An Improved Multi-slice GLM-Based Respiratory Noise Correction Technique

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Introduction: “Physiologic” noise sources (fluctuations due to normal physiology processes) dominate the noise structure of FMRI data [1], thus correcting for physiologic noise can yield considerable increases in the observed activation pattern and reduce the number of false positives. Respiration may alter MR signal through induced CSF motion [2] and/or bulk susceptibility changes [3], increasing signal variation and resulting in lower MR signal to noise ratios. Corfield et al introduced the use of the subject’s respiratory pattern directly into the statistical model used to determine activation [4]. Briefly, this approach uses a signal from a belt with an integrated strain gauge placed around the abdomen as a marker of respiration. The position of the belt for each imaged volume is recorded and entered as a covariate into a general linear model (GLM) with the FMRI data. The proper use of this technique for multislice data, however, is complicated by each slice’s signal change dependence on its distance from the lungs [5]. This work compares the effects of a slice-by-slice respiration technique with the technique of Corfield et al on the number of voxels significantly corrected and on the statistical fit of the GLM model in an FMRI investigation of pain-induced brain activation.

Methods: Seven healthy, right-handed subjects (4 male, aged 27 – 46, mean = 31 ± 6) were recruited in this Institutional Review Board approved study. For the functional task, painful transcutaneous electrical nerve stimulation (ENS) of the right index finger was used. Each pain epoch consisted of 30 seconds of painful stimulation followed by 30 seconds of rest. All images were collected on a 1.5 T General Electric (Milwaukee, WI) Signa scanner (GRE EPI, TR: 3000 ms, TE: 50 ms, flip angle: 90º, matrix: 64x64, FOV: 24 cm, slice thickness: 5 mm, 28 axial slices, 95 timepoints) in an interleaved fashion. Chest movement was quantified by a strain gauge respiratory belt (RB) placed around the abdomen. A logic signal tied to the RF pulses from the scanner was also collected for synchronization. The RB data were low-pass filtered to remove unwanted signal caused by the switching of the gradient magnets, and then were processed to determine the actual RB value timecourse for each slice and the timecourse of the average RB value over all slices using the RF logic signal. The functional images were preprocessed using FSL (FMRIB's Software Library). To remove respiratory-related noise from the MR data, both the slice-by-slice and the average RB timecourses were regressed voxel-wise against the preprocessed image set. Individual voxels were considered to possess significant regressions if they had a p-value of < 0.05. Maps of these p-values were created for both the slice-by-slice and average techniques and compared. The number of voxels with significant p-values and adjusted R^2 values (R^2_a,representing model fit) were calculated and used to compare the techniques as well.

Results: Representative images of one slice of a subject’s significant voxels for the slice-by-slice and volume average correction techniques are displayed in Figure 1. The distribution of significant voxels is typical of the other six subjects: the regression was most often significant for the voxels on the outer edge of the brain, within the cerebellum, and within a large cluster in and around the ventricles. The number of significant voxels as a function of the correction technique for each subject is presented in Table 1. When averaged over all subjects, 24% of all brain voxels were found to significantly covary with the slice-by-slice respiratory belt value. The average increase in the number of significant voxels found by slice-by-sclice correction is 188% compared to the average timecourse technique. When compared to the uncorrected data, the slice-by-slice data resulted in an increase in max R^2_a of 57%. The mean R^2_a value also increased in all subjects by an average of 45%.

Discussion: By Table 1 and Figure 1, the superiority of the slice-by-slice technique is clear. The respiration-induced variation in field caused by the lungs has been shown to vary linearly with the distance from the lungs. Forcing a slice’s variation to fit the same form as its neighbors by using an averaged belt value will thus introduce errors, and create a suboptimal correction. In addition, using the average value ignores the fact that the belt value can change drastically across the imaging of one volume since the average respiratory rate of an adult is roughly equal to the TR typically used in FMRI experiments. The use of a slice-by-slice technique does have its challenges, however. The common prepackaged FMRI software programs do not allow the specification of separate models for each slice. Thus, slice-by-slice correction must be performed before GLM analysis with typical prepackaged FMRI software, as was done for this study.

References: 1) Weisskoff et al, 1st Annual Proc Society Mag Reson, 1993; 2) Klose et al, J Mag Reson Imag, 2000; 3) Raj et al, Phys Med Biol, 2000; 4) Corfield et al, J Appl Physio, 1999; 5) Van de Moortele et al, Magn Reson Med, 2002.

Subject	Average Belt Correction Signif Voxels (Number)	Slice-by-Slice Correction Signif Voxels (Number)	Total Number of All Brain Voxels	% Increase of Slice-by-Slice over Average Calculations
1	3360	5573	23915	166 %
2	1554	5137	24204	331 %
3	2515	6176	26548	246 %
4	3478	5677	21332	163 %
5	4671	7317	21062	157 %
6	3137	4678	20513	149 %
7	4028	4207	25550	104 %
Average	3249	5538		188 %

Table 1. Comparison of the number of voxels found to be significant by both the average volume and slice-by-slice techniques

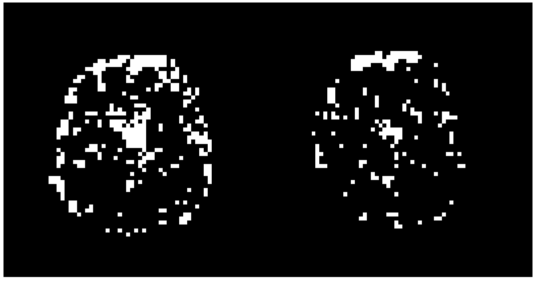

Figure 1. Comparison of the maps of voxels with significant respiratory correlations for both the slice-by-slice (left) and average (right) techniques.