Comparing Functional Contrast and Pattern Information across fMRI Resolutions

Marta Morgado Correia[1], Arjen Alink[1], and Nikolaus Kriegeskorte[1]
[1]*MRC Cognition and Brain Sciences Unit, Cambridge, Cambridgeshire, United Kingdom*

Purpose: Typical fMRI studies use voxel sizes of approximately 3x3x3mm^3. Higher resolution fMRI has the potential to reveal brain activity patterns in greater spatial detail, which promises more precise localisation and the elucidation of population-code information residing in fine-grained columnar patterns of neuronal activity. At ultra-high field strengths (7T), it has been demonstrated that fMRI can reveal columnar level neuronal organisations such as ocular dominance columns [1]. However, several arguments question the practical utility of acquiring at high-resolution at 3T, for example, higher resolution comes at the price of a lower signal-to-noise ratio (SNR) and, from a neurovascular perspective, fMRI at 3T reflects signals in venules and veins, which might limit the effective resolution. This raises the question of which resolution best balances functional contrast and spatial detail for a given neuronal representation, so as to maximise the decodability of neuronal information from the fMRI patterns. Here we address this question empirically by eliciting checkerboard-like response patterns in early visual cortex at different spatial scales.

Methods: Stimuli and design: All stimulus types were presented within an annulus (inner radius=1.5°, outer radius=7.04°) centred on fixation on a mid-grey background. The annulus was divided into log-polar tiles defined by radial lines emanating from the centre, and concentric circular divisions exponentially spaced between the inner and outer radii. The log-polar tiles were used to induce a checkerboard-like pattern of activation in the visual cortex, with alternating tiles showing either a plain grey background, or a grating pattern with a varying phase. For each stimulus type there were two exemplars (condition1 and condition 2), each showing the grating pattern in opposite locations (Figure 1). The size of the log-polar tiles was varied in order to induce three different sized patterns of activation in the visual cortex [2]: 1.5mm^2, 3mm^2 and 6mm^2. The aim of using different stimuli sizes was to assess whether there is an interaction between induced cortical pattern resolution and the resolution of the acquired fMRI data (e.g., for large cortical patches higher fMRI resolution might not show any advantage, while for the smallest stimuli size higher resolution might be essential for decoding). Each stimuli resolution was presented in a separate run using a block design divided into four equal sub-runs. Each sub-run contained 8 blocks (4 for each condition) of 16 seconds, and different sub-runs were separated by 24 seconds of fixation.

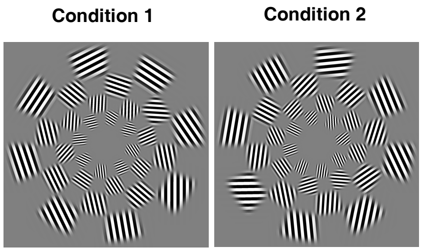

Figure 1 – 6mm^2 log-polar stimuli

Retinotopic mapping: In order to define regions of interest (ROIs) for V1-3 for each subject, we also presented dynamic grating stimuli designed to optimally drive early visual cortex.

Sequences and resolutions: Data was acquired with a 3T Siemens Trio, and using a standard 2D single echo EPI sequence. Three different spatial resolutions were compared in this study: 3x3x3mm^3, 2x2x2mm^3 and 1.6x1.6x1.6mm^3. 3D EPI offers the advantage of higher spatial SNR when compared to 2D EPI, so data at the same three spatial resolutions was also acquired using a 3D EPI sequence [3].

Subjects: Thirteen healthy volunteers (6 female, age range 21-38) took part in this experiment. Each volunteer came back for four sessions, and data was acquired for each combination of sequence type, resolution and stimuli size. The order in which each sequence and stimuli combination was acquired for each subject was randomised across subjects and sessions.

