Multivariate decoding of perceptual decisions about pain

Kay H Brodersen[1,2] · Chia-shu Lin[3] · Ekaterina I Lomakina[1,2] · Klaas E Stephan[2,4] · Katja Wiech[3,5,6] · Irene Tracey[3,5]

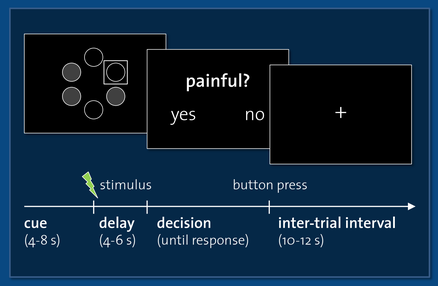
[1] Department of Computer Science, ETH Zurich, Switzerland [2] Laboratory for Social and Neural Systems Research, Department of Economics, University of Zurich, Switzerland [3] Centre for Functional Magnetic Resonance Imaging of the Brain (FMRIB), Department of Clinical Neurology, John Radcliffe Hospital, University of Oxford, United Kingdom
[4] Wellcome Trust Centre for Neuroimaging, University College London, United Kingdom [5] Nuffield Department of Anaesthetics, John Radcliffe Hospital, University of Oxford, United Kingdom [6] Research Group Health Psychology, Department of Psychology, University of Leuven, Belgium

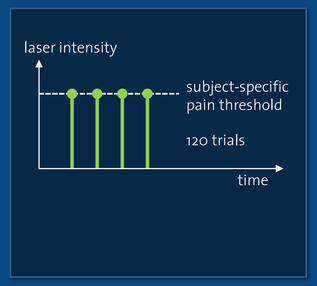
1 Summary

- Pain is a multi-faceted experience that comprises sensory, cognitive, and affective aspects.
- Individual regions involved in the perception of pain have been studied in much detail. By contrast, little is known about how multiple regions make complementary contributions.
- Using fMRI, we demonstrate that neural activity in a small network of pain-related regions jointly provides a more accurate explanation of the subjective experience of pain than any of its constituents alone.

2 Experimental design & analysis

- While undergoing 3T fMRI, 16 healthy volunteers were engaged in a simple perceptual decision-making task [1].
- On each trial, after a visual cue ('anticipation period'), subjects received a 4 ms laser pulse ('stimulation period'). The laser was calibrated to match subject-specific pain-detection thresholds. Subjects indicated by button press whether the stimulus had been perceived as painful or not.
- The experiment consisted of four sessions, each comprising 15 'high threat' and 15 'low threat' trials that were presented in a pseudo-randomized order, totalling 120 trials per subject. In 'high threat' trials, subjects were made to believe that harm might be caused at the site of stimulation, whereas in 'low threat' trials, subjects were told that the stimulation site was entirely safe.

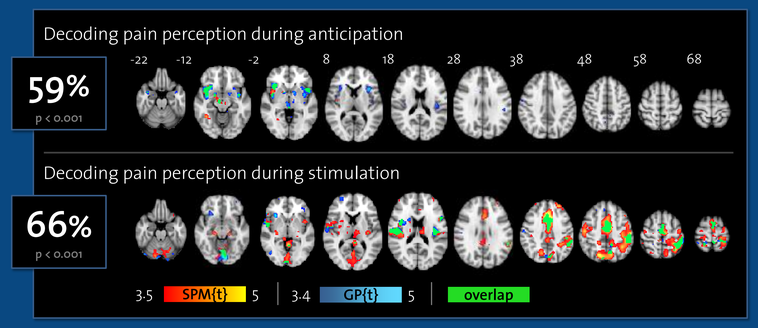




- Functional images were normalized to MNI space and smoothed using SPM8. A GLM with separate regressors for the anticipation and stimulation period of each trial was used to obtain trial- and period-specific beta images for subsequent decoding.
- To make predictions, we used a linear support vector machine (SVM) with leave-one-trial-out cross-validation. To visualize the spatial deployment of discriminative voxels, we used Gaussian processes [2] with a permutation test on voxel weights [3].

