High resolution multislice fMRI using interleaved EPI with cyclic recombination

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Introduction

High spatial resolution scanning is of vital importance in fMRI studies. Contrast to noise ratio (CNR) in fMRI studies has been shown to decrease at resolutions coarser then 1 mm^3 due to partial volume effects (1). High-resolution imaging also enables activation in grey matter and apparent activation in draining veins to be distinguished. At a resolution of 1 mm^3, veins are visible in the images as small regions of very low intensity and any activation related to those pixels can be interpret as draining vein effects.

To reach a higher spatial resolution without compromising CNR or temporal resolution a dedicated surface coil with a small sensitive volume was used. Pre-saturation pulses were also used to suppress a band of signal in the phase-encode direction (2) and hence avoid wrap around artefacts. The pre-saturation pulses will be referred to as zoom-pulses, because they facilitate 'zooming in' on part of the brain for multislice imaging. To achieve a shorter echo-time, a two-shot interleaved EPI sequence was implemented and the results compared with those of a one-shot measurement.

Method

Six subjects were scanned on a 3T scanner using a 27-cm diameter, TEM volume excitation coil and a home-built 4-cm diameter surface, receiver coil. The gradient switching frequency was 500 Hz.

Single shot fMRI data were acquired with 1 mm in-plane resolution and 1.5 mm slice thickness in a 128 x 64 matrix, with a shortest achievable echo time of 55 ms. One volume, comprising 8 sagittal slices, was sampled every 2 seconds. Four double slice saturation pulses were applied before the start of each volume acquisition, with spoilers played out after each zoom-pulse. Slices were acquired in a medial to lateral order, to ensure optimal signal suppression from zoom pulses in the slices where wrap around was most severe. Subjects were shown a visual cue for 10 seconds, during which they were asked to tap their fingers, thus was followed by a 16 second rest period. This cycle was repeated 10 times.

The interleaved experiments had an effective echo-time of 40 ms (TE ≈ T_2^*). One volume was sampled every 4 seconds. The effective temporal resolution was increased to 2 seconds by acquiring an odd number of interleaves per fMRI cycle and recombining interleaves that had been sampled at the same delay after the onset of the stimulus in sequential cycles as shown in Fig. 1. This is referred to as cyclic recombination.

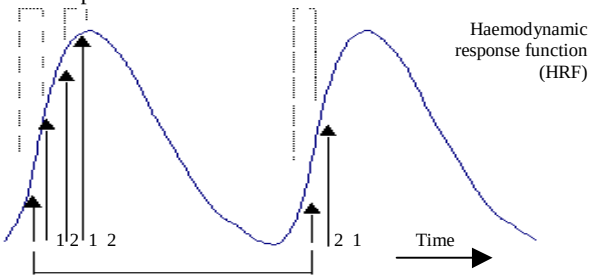

Figure 1. Recombination pattern of interleaves. The dotted lines indicate the conventional way of recombining. The solid line at the bottom shows how two interleaves can be recombined to retain high temporal resolution.

Analysis: The interleaved images were combined both sequentially and cyclically. Both the interleaved and single shot data sets were then motion-corrected (AIR rigid-body 6 parameter), spatially filtered with a Gaussian of FWHM 1.5 mm, and temporally filtered by convolving with a Gaussian filter of 3 s FWHM and applying a high-pass filter with a 0.01 Hz cut-off. Activation patterns were then compared across the three data sets.

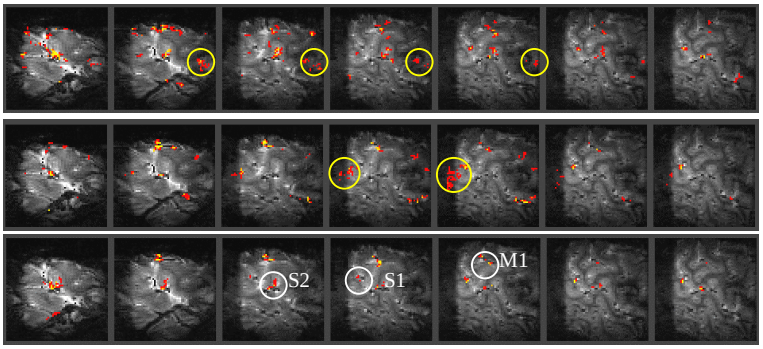

Figure 2. From top to bottom: activation maps overlaid on EPI images, acquired using a single shot EPI sequence, the interleaved EPI sequence and the cyclically recombined EPI. Yellow circles denote areas of false positive activation. Areas M1, S1 and S2 are marked with white circles. The effect of the zoom pulses can be seen in the background images: Signal suppression is optimal in the most medial slices.

Results

Activation maps from a representative subject are shown overlaid on the T_2^*-weighted EPI images in Fig. 2 ($p_{corrected}$ <0.05). It can be seen that the train of zoom pulses effectively suppresses all signal that would otherwise have wrapped back into the image in the most medial slices. Activation patterns in the maps acquired using interleaved and single-shot EPI showed comparable activated areas when assessed across an equal number of cycles (five). However, false positive activation is found in both the single-shot maps, as result of the long echo-time and hence reduced SNR, and in the sequentially recombined interleaved maps (middle row Fig. 2), as a result of the low number of time points used to sample the haemodynamic response function (3). When interleaved data is cyclically recombined, the temporal resolution is twice that of sequentially recombined interleaved data yielding improved statistical maps with increased maximum and mean Z-scores for activated clusters, as shown in Table 1.

	Cyclic recombination		Sequential recombination	
	max	mean	max	mean
M1	6.1	4.2	7.5	3.9
S1	7.0	4.2	5.8	4.0
S2	6.0	3.8	5.0	2.4

Table 1. Z scores of active areas shown in Figure 2.

Conclusion and discussion

Activation maps with a resolution of 1.5 mm^3 have been produced. In future work, navigator echoes will be used to improve the stability of the interleaved EPI data sets. This sequence will be exploited in studies of somatosensory cortical dynamics, where both high spatial and temporal resolution are needed to visualise the small temporally varying shifts in activation during prolonged vibrotactile stimulation of digits (3).

References

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