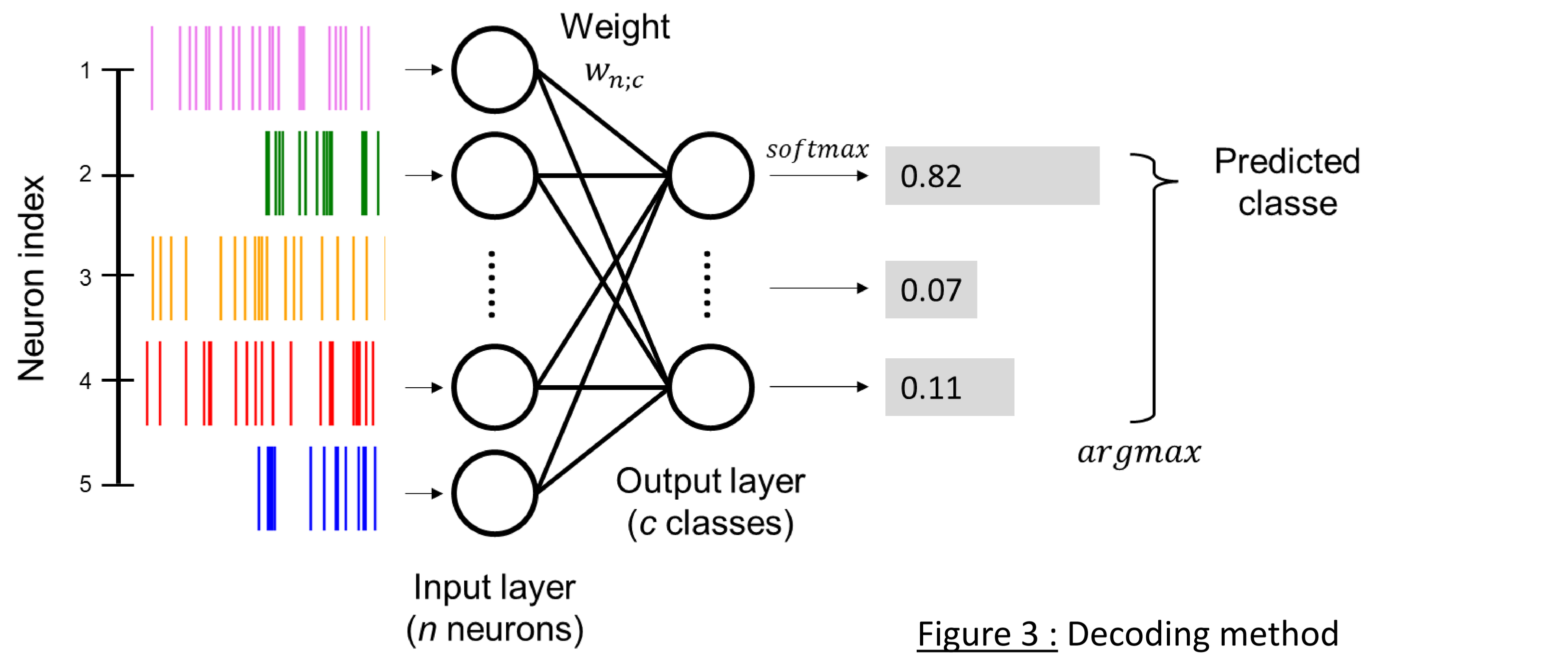
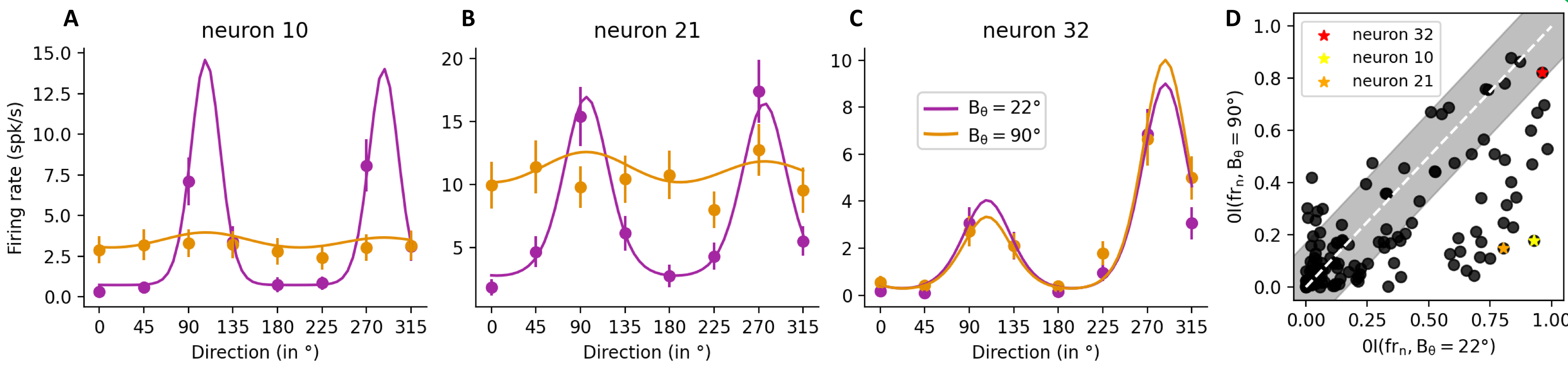


