Challenges and potential of 7T (f)MRI for investigating attention and perception

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Summary

This thesis contains three empirical studies, which describe our journey of trying to investigate the neuronal mechanism of attention and surface perception using functional magnetic resonance imaging at ultra-high field (UHF). The cholinergic system has an essential role in mediating attentional control. Thus, our interest was drawn to the source of cortical acetylcholine; the nucleus basalis of Meynert (nbM). The initial plan was to test for functional specialisation within the nbM, first by comparing activation patterns during auditory and visual attention, using 7T fMRI. However, this plan was abandoned after collecting datasets from 8 participants (half of them had two scanning sessions) due to difficulties in accurately defining the region of interest for the nbM in those datasets using the existing atlases. As a result, the project turned to an examination of the methods and limitations of previous MRI studies that attempted to localise the nbM, as well as potential ways to improve upon them. The findings in Chapter 2 showed that the reported volume of the nbM varied greatly depending not only on the atlas and threshold used, but also among datasets using the same atlas and threshold. To test the effect of spatial resolution on volume variability, we created a novel mask based on the BigBrain dataset. It was found that the variance of the estimated nbM volume increased dramatically for voxel sizes above 1.3 mm isotropic but not for datasets with higher resolutions (0.1 - 1.3 mm isotropic). It will likely always be challenging to apply a mask that was defined originally in histological space from one (or more) brain(s) to MR images of other brains. One potential solution to this issue could be to directly delineate the nbM from each individual MRI dataset. To evaluate this possibility, we explored publicly available and novel high-resolution MRI ex vivo datasets. We found that the nbM could be visualised in the quantitative T_2^* dataset acquired at 9.4 T with 200 μm isotropic resolution. As technology continues to advance, we are increasingly optimistic that we

will be able to visualise the nbM and investigate its function in vivo in the (near) future.

Given that our work in Chapter 2 suggested that accurate fMRI measures in the nbM were not (yet) feasible, we next addressed what we considered to be a more tractable problem in the cortex. Specifically, we used 7T fMRI to investigate the role of the early visual cortex in surface perception. Previous work at 3T in our group had shown a significant fMRI signal in V2, and a trending signal in V1, related to perceived surface brightness. Re-examining these findings at 7T could clarify the pattern in V1, and crucially could allow us to make statements about the laminar organisation of the response. In Chapter 3, we used a brightness induction paradigm with uniform surfaces, wherein decreasing luminance in a surrounding stimulus (inducer) induces an illusory increase in brightness of a physically constant centre stimulus (probing region). Increasing the luminance of the inducer induces a perception of decreased brightness of the probe. We grouped the temporal response into positive-dominant BOLD (Early), post-stimulus undershoot (Late) and recovery periods (End). For the Early response, we found that luminance decrement of the inducer induced a significant negative response in the inducer representations and a non-significant trend towards a positive BOLD response in the V1 representation of the probing region. In the Late response, we found stronger BOLD signals in the inducer and probing representations than in the edge representation, which might indicate additional cortical processing in these regions. However, while these effects were interesting, the overall pattern in this study was of weak or absent responses for the probing region. Furthermore, we found no response in the inducer representation in the luminance increment condition. Thus, we did not find clear evidence supporting a neural mechanism of brightness induction in the early visual cortex.

In addition to the weak response, another challenge in Chapter 3 was dissociating responses caused by perceptual change in brightness from responses caused by changes in the (mean) luminance of the stim-

ulus, since these two factors are necessarily confounded in the simultaneous contrast illusion. Modulation of luminance in the inducer in Chapter 3 creates different mean luminance during the different stimulation blocks and compared to the fixation periods, which may lead to responses in the cortical representation of the probing region through scattering of light around the MRI bore and in the eye. In order to meet these challenges with a new stimulus, in Chapter 4, we used online psychophysics experiments to investigate the characteristics of Anderson and Winawer' s brightness illusion stimulus. In this illusion, identical textured probe surfaces appear either as either black or white surfaces behind a veil of respectively either light or dark clouds, depending on the mean brightness of the textured surrounding region. In addition, this illusion can be nullified by breaking the geometric alignment of the texture in the probe with the texture in the surround. This means that the illusion can be manipulated without a change in the luminance properties of the stimulus. Given these features, and the fact that Anderson and Winawer described the induction illusion in their stimulus as very powerful, we considered that their stimulus could be a useful tool for future fMRI research, and we wished to investigate it further. In our own version of the Anderson & Winawer stimulus, we found that the illusory perception could also be induced by only manipulating the luminance of a small region of the inducer near to the probing region' s border, thus minimising the overall luminance difference between light and dark appearing probe conditions. However, the measured illusory effect was small for both the full-background manipulation (as used by Anderson and Winawer) and our novel narrow inducer manipulation. We tested whether larger effect sizes could be obtained with different stimulus parameters or behavioural paradigms in a series of online experiments. Nonetheless, all of our tests showed small illusory effect sizes, hence we could not replicate the large effects reported by Anderson and Winawer in online experiments. We believe nevertheless that Anderson and Winawer' s stimulus is promising, and that larger effect size may be obtained in further psychophysics testing in the lab.

In summary, the studies in the present thesis aimed to explore brain

function using functional neuroimaging at UHF. The work indicates what the boundaries are of what is possible in contemporary UHF-fMRI, and how important it is to optimise experimental and stimulus design to make maximal use of the current possibilities. At the same time, there are indications in the reported data that, with ongoing and further developments of the technology, a deeper understanding of the neural mechanisms of attention and of surface perception will be achieved.