**Reconstruction of continuous motion direction from fMRI data**

Riccardo Barbieri 1,\*, Felix Töpfer 1,6,\*, Joram Soch 1,2, Carsten Bogler 1,2, John-Dylan Haynes 1-8

1 Bernstein Center for Computational Neuroscience, Berlin, Germany

2 Berlin Center for Advanced Neuroimaging, Berlin, Germany

3 Berlin School of Mind and Brain, Berlin, Germany

4 Clinic for Neurology, Charité-Universitätsmedizin Berlin, Germany

5 Department of Psychology, Humboldt-Universität zu Berlin, Germany

6 EXC NeuroCure, Charité-Universitätsmedizin Berlin, Germany

7 EXC Science of Intelligence, Technische Universität Berlin, Germany

8 CRC Volition and Cognitive Control, Technische Universität Dresden, Germany

**Introduction:**

The neural representation of motion perception has been extensively studied in cognitive neuroscience. Functional magnetic resonance imaging (fMRI) is often used in combination with multivariate pattern analysis (MVPA) to identify brain areas associated with motion perception [1,2]. The rationale behind this is that certain voxels are sensitive to motion direction, and the resulting activity pattern can be exploited by a classifier to discriminate between possible motion directions from previously unseen data.

An alternative approach, inverted encoding modelling (IEM), consists in specifying a forward model describing the mapping between changes in motion direction and the expected voxel activity. Then, this model is inverted to perform stimulus reconstruction from new data [3,4]. IEMs typically seek the ideal response profile of motion-selective neuronal populations tuned to different directions, but the choice of basis functions is often difficult, as cells tuned to motion direction can exhibit a variety of response profiles [5].

Here, we test a novel non-parametric approach to the reconstruction of continuous motion direction. This method uses a cyclic version of Gaussian Process Regression (GPR) [6] to obtain a continuous estimate of trial-wise direction of motion.

**Methods:**

*Experimental paradigm:* 24 participants performed a feature-continuous perceptual decision-making task during an fMRI experiment (see Figure 1). In each trial, they viewed a 2s random dot kinematogram (RDK) with different coherence (0%, 100% and a medium level) and direction (randomly varying from 0° to 360°). After the stimulus presentation, they indicated the perceived motion direction (see Figure 1).

*fMRI data analysis:* For each subject, we estimated a trial-wise general linear model (GLM), convolving each 2s RDK period with the canonical hemodynamic response function (cHRF), to obtain trial-by-trial fMRI response amplitudes. Then, responses within each coherence condition were subjected to a GPR against presented motion direction [6], accounting for the cyclic nature of the independent variable, to obtain a continuous response profile for each individual voxel. Finally, the estimated response profiles within a searchlight were combined to obtain a reconstructed direction of motion.

**Results:**

*Behavioral data:* We found that subjects’ response deviation decreased with increasing coherence (see Figure 2A), in line with previous studies employing continuous report [7,8,9]. Participants were unable to identify motion direction in the 0% coherence condition.

*fMRI results:* We found that reconstruction of motion direction becomes more precise with increasing coherence (see Figure 2B) and that it is impossible in the 0% coherence condition. At the group level, there was a main effect of coherence condition on reconstruction performance (F2,46 = 12.72, p < 0.001), according to a repeated-measures ANOVA of recons­truction precision in motion-sensitive areas, as defined by an independent localizer task.

**Discussion:**

The novelty of our research consists in two aspects: First, this is one of the first neuroimaging studies employing a feature-continuous RDK, following categorical tasks almost universally applied in the past [2]. Second, this is the first application of Gaussian process regression for predicting a continuous modulator variable (here, direction of motion) from fMRI signals in the field of visual reconstruction [1]. In the future, we want to extend this work from reconstruction of *presented* to reconstruction of *reported* direction of motion and compare them across coherence levels.

**References:**

1. Kamitani, Y. (2006), ‘Decoding seen and attended motion directions from activity in the human visual cortex’, Current Biology, vol. 16, iss. 11, pp. 1096-1102.
2. Hebart, M. (2013), ‘On the Neuronal Systems Underlying Perceptual Decision-Making and Confidence in Humans’, PhD Thesis, submitted to the Humboldt University of Berlin, 24/07/2013; URL: [https://edoc.hu-berlin.de/bitstream/handle/18452/17576/hebart. pdf?sequence=1](https://edoc.hu-berlin.de/bitstream/handle/18452/17576/hebart.pdf?sequence=1).
3. Brouwer, G.J. (2009), ‘Decoding and reconstructing color from responses in human visual cortex’, Journal of Neuroscience, vol. 29, iss. 44, pp. 13992-14003.
4. Sprague, T.C. (2018), ‘Inverted encoding models assay population-level stimulus representations, not single-unit neural tuning’, eNeuro, vol. 5, art. 3.
5. Albright, T.D. (1984), ‘Direction and orientation selectivity of neurons in visual area MT of the macaque’, Journal of Neurophysiology, vol. 52, pp. 1106-1130.
6. Rasmussen, C.E. (2006), ‘Gaussian Processes for Machine Learning’, MIT Press, Cambridge, Massachusetts; London, England.
7. Smith, P. L. (2016), ‘Diffusion theory of decision making in continuous report’, Psychological Review, vol. 123, iss. 4, pp. 425-451.
8. Bae, G.-Y. (2018), ‘Motion perception in 360° space: Illusory perception of opposite direction of motion‘, VSS 2018; URL: [https://static1.squarespace.com/static/ 5ac114ac96d455c1a62e09e7/t/5afa60e7aa4a9925e936c33c/1526358263492/Bae%26Luck\_VSS2018.pdf](https://static1.squarespace.com/static/5ac114ac96d455c1a62e09e7/t/5afa60e7aa4a9925e936c33c/1526358263492/Bae%26Luck_VSS2018.pdf).
9. Bae, G.-Y. (2019), ‘Decoding motion direction using the topography of sustained ERPs and alpha oscillations’, NeuroImage, vol. 184, pp. 242-255.