Figure 3 : Decoding method

Results

Figure 4 : (**A/B/C**) Fitted tuning curve of three neurons show the emergence of two different behaviors. Some orientation selective neurons are modulated by the level of precision like neuron 10 and 21, while others are not (neuron 32). Dots indicates mean firing rate, error bar are the standard error and line represent the fitted function. (**D**) Influence of precision level (B_θ) on orientation selectivity index (OI) for each neuron. White dashed line represent the diagonal, on which the index is the same between both B_θ. Based on this metrics it's possible to study the occurrence of those behaviors in the population.



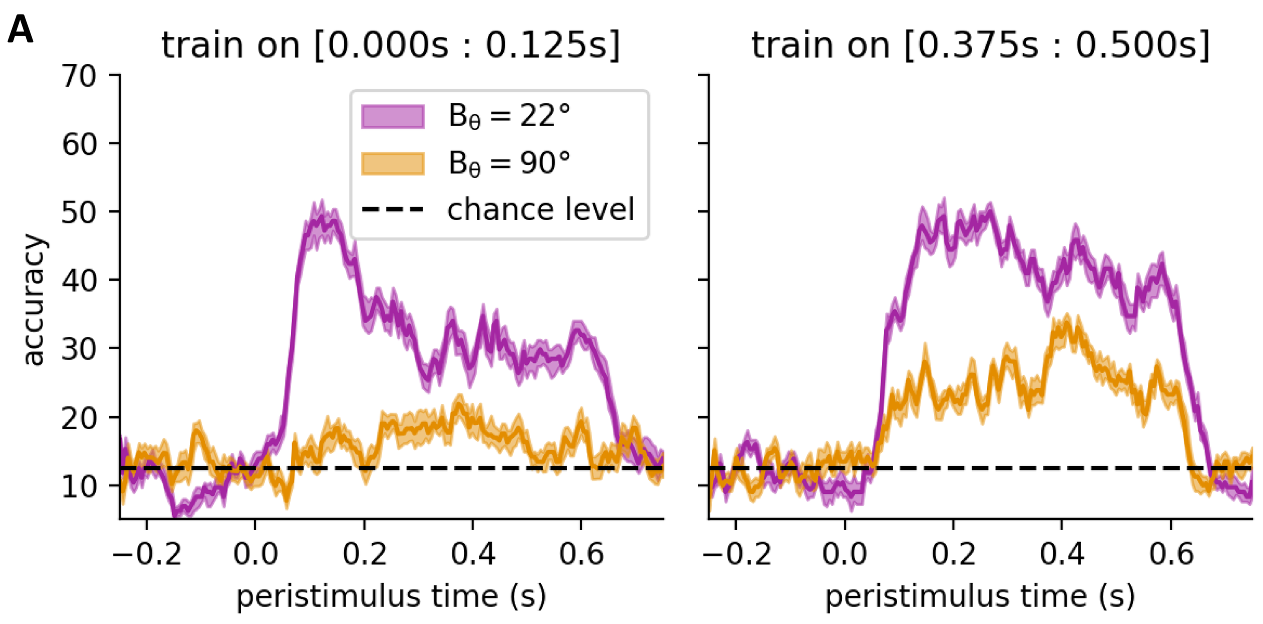
