What kind of information can be provided by Optical Imaging?

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Introduction

The goal of our project was to estimate, how much information is contained in Voltage Sensitive Dye Imaging (VSDI) data [1, 2]. Typically, the fluorescence changes (ΔF) recorded in response to the visual stimulation are global, *i.e.* spanning most of the recording frame.
Can we read much more from VSDI recordings?
To answer this question we employed stimuli with a rich spatio-temporal structure—natural scene movies.

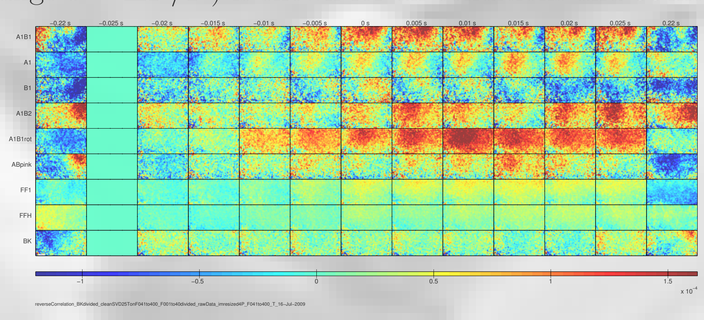
Methods

Voltage Sensitive Dye Imaging was performed over the primary visual cortex (area 18) of cats. Parallel electrode recordings were available in 11 experiments. The stimuli were natural scene movies (1&2) in either a full (FF), or a local field of view (circular Gaussian patches A&B) presented on a computer screen. The stimuli movies were recorded (at 25 Hz) from a camera mounted on a head of a cat strolling through a leafy environment. The sampling rate was 200 Hz for VSDI and 1000 Hz for electrode recordings.
The preprocessing applied to most of the images involved pixelwise division by "frame zero" (the first 200 ms recorded before the stimulus onset), followed by a "blank"-normalisation. For Step 1 and 2, the PCA decomposition was used for denoising (first 25 (50) components of each condition were included), in Step 3 — low-pass spatial filtering with a Gaussian was used instead. In Step 3, frames were binned by 40 ms to match the movie frequency, most of the figures are also prepared on resized frames (4x).

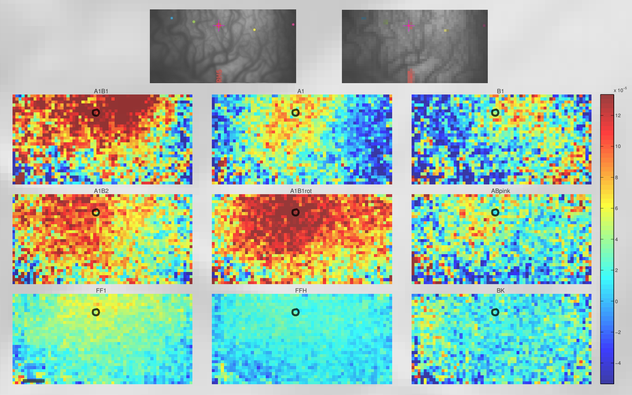
Step 1

The "electrode-trace" in the VSDI

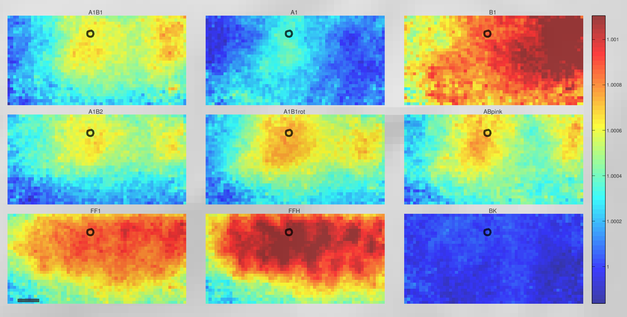
Spike-triggered averaging method was used to reveal VSDI activity maps before and after the spike occurred. Here, the activity rise (Δs, where s stands for the relative fluorescence change $s = \Delta F/F$) is shown for all conditions and 50 ms:



