Challenges in Functional Imaging of the Visual Cortex: Data-driven Model-agnostic Estimation of Population Receptive Fields

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Abstract

Disorders that affect sight and the visual system can afflict people across the life span. Common such disorders are amblyopia (a disorder in young people characterised by degradation in the visual input from one eye to the visual cortex during critical periods of development, leading to deficits in stereopsis and spatial vision) and age-related macular degeneration (a disorder characterised by a progressive loss of vision at the centre of gaze). A challenge for the development of better treatments for these disorders is that the underlying physiological mechanisms are not completely understood. A key problem that has limited the study of these mechanisms is that existing methods for investigating human visual cortical function - primarily functional magnetic resonance imaging (fMRI) - cannot easily be used with patients, largely as a result of symptoms associated with the disorders. A main limitation is represented by the requirement for steady fixation and relatively long data acquisition times. Because patients with visual disorders, often have severe fixational instability, these methods cannot be straightforwardly applied to such patients. Moreover, deficits in attention and motor control, as well as issues related to the age of patients, make long scanning sessions impractical. Hence there is a need for development of methods that are robust to fixation instability and subject motion, while being practically feasible in a relatively short time span.

To this end, population receptive field (pRF) modelling ([1], [2], [5] and [3]) is a relatively novel approach that seeks to characterise individual fMRI voxels both in terms of their spatial response properties and visual field representation, as well as their stimulus selectivity. pRF modelling, while still measuring responses reflecting the pooled activity of thousands of neurons, is conceptually more similar to neuronal recording methods used to study animal models of visual system disorders, and thus holds promise for providing a better understanding of the neuronal mechanisms of the disorders by linking measurements in humans and animals. A limitation of current pRF modelling techniques is their requirement of assumptions about the receptive field structure that puts some a priori constraints on the ability to extract the pRF. To overcome these problems, we propose a new data-driven model-agnostic[1] approach that estimates the structure of the pRF. Our method does not make a priori

[1] It forsakes the need for a model and requires no a priori knowledge, as the inferences are informed by the data through the layers of information that are available in the intrinsic salient structure of the dynamic response.

assumptions about the specific haemodynamic response function (HRF) and pRF shapes and is therefore a useful tool for uncovering the underlying pRF structure at different spatial locations in an unbiased way. Our method is based on the idea of reverse correlation ([4]) applied to BOLD signals. Reverse correlation or white noise analysis is a standard technique for estimating receptive fields of single neurons by cross-correlating the stimulus with the spiking response for a neuron, using so-called spike triggered averaging. A limitation of applying this technique to estimate pRFs from fMRI data is that it ordinarily requires large numbers of spatially independent stimuli to avoid biased estimates. In this work we have applied the reverse correlation approach by making specific assumptions about the temporal structure of the fMRI response. Figure 1 outlines the whole processing workflow, from the raw data to the final estimation of the pRF and time course prediction

Our method provides (i) rapid and reliable estimates of the size and shape of pRFs with fewer stimuli than conventional reverse correlation, (ii) does not have as stringent requirements for spatially independent stimuli, and (iii) has the potential to be used in patients with visual disorders that cannot be routinely tested with currently available methods.

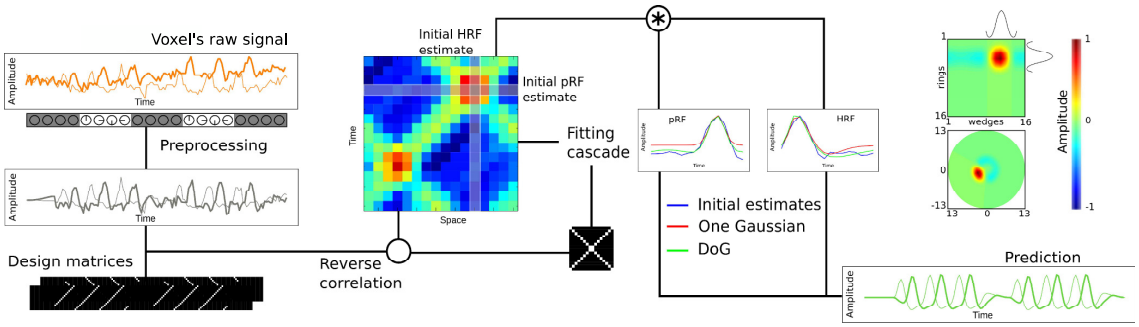

Figure 1: **pRF estimation workflow.** The reverse correlation is applied to the filtered fMRI time courses. The spatio-temporal kernel obtained provides initial estimates for the pRF and HRF. These are subsequently refined through a fitting cascade process.

References

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