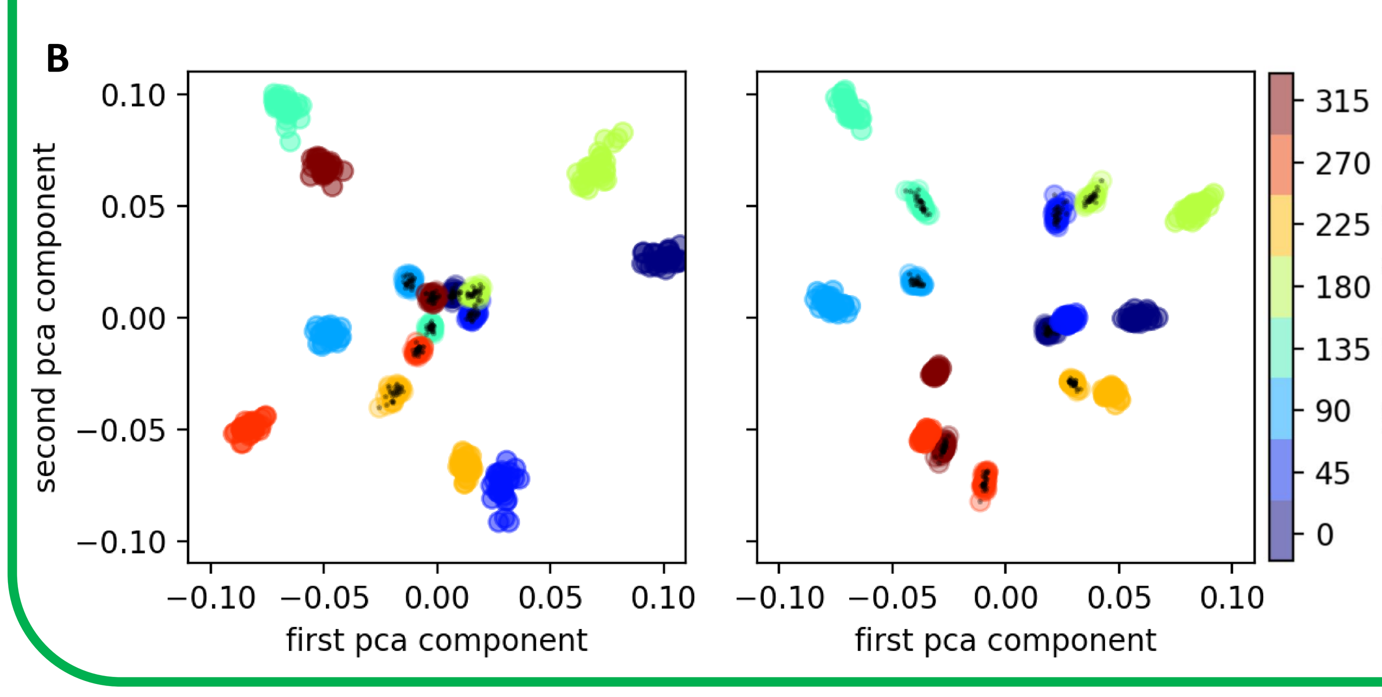


Figure 5 : (**A**) Time course of the decoding accuracy modulated by B_θ and by the training windows. At this population level, two dynamic emerge. Lines are the mean accuracy of $k = 30$ cross-validation folds. Chance level represented by the black dashed line is equal to 12.5%. (**B**) The first two components of the PCA show that the level of precision influences the discrimination of optimized weights, which may explain the modulation of the decoding accuracy. (**C**) dPCA reduction reveals that weights of neuron are mainly modulated by the direction (θ), but also by combined parameters (e.g. $B_\theta \times \theta$).