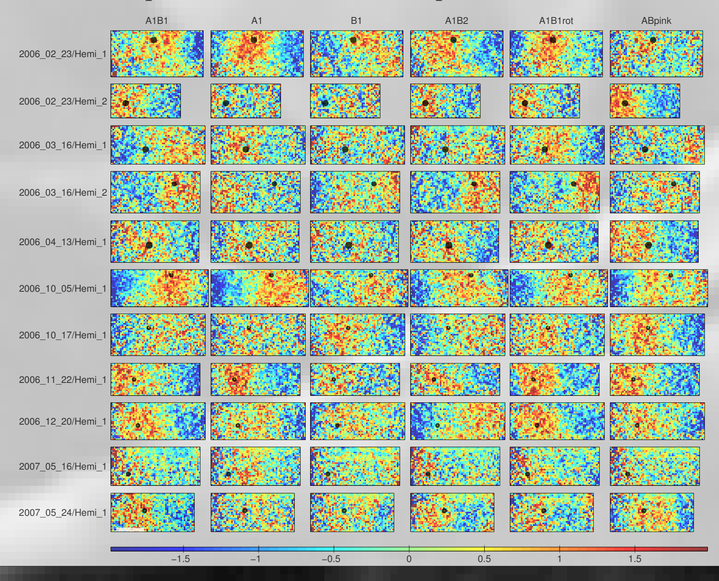
Δs is in agreement with the electrode position (0–10 ms):



much better than the overall activity (s) at the same time:



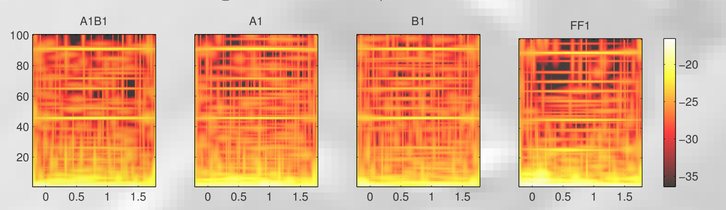
The quality of the differential maps depends on the number of available spikes. Δs across all experiments:



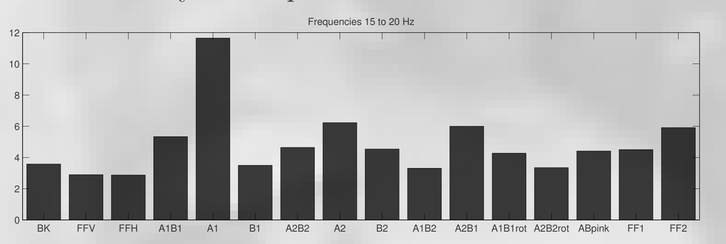
Step 2

Time-frequency decomposition

Matching pursuit (mp4, `http://eeg.pl/mp`, [3]) was used to approximate the Wigner distribution of the signal recorded over a chosen cortical region (here, the area retinotopically corresponding to the upper (A) patch of the movies). With 200 Hz sampling frequency of VSDI, we expected to see the signatures of γ oscillations.



However, the highest frequencies in the signal (46 and 92 Hz) turned out to be caused by the slight fluctuations in the intensity of our excitation light. The second highest frequency (25 Hz) corresponded to the natural movie refreshment rate preventing us from forming hypotheses about the β activity in this higher frequency range.
Activity in the lower β range (15–20 Hz) seemed to be most robust when only the A-patch was stimulated:

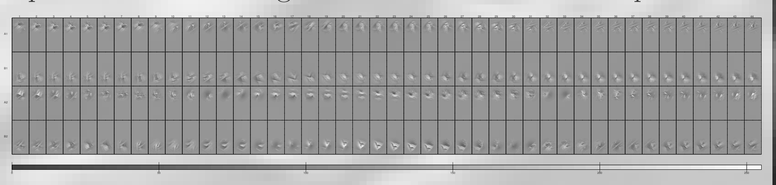


We conclude that the lack of evidence for the higher frequency brain activity in our recordings is either due to (i) our signal-to-noise ratio, (ii) a different nature of VSDI against LFP, or (iii) the γ activity can only be read from single trials (induced activity).

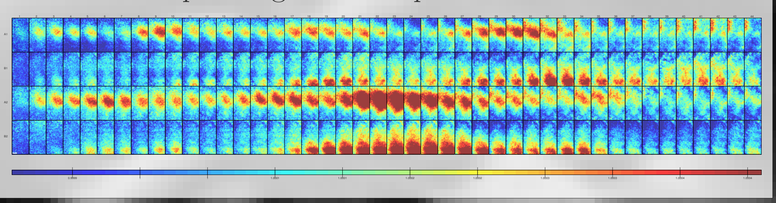
Step 3

Linear decomposition of stimuli *vs* VSDI movies

Principal Component Analysis provides a linear decomposition of signal into orthogonal components. Our goal was to compare, how many of these components are necessary to explain most of the signal variance in both the input:



and the corresponding VSDI responses:

