The efficacy of cardiac gating with variable TR correction in fMRI

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Introduction

Temporal signal fluctuations due to cardiac pulsations have shown to be significant in functional magnetic resonance imaging (fMRI), particularly at the base of the brain. Poncelet et al (1) has shown that brain tissue in this region can move up to several mm within a cardiac cycle. Cardiac gating ensures that an image is collected at the same phase of the cardiac cycle, ensuring that the images are precisely registered. The variability in heart rate results in a variable TR. If the TR is short, then large signal variations due to varying T1 saturation occur and must be corrected. A gating and correction scheme has been shown by Guimaraes et al (2) to be feasible in reducing cardiac noise and improving the imaging of subcortical regions. This technique, however, has not been widely adopted for fMRI studies, even for imaging subcortical areas or the spinal cord, relying instead on long TRs, signal averaging, flow compensation, and spatial saturation pulses (3). This is possibly due to the additional processing required to reduce the effects of the variable TR, a lack of information on the relative magnitude of cardiac noise, and an uncertainty in how accurately the signal variations due to the variable TR can be corrected. The purpose of this study is to evaluate 1) the efficacy of correcting signal fluctuations due to the variable TR in gated fMRI studies and 2) the importance of gating in reducing signal variations of cardiac origin especially in inferior regions of the brain.

Methods

A series of T2*-weighted coronal single-shot spiral images were acquired on a General Electric Horizon LX scanner (3T/90cm) during bilateral finger tapping. (FOV:24cm, matrix: 128x128, slice thickness:5mm) In the first run, a constant TR of 1600 ms was used. In the second run, the acquisition was gated to every 2nd heartbeat, with an average TR of approximately 1600 ms. The finger tapping was performed in a blocked design, alternating 20-second periods of finger tapping with 20-second periods of rest. Two echoes were acquired for each excitation – the first at a TE of 3 ms and the second at a TE of 30 ms. Large crusher gradients were applied to minimize the contribution from previous excitations.

For the cardiac gated images, signal variations due to the variable TR were reduced by fitting the signal time course in each voxel to a T1 saturation model,

$$S(TR)=M0\,[1-\exp(-TR/T1)]$$

and estimating M0 and T1, given the TR for each acquired image. Signal intensities were corrected by adjusting the intensities to what they should have been at the mean TR value (2). The correction was also performed using the T1 estimated from the first echo to correct the second echo. The first echo has a higher signal intensity, and may be less influenced by BOLD signal changes, which allows a more accurate estimation of T1. Noise levels were assessed as the residual temporal variance after functional signal changes fitting an ideal BOLD response were subtracted.

To assess the effect of gating with the variable TR correction on the temporal signal stability, a series of spiral images were acquired of a phantom both with and without gating. The acquisition was gated by connecting the cardiac sensor to a subject seated outside the magnet while the phantom was being imaged. Variable TR correction was employed as described previously. The corrected time series were then compared to the time courses from images acquired at a constant TR.

Results

The phantom studies showed that cardiac gating with variable TR correction adds a small amount of noise due to imperfect correction of signal fluctuations from the variable TR. The noise level increased from 0.4% to 1.3% (Fig. 1c). Correction for the variability in the TR was vital when employing cardiac gating. Signal fluctuations prior to correction were 8.0%. In human studies, the noise was only slightly increased in regions of the primary motor cortex, from 1.1% without cardiac gating to 1.2% with cardiac gating (Fig 1a). Signal variations in the inferior region of the brain, however, was reduced considerably, from 9.7% to 2.6% (Fig 1b). Using the T1 estimate from the first echo instead of the second echo improved the correction slightly in some brain regions.

Discussion

Cardiac gating considerably reduced signal fluctuations in the inferior regions of the brain. More importantly than simply reducing fluctuations, gating ensures that the same tissue was imaged in each voxel throughout the time series. For relatively short TRs, correcting for the variability in the TR is vital as can be appreciated from Figure 1a.

Imperfections in the corrected time-series may be due to imperfect estimation of M0 and T1, or because the signal relaxation is not purely exponential. Acquiring a separate T1 map may improve the correction.

References

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2. A.R. Guimaraes et al., Human Brain Mapping, 6, 33-41, 1998.
3. P.W. Stroman et al., Magn. Res. Med., 42, 571-6, 1999.

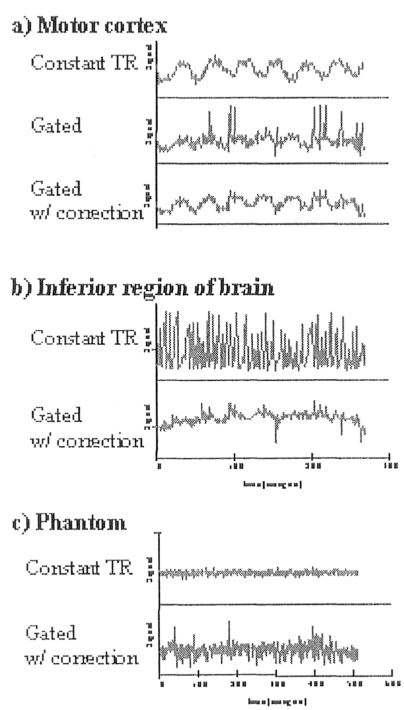

Figure 1

Signal intensity time-courses from **a)** a voxel in the primary motor cortex without gating, with gating, and with gating after correcting for signal fluctuations due to the variable TR; **b)** a voxel in the inferior region of the brain showing large cardiac signal changes without gating, and substantially less oscillation after gating with the correction; **c)** a voxel in a phantom without gating, and with gating and variable TR correction.