Magnetisation transfer effects in an IR-TSE study of cortical layers in the area V1

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Introduction The correspondence between the functional organisation of the neocortex and its cytoarchitectonic fields is one of the major topics in modern neuroscience. In order to investigate this question, the development of techniques which allow for the identification of cortical layers in the living cortex by MRI has made significant progress in recent years [1-5]. Very high and isotropic resolution is needed for the study of layers with thickness of the order of 300um, and the need for high white-grey matter contrast and high SNR favours the use of high magnetic field. Turbo-Spin Echo, TSE, is an imaging technique that benefits particularly from the use of higher field strengths, since the longer T1 gives rise to potentially longer echo-trains, as the unavoidably imperfect refocusing pulses maintain useful magnetization in the form of stimulated echoes. Thus it is expected that TSE SNR rises faster than the raw FID SNR, generally assumed to be linear with field strength. Added to this benefit is the comparatively tight point spread function (PSF) of TSE, which can be even more sharply defined using feathering [6]. We have achieved visualisation of the stria of Gennari in each of 6 volunteers, using a 3D magnetisation prepared turbo-spin echo (IR-TSE) sequence with nearly isotropic resolution of $0.4x0.4x0.5mm^3$, and a 3T scanner [7]. The repetition time, inversion time and turbo factor were adjusted to give optimal signal, contrast and PSF properties. A substantial shortening of the effective T1 relaxation times was noticed, as compared to results of a dedicated sequence for T1 mapping. The reduction in the T1 values, as well as part of the good contrast achieved with the sequence, are attributed to magnetisation transfer effects and further investigated in the following.

Methods All the measurements were performed on a 3T scanner (Siemens Trio), equipped with a 40mT/m gradient coil, an RF body coil operated in the transmit mode and a head phased array RF coil with 12 elements for signal detection. The manufacturer's 3D turbo-spin echo (TSE) sequence was used, with a module for magnetisation preparation. Acquisitions for several inversion recovery times TI were performed on one volunteer and are shown in Fig. 1. The contrast between grey and white matter was measured as a function of TI, as shown in Fig. 2. The maximum number of 5 slabs was chosen, as allowed by the various hardware and software constraints. In order to study the effect of the number of pulses on the effective relaxation times, acquisitions with varying TI were performed for two different turbo factors, with a number of pulses differing by approximately a factor of 2. The following parameters were used: TR=2860ms, TE=15ms, TI = 0 - 550ms , turbo factor =15 or 7, isotropic resolution of $(0.8mm)^3$, provided by FOV= 192 mm x 162 mm x 0.8 mm and matrix size=256 x 216, 10 slices/slab, 4+1 slabs (two slab groups). The first group of four slabs was placed in coronal orientation through the middle of the brain, leaving one slab thickness gap between the slabs to minimize cross-talk effects. The fifth slab (second slab group) was placed in the area V1, approximately perpendicular to the calcarine. This set-up mimicked the off-resonance properties of the slab set-up used for the visualisation of the stria of Gennari (4 or 5 slabs perpendicular to the calcarine, and a fiducial slab in mid-brain coronal orientation).

Results and discussion The dependence of the contrast between grey (GM) and white matter (WM) on the inversion time was investigated experimentally and modeled as a function of TR, and tissue characteristic T1, T2 and M0. The signal intensity in 3D TSE can be described (see also [8]) as:

$$Meq= M0[1-\exp(-(TR-2NxTE-TI)/T1)]; \qquad M=[M0-(M0+Meq)\exp(-TI/T1)]\exp(-TE/T2) \quad [1],$$