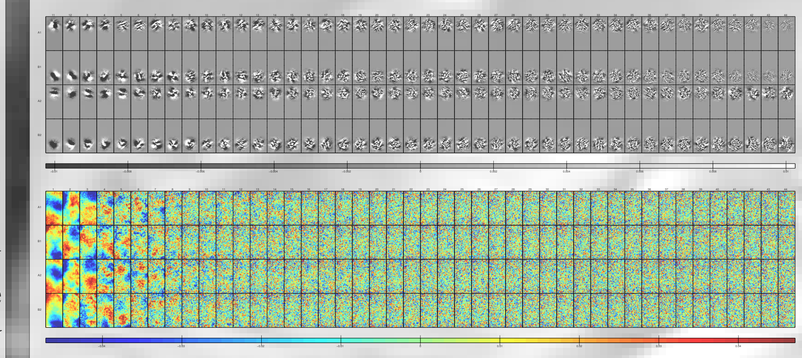


Let X be a $t \times n$ data matrix, centered such that $\langle X \rangle_n = 0$.

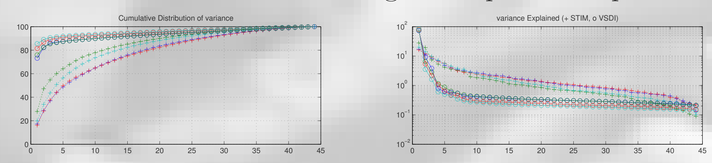
$$C = XX^T/n = U\Lambda U^T \quad (1)$$

$U\,[t \times t]$ are the orthonormal PCA components, $\Lambda\,[t \times t]$ represents the variance of the signal explained by each component. The corresponding spatial patterns were achieved by projecting the data onto the (temporal) components:

$$Y = U^T \Lambda^{-1/2} X. \quad (2)$$



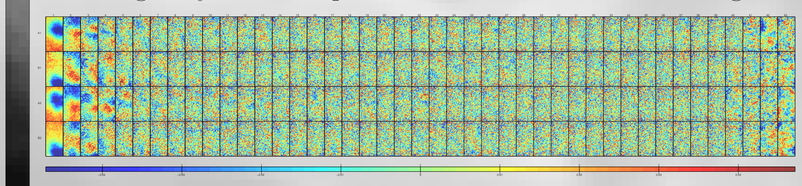
The variance distribution among consequent components:



strongly depends on (i) size of the image, (ii) spatial filtering, *i.e.* signal quality.
We realised it is not straightforward to compare the natural scene movies and VSDI decomposition, because VSDI contains not only the neural-related response, but also artifacts carrying large variance. Unless we assume some characteristics of the interesting signal (e.g. a low spatial frequency), it is hard to decide, what are the informative parts of the signal.

Additionally, we tried a co-PCA on the sphered input-output signals. The resulting co-PCA components had almost identical λ values, thus we achieved a set of orthogonal images, but there were no components more important than the others in explaining the signal.

Finally, feeding the PCA with the first time derivative of the VSDI signal yields components that are much more regular:



Either of the procedures leads us to conclude, that much fewer components are necessary to explain the VSDI signal than the natural scenes, *i.e.* dimensionality of our signal is strongly reduced in comparison to the input.

Conclusions and Further Directions

- VSDI-STA provided a good prediction of the electrode position, though the excited field around it was wide,
  ⇒ Use the movie features for triggering;
- PCA is not the best tool for analysing movies, because it does not take into account the history,
  ⇒ Try feeding more frames for each input to the PCA,
  ⇒ Non-linear PCA.
- Correct preprocessing is of the most importance,
  ⇒ Looking at the derivative of the signal already provides interesting information. More elaborate preprocessing assumptions possibly will yield more informative results.

References

[1] A. Grinvald and R. Hildesheim. VSDI: a new era in functional imaging of cortical dynamics. *Nat. Rev. Neurosci.*, 5:874–885, Nov 2004.

[2] G. Palagina, U. T. Eysel, and D. Jancke. Strengthening of lateral activation in adult rat visual cortex after retinal lesions captured with voltage-sensitive dye imaging in vivo. *Proc. Natl. Acad. Sci. U.S.A.*, 106:8743–8747, May 2009.

[3] Mallat S. and Zhang Z. Matching pursuit with time-frequency dictionaries. *IEEE Transactions on Signal Processing*, 41:3397–3415, 1993.

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