

Does multivariate pattern analysis (MVPA) of BOLD fMRI data benefit from higher resolution at 7T?

Hendrik Mandelkow¹, Jacco A de Zwart¹, and Jeff H Duyn¹

¹Advanced MRI, LFMI, NINDS, National Institutes of Health, Bethesda, MD, United States

INTRODUCTION

High-field MRI systems at 7T show great promise for functional brain imaging in humans, because increases in both SNR and functional BOLD contrast facilitate fMRI scans with higher spatial and temporal resolution. It has been argued, however, that the co-amplification of physiological noise and the lack of precise inter-subject alignment methods limit the gains of higher field strength in many practical applications [1]. Recent information-theoretic approaches to BOLD fMRI analysis, a.k.a. *multivariate pattern analysis* (MVPA), aim to circumvent the alignment problem by “*hyper-alignment*” in an abstract functional space and offer new ways of detecting and quantifying stimulus driven BOLD signal based on *pattern-recognition* algorithms [2][3]. Though still a matter of debate, the success of such MVPA methods is generally attributed to additional stimulus-related information available at a fine spatial scale (<cm) that is ignored by conventional (univariate) fMRI analysis (i.e. *statistical parametric mapping*). Here we investigate whether or not MVPA techniques benefit from high-resolution fMRI at 7T.

METHODS

The effect of fMRI spatial resolution on the *discriminability* of BOLD signal responses to a large variety of naturalistic stimuli was evaluated in subjects, who watched 5-minute scenes from popular action movies in the scanner repeatedly, i.e. 10-20 times over 3-5 scan sessions. fMRI data were acquired with a TR of 2s and either a high (1.2mm) or a low (2mm) isotropic resolution. The **high-resolution (HR)** scans had about 50% less *temporal SNR* (tSNR < 60) and coverage than the **low-resolution (LR)** scans. The data analysis therefore focuses on a common FOV covering inferior temporal cortex and most of the occipital lobe. Single-shot EPI images in transversal orientation were acquired on a 7T MRI scanner (Siemens, Erlangen, Germany) using a 32-channel receive head coil (Nova Medical, Wilmington, USA) and typical fMRI sequence parameters. Subject behaviour and physiology were monitored by recording cardiac, respiratory and optical eye-tracking signals. **Pre-processing and analysis** of the fMRI data was done using custom code in Matlab (<http://www.mathworks.com>) supplemented by tools from AFNI (<http://afni.nimh.nih.gov>) and FSL (<http://fsl.fmrib.ox.ac.uk>). fMRI data from all experimental runs were motion corrected, aligned to each subject’s individual T2-weighted anatomical scan and resampled to a common isotropic resolution of 1.2mm. This acquisition and alignment scheme largely preserved the original resolution. Smoothing by a *sinc* or Gaussian kernel was used to mimic even lower resolutions. Motion parameters, linear and quadratic trends were regressed out from each voxel time series before subtracting the mean and normalising the variance. The mean time course for each voxel, obtained by averaging across experimental runs, is a *non-parametric* estimate of the stimulus response. Statistically significant voxel responses were identified by the variance ratio of this mean over the residual (=ANOVA), which is a measure of CNR² for each voxel and follows an F-statistic under the null hypothesis (Figure 1). Using the thresholded F-map as a functional activation mask to exclude unresponsive voxels we quantified the similarity between any two BOLD signal volumes within and between experimental runs *in the same subject* by normalized correlation (in space). Using each fMRI scan HR and LR in turn as a reference we determined the most similar match for each volume in all other scans and counted how often the best match corresponded to the same time point (± 1 TR) in the movie stimulus. The *percentage of correct matches* averaged separately for inter-scan comparisons of HR or LR fMRI volumes as well as mixed pairs of HR vs. LR, LR vs. HR quantified the *discriminability* of BOLD signal patterns (Figure 2).

RESULTS & DISCUSSION

The eye tracking data from repeated experimental runs show similar fixation trajectories, confirming a high degree of reproducibility in the way subjects view the movies (data not shown). In Figure 1 the F-statistic maps for HR and LR scans clearly delineate corresponding regions in the occipital and inferior temporal cortices commonly associated with the *ventral stream* of high-level vision and object recognition. Evidently, the HR data yielded a more confined area of significant activation with lower BOLD CNR on average, but increased F-values at the peaks and around the fringes suggest some positive partial volume effects. The success rate of stimulus identification by cross-correlation (= *nearest neighbour classification*) was always above chance (>3/150) but it depended strongly on the extent of the functional activation mask (Figure 2, x-axis), which we varied to include 10 to 10⁵ of the most significant voxels in the F-map. The concave function with a broad maximum for both HR and LR reference data revealed **consistently higher success rates for LR than for HR data**. Spatial smoothing levels this difference, mostly by affecting HR data, but even extensive smoothing up to 9mm FWHM degraded stimulus matching performance by less than 20% (data not shown).

CONCLUSIONS

While HR fMRI may offer better accuracy in localizing activated brain regions in the cortex, the current study suggests that this increase in spatial precision does not necessarily translate into better stimulus discrimination. On the contrary, lower resolution fMRI data was found to be a better predictor of the BOLD signal across all scans and resolutions. Moreover, smoothing maximizes BOLD signal reproducibility at 2-3mm FWHM. These findings are consistent with the hypothesis that the distribution of *independent* BOLD signal sources throughout the brain is essentially sparse and can therefore be under-sampled without loss of information. We are still investigating whether or not more flexible feature-selection and classification algorithms involving e.g. *mutual information* or the *support vector machine* might extract additional information from higher statistical moments and non-linear interactions. But one may be sceptical, that such higher-order effects would outweigh the linear correlations analysed here.

REFERENCES

- [1] Krüger & Glover, 2001, MRM, 46(4):631-637, doi:10.1002/mrm.1240
- [2] Haxby et al, 2011, Neuron, 72(2):404-16
- [3] Kriegeskorte, Goebel & Bandettini, 2006, PNAS, 103(10):3863-3868

Figure 1 F-statistic maps ($p < 1\%$). Background: mean EPI, posterior half of an axial slice through the occipital and inferior temporal lobe.

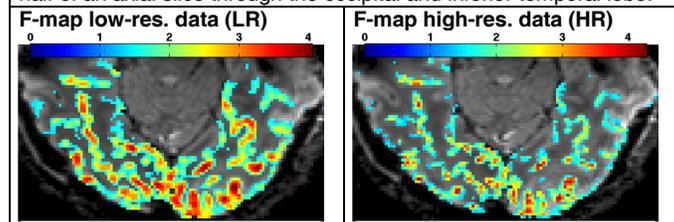


Figure 2 %-correct stimulus matches based on cross-correlation with high-resolution (blues) and low-resolution (greens) reference.