where TE is the echo time, N the number of echoes (turbo factor), TI the inversion time, TR the repetition time, M0 the tissue equilibrium magnetisation and T1 and T2 the tissue relaxation times. Signal intensities for the WM and GM were measured in typical ROIs: the genu of the corpus callosum (GCC) for the WM, and the nucleus caudate (NC) for the GM. Using the model for the signal (eq. [1]) and the experimental signal values (Fig. 2), the relaxation times were extracted with the IR-TSE sequence: for GCC(WM), T1=523(5) for N=15 and 611(11) for N=7; for NC(GM) T1=970(25) for N=15 and 1041(26) for N=7. The numbers given in parenthesis represent the fit errors. In a separate study, T1and T2 relaxation times were measured at 3T using a dedicated relaxometric sequence on 12 volunteers [9]. The relaxation times characterising the same regions were found to be: T1=1225+-53 ms for NC and T1=740+-24 ms for GCC. The numbers represent the mean value and SD over all 12 volunteers, and it is seen that the SD is far too small to explain the difference from values measured with IR-TSE. If we assign an effective turbo factor of 1 to the relaxometric sequence (which uses a gradient echo read-out, but quite a large number of small flip angle pulses), t he dependence of the variation of T1 on the number of pulses seems non-linear, judging from the three data points (N=15, 7 and ~1). Furthermore, the inversion time required to null the signal intensity from a given type of tissue was observed to depend on the slab position, as also reported recently and independently by Meara and Barker [Meara 2007].

It is well understood [Ref. 6 and refs therein] that magnetization transfer effects play an important role in TSE contrast in brain tissue, due to the large number of rf refocusing pulses. A major contribution of magnetization transfer contrast (MTC) in providing good grey-white contrast was recognised in 2D-FSE images at 4.7 T [6]. Here the contrast builds up from slice to slice, because slice selective pulses that are required to form images of any particular slice provide off-resonance excitation of myelin protons in surrounding slices. In 3D TSE this effect is expected to be reduced, since here it is the spatial and frequency separation of adjacent slabs that determines MTC contrast, which are usually further apart than adjacent 2D slices. However, especially for high-resolution studies with thin and closely spaced slabs (10 slices of 0.5mm thickness per slab, spacing of one slab thickness, as used in our study of the area V1), the effect is clearly present, and most probably explains the observed disparity between the T1 relaxation times measured with IR-TSE and the ones measured with a relaxometric sequence with small flip angle pulses. In any case, MTC, which is more pronounced for white matter, assists in giving better contrast in the images obtained as described using 3D TSE, where grey matter appears brighter than white matter. For imaging purposes, this implies that optimisation of the inversion time required to produce good WM-GM contrast in an IR-TSE sequence needs to be checked for each combination of number and positioning of slabs and turbo factor. The choice of an inversion time in a region of values where the dependence of the contrast on the above parameters is quite flat is recommended, and has been used in our study of the area V1.

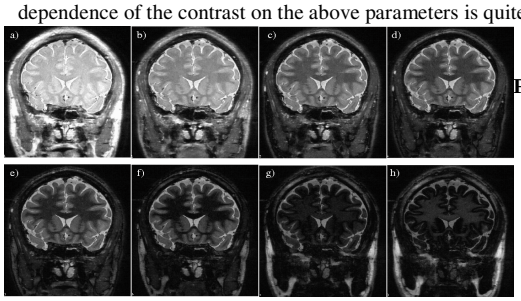
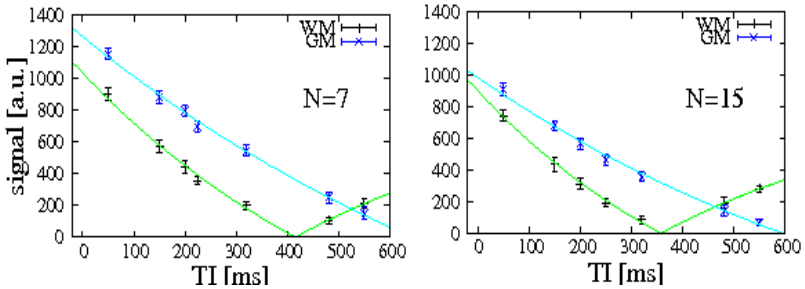


Fig 1.

Fig. 2



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