Data analysis: The fMRI data was processed using SPM 8 (http://www.fil.ion.ucl.ac.uk/spm/software/spm8/). After pre-processing (motion correction, trend removal, temporal high-pass filtering, and slice time correction for 2D sequences) a general linear model (GLM) was fitted to the data using one predictor per condition for each sub-run (eight predictors per sub-run). We also included 6 predictors specifying the head motion parameters. From this GLM we computed eight t-value activity pattern maps for V1-3. We decoded the two conditions (Figure 1) with a linear support vector machine (SVM) using leave-one-subrun-out crossvalidation [4]. For each combination of sequence and stimuli type, temporal SNR (tSNR) and functional contrast-to-noise-ratio (fCNR) maps were also obtained.

Results and Discussion: We found a very significant effect of stimuli size: the larger the cortical pattern induced, the higher the decoding ability (Figure 2). However, for the smallest stimuli size (1.5mm^2) the cortical patterns were not decodable above chance level for any of the fMRI resolutions compared.

There was no significant difference between 2D and 3D sequences (p>0.1). Differences between fMRI resolutions are small, but there is an overall significant effect, with 3mm voxels resulting in the highest decoding accuracies (ANOVA, p<0.001).

tSNR was found to increase linearly with voxel volume (as expected), while fCNR was found to increase with cortical pattern resolution. Decoding Accuracy was mostly explained by cortical pattern resolution and fCNR (Figure 3), and it only correlated with tSNR for the largest the cortical pattern size. This suggests that for smaller pattern sizes the fCNR is lost through partial voluming, i.e., opposite effects cancelling in the same voxel.

The total head motion during a run was also found to correlate significantly with the decoding accuracy obtained for that run (p<0.001, R^2=0.069).

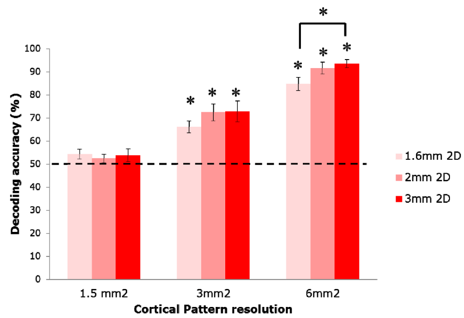

Figure 2 – Decoding accuracy as a function of cortical pattern resolution and fMRI sequence resolution (2D).

Conclusion: Overall, no significant advantage of higher resolution fMRI has been identified. The smaller cortical patterns were expected to benefit the most from the higher resolution acquisition, so future work will investigate why these patterns are not decodable above chance level, looking in particular at the effect of saccadic eye movements in blurring of the cortical patterns. Another limitation of the current analysis is that decoding accuracy shows a noticeable ceiling effect (Figure 3). Future work will use discriminant t-values [5] in order to remove such effects.

Despite there being no obvious advantages of higher resolution fMRI for this particular set of stimuli, this study has shown that robust and comparable classification accuracies can be achieved for a range of resolutions at 3T. This suggests that good quality data can be achieved at 3T for voxels smaller than 3x3x3mm^3, despite the loss in spatial SNR, which is very promising for studies where spatial localisation is of great importance.

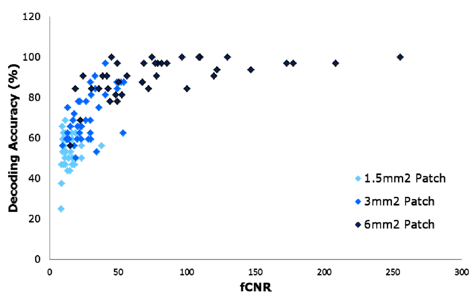

Figure 3 – Decoding accuracy as a function of fCNR.

References: [1] Yacoub et al, PNAS 105(30):10607-12. [2] Schira et al, J Neurophysiol 97(6):4284-95. [3] Poser et al, Neuroimage 51(1):261-6. [4] Mur et al, Soc Cogn Affect Neurosci 4(1):101-9. [5] Kriegekorte et al, Proc Natl Acad Sci USA 104(51):20600-5.