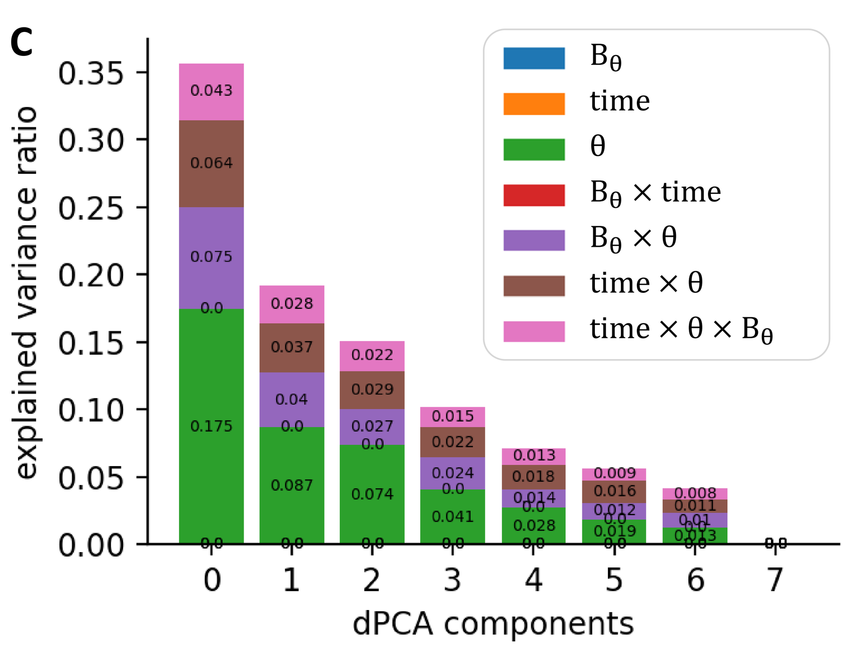
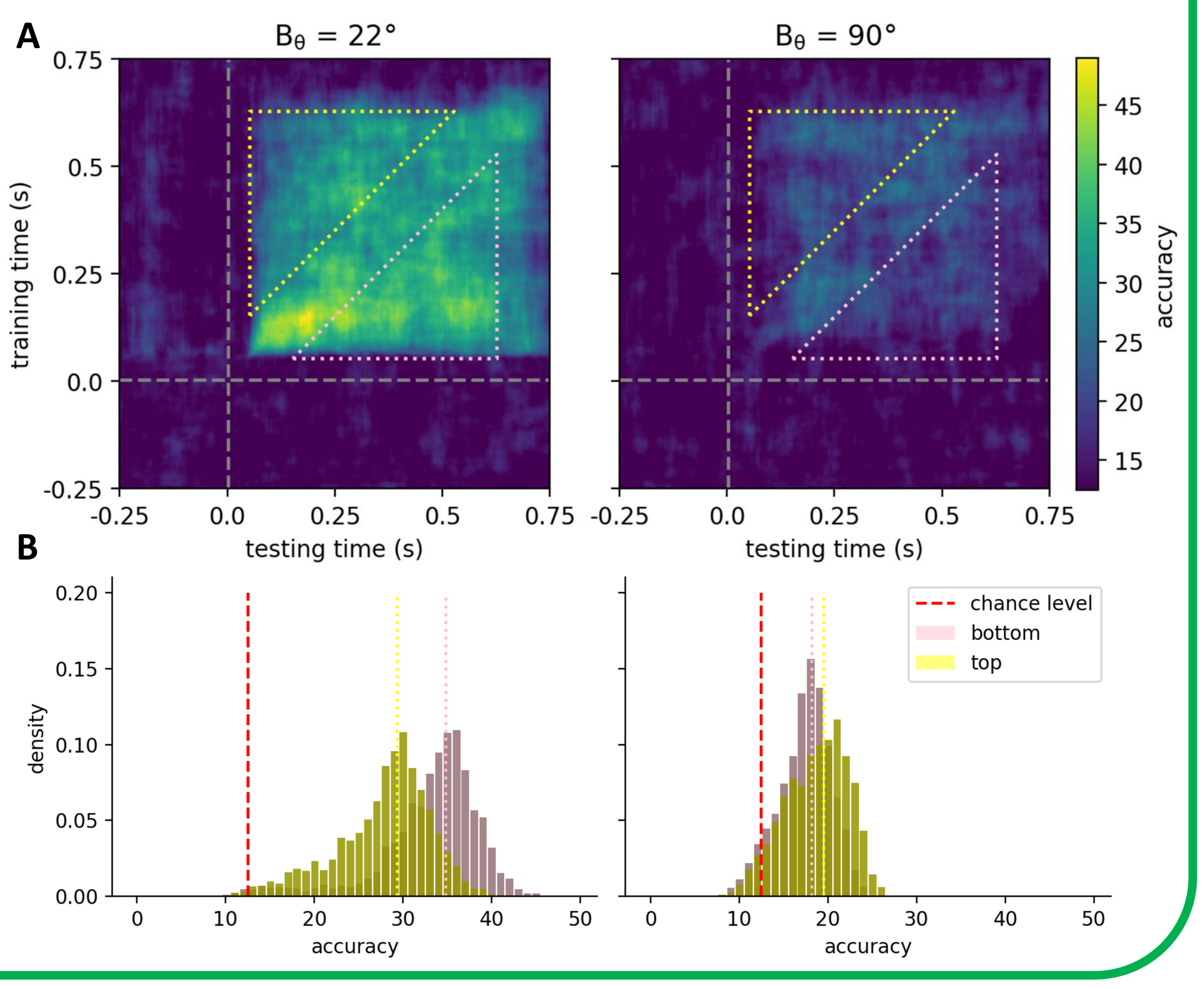


