Investigations on bottom-up and top-down processing in early visual cortex with high-resolution fMRI

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Summary

This thesis presents three empirical studies, all of which employed cutting-edge high-resolution functional magnetic resonance imaging (fMRI) at sub-millimetre resolution to study visual perception in the human brain. First, we studied bottom-up (i.e. sensory driven) processing in visual cortex (Chapter 2). In particular, we investigated how variations in simple physical properties of a visual stimulus affect neuronal activity in visual brain areas. The unprecedented high level of spatial detail in our studies enabled us to resolve activity at different cortical depths. Because cortical layers are thought to form distinct computational networks with specialised roles, a more fine-grained understanding of these neuronal networks has the potential to refine cognitive theories of visual perception.

A major challenge in the high-resolution mapping of cortical layers is a spatial bias in the measured fMRI signal caused by the flow of blood perpendicular to the cortical layers. We employed, for the first time in a human fMRI study, a spatial deconvolution model that allowed us to partially remove this bias. In this way, we were able to approximate the local neuronal contribution to the fMRI signal at different cortical layers. The field of high-resolution fMRI is still evolving, and we hope that our methodological contributions will benefit future research. Methodological aspects pertaining to the removal of the draining veins bias, and the spatial specificity of the fMRI signal at 7T, are extensively discussed in Chapters 2 and 4, respectively.

The first study on bottom-up processing (Chapter 2) was followed by a complementary study on top-down effects (Chapter 3). The term 'top-down' is used to describe aspects of perception and cognition that are not directly driven by physical properties of the sensory input, but by prior knowledge, expectations, attention, or other high-level mechanisms. We investigated the processing of a centrally fixated stimulus that is perceived to move as a whole, although the retinotopic input from one visual hemifield is constant. The cortical depth profile of top-down effects suggest a role of re-entrant feedback at the level of V1. However, other interpretations, such as indirect feedback, for example via the pulvinar, are possible.

We continued our investigation of visual perception with a study on the spatial and temporal dynamics of neuronal responses to illusory contours ('Kanizsa' type visual illusions; Chapter 5). This type of illusion is a popular test case in psychology and neuroscience, because it is a simple and powerful example of how top-down expectations shape visual perception. Although the analysis of the data is ongoing, our preliminary findings indicate a previously unknown pattern of activation in early visual cortex.

In summary, our projects comprise research into the detailed spatial profile of bottom-up and top-down processing in human early visual cortex. We have explored activation profiles of stimuli that were designed to preferentially engage bottom-up or top-down perceptual mechanisms, and have employed a new modelling technique to account for known biases in the high-resolution fMRI signal.