ULTRA-HIGH MAGNETIC FIELD DIFFUSION, PERFUSION & FUNCTIONAL MRI

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Studying tissue physiology and function at Ultra-high field: Nottingham Experience

- Ultra-high field (UHF) provides improved CNR for BOLD and perfusion imaging allowing data to be collected at high spatial resolution. Examples will be shown.

- At UHF there are challenging issues related to B_1 and B_0 inhomogeneity and remaining within the SAR limits. Developments are required to overcome these limitations, including image readout and hardware developments.

TARGET AUDIENCE: Physicists, neuroimaging researchers and neuroscientists.

OBJECTIVES: To develop techniques for functional and perfusion imaging at UHF

METHODS AND RESULTS

The use of ultra-high field (UHF) (here defined to be 7 T) magnetic resonance imaging (MRI) provides the means to study detailed structure and function. 7 T provides the principal advantages of higher image signal-to-noise ratio, increased longitudinal relaxation (T1) times for Arterial Spin Labelling (ASL), and changes in T2 and T2* contrast providing increased blood oxygenation level dependent (BOLD) contrast for use in functional MRI. These gains can be exploited to improve the spatial resolution and/or temporal resolution of physiological and functional images.
This talk will demonstrate how these advantages have been applied for functional and perfusion imaging applications on the 7T Philips Achieva system in Nottingham. The practical limitations of 7 T including the issue of specific absorption rate (SAR), and B1 and B0 inhomogeneity will be described, and developments to overcome these discussed.

UHF fMRI provides increased BOLD contrast-to-noise ratio (CNR), we have exploited this for high spatial resolution fMRI (~ 1 mm isotropic resolution) to study basic neurosciences questions in the somatosensory and visual domain. We show that regions of the cortex responding to vibrotactile stimulation along the phalanx of individual fingers can be well localized at 7 T [1,2] (Fig.1A). An organized somatotopy with four mirrored, within-finger (base-to-tip) maps is found in the primary somatosensory cortex (S1), consistent with electrophysiology measurements in non-human primates. These highly reproducible functional maps allow, for the first time, the definition of the borders of four distinct tactile Brodmann areas (3a/3b/1/2) *in vivo* [3] (Fig.1B). In order to resolve the central projections of individually characterised single mechanoreceptors, we combine 7 T fMRI with the technique of intraneural microstimulation (INMS) to stimulate single afferents, this offers improved spatial precision of the fMRI response relative to conventional tactile stimulation [4]. In the visual domain, we study the correspondence of function and structure

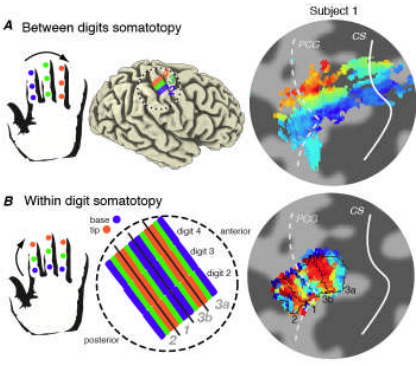

***Figure 1**: A) Between digit somatotopy and B) Within digit somatotopy at 7 T.*

in visual areas [5], assess orientation preference and demonstrate the presence of coarse-scale orientation maps that are strongly correlated with the angular component of retinotopic maps, and show preferred disparity is evident in early extrastriate regions. Data is analysed to assess cortical depth specific fMRI patterns of activity. At coarser spatial resolution, the improved BOLD CNR at 7 T allows the study of single events, and is is used to employ novel techniques to investigate the temporal dynamics of functional connectivity, and investigate the contribution of spontaneous BOLD events to this connectivity [6,7].

Spin echo (SE) fMRI offers an alternative to standard gradient echo (GE) EPI for fMRI measurements of BOLD signal. While SE-EPI offers improved spatial specificity, as signal changes originate from the microvasculature, it is limited by a lower functional sensitivity [8]. We use complementary rings of contrast-reversing checkerboards (8Hz) to stimulate bands of primary visual cortex with defined widths to assess the sensitivity and point spread function of GE-EPI and SE-EPI BOLD data [9]. Simultaneous GE/SE BOLD fMRI is also used to identify functional connectivity maps in both SE- and GE-BOLD data and assess the ratio of the changes in relaxation rate on activation in gradient and spin echo data ($\delta R2^*/\delta R2$) at 7 T [10].

There are significant potential advantages to performing Arterial Spin Labelling (ASL) at UHF [11], arising from an approximately linear increase in signal-to-noise ratio (SNR) and an increase in tissue and blood longitudinal relaxation time (T_1) with field strength ($T_1 \sim \omega^{1/3}$) to approximately 1.85 and 2.1 s respectively. These changes result in an expected increase in the perfusion weighted (PW) signal, with the peak in the PW signal occurring at a longer post-labelling delay time (TI) than at lower field strength. Despite the potential gains of ultra-high field, there are still relatively few published ASL studies at 7T, likely due to the fact that the implementation of ASL at UHF presents several challenges, including the increased B_1 and B_0 inhomogeneity causing problems in delivering a label of sufficient efficiency and of a clearly defined width, and increased RF heating. These issues will be discussed.

The gain in perfusion CNR is applied to high resolution ASL measurements using both 2D and 3D ASL readout schemes [12]. The use of multiphase ASL data and the possibility to collect data at longer post-label delays for improved quantification of transit time and perfusion is illustrated. The application of these ASL methods to clinical studies of baseline perfusion is highlighted, for example in multiple sclerosis and Alzheimers disease. Perfusion imaging is used to assess functional changes with higher spatial specificity than for BOLD, where detailed retinotopic maps are visible. Using signal changes in response to a hypercapnic gas challenge, the possibility of performing calibrated BOLD and voxelwise mapping of $CMRO_2$ at 7 T will be shown [13], and the physiological effect of hyperoxia on tissue physiology assessed [14].

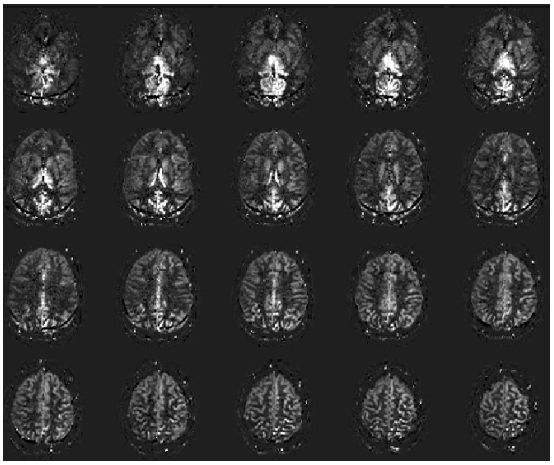

***Figure 2**: A) Example perfusion weighted images acquired at 7T using a FAIR pulsed ASL scheme and 2 x 2 x 3 mm^3 3D-EPI readout.*

CONCLUSION

UHF provides the increased CNR to study physiology at the high spatial resolution for use in clinical and basic science studies.

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