Constrained Source Space Imaging: Rapid Point Measurement of fMRI Paramaters

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Purpose: Typical whole-brain functional magnetic resonance imaging (fMRI) using echo planar or spiral k-space readouts require a repetition time (TR) of about 1 s. Due to the relatively slow hemodynamic fMRI response this is sufficient for most applications, however there are reasons why decreasing the TR is of interest. For example, some physiological signals, such as blood flow due to the cardiac cycle, have a frequency of about 1 Hz, which is aliased in typical fMRI experiments. Also, an increased sampling frequency could be used to characterize the blood-oxygen-level dependent (BOLD) hemodynamic response function (HRF) more precisely, accurately measure timing of activation between different brain regions and be used for fast correlations in resting state connectivity fMRI. The purpose of this work is to improve upon a technique referred to as constrained source space imaging (CSSI)[1] for high temporal fMRI to measure fast brain activity from one or more coarse voxels.

Methods: The original proof of principle for CSSI used a modified stimulated echo acquisition mode[2] (STEAM) sequence to excite four voxels on a Cartesian grid, with two out of four of the voxels being positioned arbitrarily and a TR of 250 ms. For our current work we chose to modify a point resolved spectroscopy (PRESS)[3] sequence for the factor of two improvement in SNR. Additionally, a localization algorithm was developed and implemented that allows for a third voxel to be arbitrarily positioned, with a total of four voxels still being excited. However, due to the new localization algorithm the voxels are now rhomboidal and not rectangular. This is acceptable provided the three excited voxels are not close to a line, where the voxels become highly elongated. The pulse timings were modified to allow a minimum TR of 50 ms with a readout of 8 ms, although due to the low SNR a TR of 73 ms with a readout of 32 ms was used. This allows frequencies as high as 6.8 Hz to be sufficiently sampled. Fig 1 is the CSSI sequence implemented on a GE MR750 3.0T. The first two RF pulses are cosine amplitude modulated, to excite two dual bands. The intersection points of the five excited planes define the locations of the four excited voxels. The four individual voxel signal time courses are then reconstructed using strong SENSE[4]. For each voxel, the signal decay at each at each TR value is fit to a monoexponential function, Aexp(-T/T2*), where estimated signal amplitude, A, is dependent on T2. The value for T2* can then be used to generate BOLD-dependent time series data.

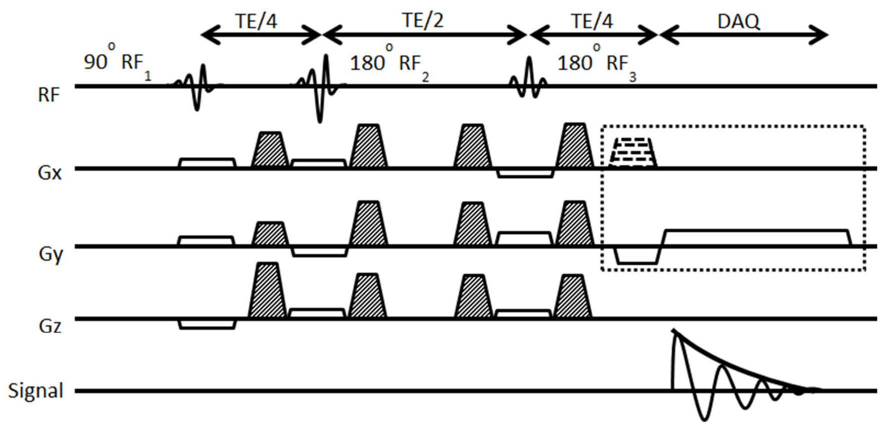

Fig 1: Pulse sequence for CSSI.

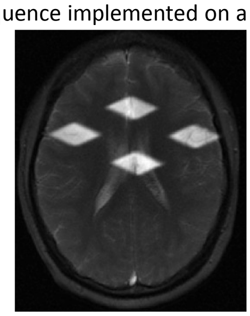

Fig 2: Voxel positions.

Results: Fig 2 is an image of the excited voxels using the optional gradient echo readout shown in the dotted box in Fig 1, overlaid on an anatomical image of a volunteer's brain. For proof of concept Fig 3 is the average time-domain signal of a volunteer for one of the four voxels reconstructed using this technique with TE/TR = 30/73 ms, 1024 excitations (acquisition time of about 75 seconds), flip angle = 20°, readout bandwidth = 32 kHz with 1024 points, voxel size = $(20\ mm)^3$. The signal was also measured with identical parameters using a stock PRESS sequence, for comparison, and is also plotted in Fig 3; similar curves for the other three voxels were observed. As can be seen from Fig 3 there is both an increase in noise from the g-factor[4], and a systematic discrepancy between the two curves introduced from the reconstruction. This deviation is quite small, however, as the measured R^2 and the root mean square of the standardized difference[5] was 0.996 and 1.21, respectively.

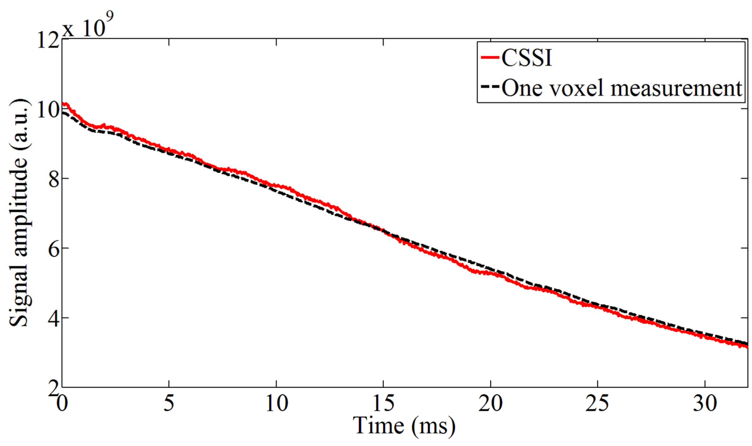

Fig 3: Plot of signal versus time from both CSSI and a one voxel measurement.

Conclusions: We have shown that this technique can accurately extract multiple voxel signals simultaneously at very low TR. The option to excite eight voxels and localize a fourth exists. Using this technique we can extract values for T2*, as well as have an estimate for T2 through the amplitude of the signal, and the centre frequency through the phase of the signal. We will use this technique to measure fast brain activity for mental chronometry by densely sampling the HRF. We are also interested in applying this to resting state connectivity fMRI.

References
1. M. Chiew *et al, Magn Reson Med (2012)* 70:1058–1069.
2. J. Frahm *et al*, *J Magn Reson* (1969) 72:502-508.
3. P.A. Bottomley, *Ann NY Acad Sci* (1987) 508:333-348.
4. K.P. Pruessman, *Magn Reson Med* (1999) 42:952-962.
5. J. Fan *et al*, *JASA* (1998) 93:1007-1021.