Figure 6 : (**A**) Temporal generalization indicate that the representation of direction information by the population is sustained during all the stimulus presentation. (**B**) Comparison between bottom and top triangles accuracy distribution show a difference that is modulated by the precision level.



Discussion

This decoding method clarifies how **directional information** is represented and modulated by precision in the primary visual cortex of the marmoset. The precision level of the orientation in MotionClouds appears to influence the encoding dynamics of a subset of the neuronal population. The coexistence of **transient and sustained representations** suggest that there are distinct functional roles that can take place across cortical layer. PCA and dPCA reduction methods help us to explain the origin of our different accuracy level and demonstrate that the influence of the precision level and the training window is not uniform across the population. Temporal generalization confirms that neuronal population maintain a **stable representation** of the direction information. The shape of this result could provide insight into the **underlying mechanisms**, particularly when asymmetry appears between the upper and lower triangles.

References

[1] Hubel & Wiesel, 1959
[2] Hubel & Wiesel, 1968
[3] Leon et al., 2012
[4] Ladret et al., 2023
[5] Steinmetz et al., 2021
[6] Mazurek et al., 2014
[7] King & Dehaene, 2014
[8] Kobak et al., 2016

Bibliography

GitHub

Acknowledgements : This work is supported by ANR-NSF CRCNS grant "PrioSens" N° ANR-20-NEUC-0002 attributed to G.S.M., N.J.P. and L.U.P. and by a doctoral grant from the French Ministry of Higher Education and Research, awarded by the doctoral School 62 of Aix-Marseille University to A.L.