Modified Weisskoff test for assessing fMRI stability

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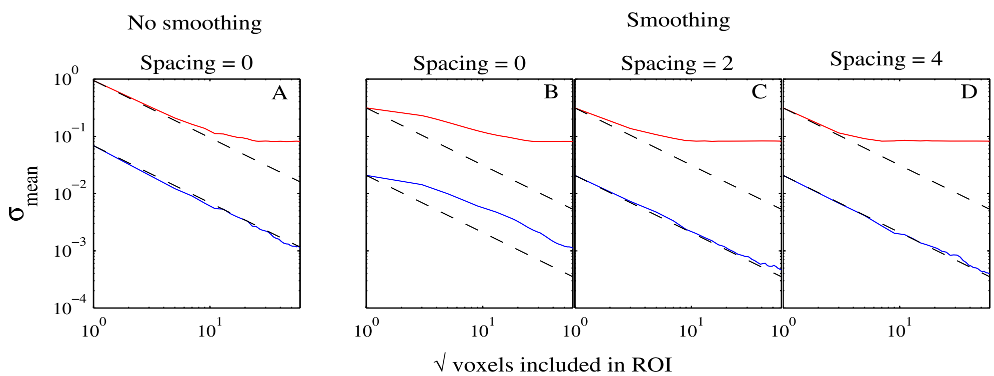
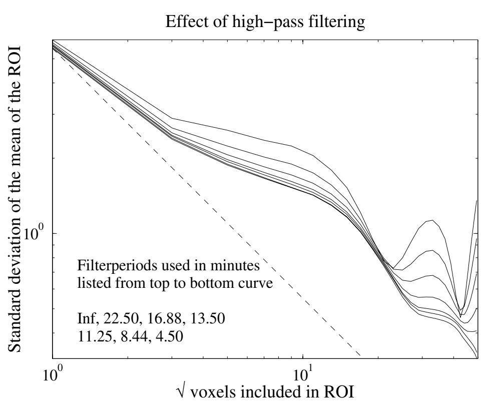
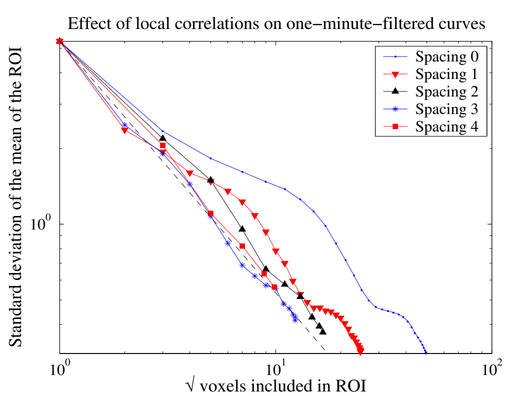
Introduction: In 1996 R.M. Weisskoff [1] proposed a test to measure intrasession scanner instability in fMRI datasets. Since fMRI data consist of relatively long time series, it is plausible that small fluctuations in the hardware over time compromise the fMRI contrast. In the original Weisskoff test, the influence of local voxel correlations is neglected and the test can only be applied to images in which the SNR does not vary with the location of the region of interest. Here the test is adapted such that the latter condition is not necessary anymore. Furthermore it is shown how the test can be used to determine 1) the amount of spatial correlations between voxels and 2) the amount of high-pass filtering needed to remove global fluctuations in fMRI time series.

Theory: The basic principle of the test proposed by Weisskoff is as follows: A small region of interest is selected within a single slice of an image. The relative noise in this ROI is determined by calculating the standard deviation over time of the ROI mean and dividing this by the timeseries mean intensity of the ROI. Then the size of the ROI is increased and the new relative standard deviation of the mean is determined. This process is repeated several times. Basic statistics states that when the number of measurements increases with a factor N, the noise decreases by the square root of N. If the noise does not decrease this fast when increasing the size of the ROI, there apparently is some degree of correlation present between the selected voxels, influencing the noise behavior. The formula used by Weisskoff is: $F_n = \sqrt{\frac{1}{N-1} \cdot \sum_{images,i} (m_i^n - m_{avg}^n)^2} / m_{avg}^n$. Where, F_n is the relative fluctuation of ROI number n, N is the number of images acquired, m^n_i is the mean of ROI number n, in image i and m^n_{avg} is the mean of ROI number n, averaged over all images. The assumption that SNR does not vary with the location of the region of interest did not hold in our case: variations in signal intensity due to an inhomogeneous RF profile caused F_n to fluctuate while the standard deviation of voxel time series showed little correlation with the average voxel intensity. To circumvent this problem we used the formula without the dominator term.

Methods: Both simulated and phantom data were used to study the effect of spatial voxel correlations and high-pass filtering in fMRI like data. The simulated data set consisted of 200 times a single slice of 300x300 voxels with intensity 100. Global intensity fluctuations were added through a sine wave with amplitude 0.1 and a period of 100 timepoints and a trend with a slope of 0.001 per timepoint Random Gaussian noise (average 0, sd 1) was added. Spatial correlations were studied by smoothing the data with a Gaussian filter with a FWHM of 2 voxels. Phantom data were acquired by placing a fluid phantom in the standard T/R head coil of a Philips Intera 3T scanner. EPI time series were acquired with the following parameters: TE=42ms, TR=3s, FOV=400mm, matrix=128, slice thickness=5mm, number of slices=1 and 300 volumes. A second series with 33 slices was acquired to study the effect of the increased demand on scanner hardware. For both simulated and phantom data F_n was plotted against square root of N. The amount of spatial correlation between the voxels was determined by using different region growing algorithms: all started with a single voxel in the center of the image but when more voxels were added different amounts of spacing between the voxels were used. The more spacing the less sensitivity to correlations between the voxels in the image.







Results and discussion: The top figure shows the results for the simulated data sets. The upper curves represent the data without high-pass filtering. The lower curves show the effect of high-pass filtering with a cut-off frequency which removes all added fluctuations. The dotted lines represent the theoretical Weisskoff relation if there is no correlation at all between the voxels and their timeseries. If the data is unsmoothed high-pass filtering is sufficient to let the data match the theoretical line of no correlations at all. For the smoothed data high-pass filtering in combination with a voxel spacing in the region growing algorithm is necessary. The figures at the bottom show the effect of high-pass filtering (left) and voxel spacing (right) on the phantom data. The varying curve shapes in these figures are caused by the fact that there are regions within the phantom where the fluctuations are much larger than elsewhere. As soon as the expanding ROI enters such a region the standard deviation increases again. However, as in the simulated data both high-pass filtering and voxel spacing are necessary to let the data coincidence with the Weisskoff theory. The cut-off period of the high-pass filter was lower when the demand on the scanner increased.

Conclusion: Using an adapted Weisskoff test, the amount of spatial correlations between voxels and the amount of high-pass filtering needed to remove global fluctuations in fMRI time series can be determined.

References: 1) R.M. Weisskoff, MRM 36,643-645 (1996).