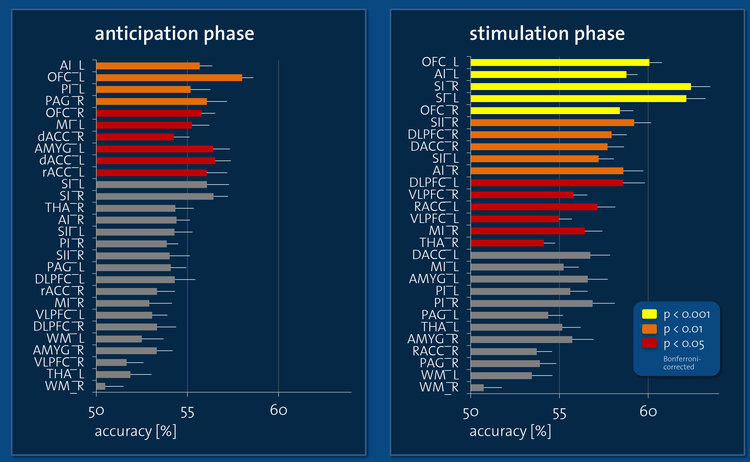
3 Is it possible to decode the perception of pain from trial-wise data?

- We found that pain could be decoded from whole-brain trial-wise fMRI data with significant accuracies both during anticipation and during stimulation.
- Contributions to this result were made by many brain regions, as revealed by an analysis of the spatial deployment of jointly informative voxels. Several informative clusters had gone unnoticed by a conventional univariate analysis, including parts of the bilateral insula, the ACC, and the OFC.



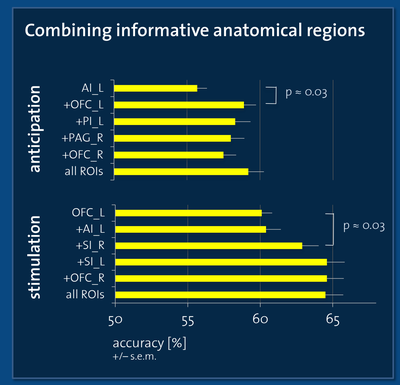
4 How much information can be decoded from individual regions?

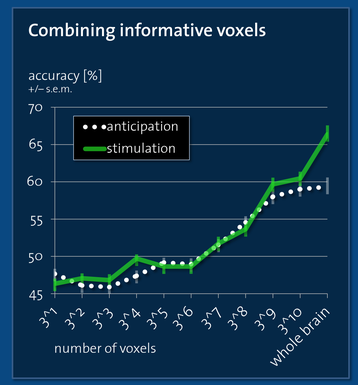
We examined 26 anatomically defined areas that are commonly associated with the perception of pain. This analysis revealed that not all areas allowed for accurate predictions – only a subset was predictive.



5 Which spatial scale affords the best explanation of pain perception?

We investigated the predictive capacity of brain activity on different spatial scales: individual voxels, anatomical regions, combinations of regions, and whole-brain data.





We obtained significant increases in decoding accuracy until a small number of pain-related regions had been included. After this, further information gains were counterbalanced by the increasing amount of noise.

6 Discussion and conclusions

- Our results show that the subjective experience of pain can be decoded from trial-wise fMRI data, even in the absence of physical stimulus alterations. The strongest predictions are produced when considering both regions involved in affective-cognitive functions (anterior insula, OFC) and regions involved in sensory-discriminatory functions (S I).
- Pain perception can be decoded most accurately when considering multiple anatomical regions. This suggests that the neural representation of pain is genuinely multivariate; it can only be understood by carefully considering simultaneous activations in multiple regions.
- Our results open up the possibility of applying the same techniques (i) across subjects and (ii) in the context of longer-lasting clinical pain.

Acknowledgements
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References

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