# Suppression of Noise in Dynamic Magnetic Resonance Inverse Imaging using Signal-Space Projection

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## INTRODUCTION

Magnetic Resonance Inverse Imaging (InI) is capable of extremely fast data acquisition due to minimal gradient used for spatial encoding [1]. Previously we demonstrated that the high temporal resolution of InI in dynamic functional brain imaging can resolve physiological fluctuations associated with, *e.g.*, cardiac and respiratory cycles. Such physiological processes can confound the detection of functional activations in an fMRI experiments. Here we present the Signal-Space Projection (SSP) method to mitigate this issue. SSP is a spatial filtering technique assuming the noise patterns are uncorrelated with the signal pattern. SSP has been previously employed in magnetoencephalography (MEG), electroencephalography (EEG) [2], and optical imaging [3]. We implemented SSP for event-related fMRI and applied SSP to InI reconstructions in a visual fMRI experiment with a 32-channel head array coil at 3T.

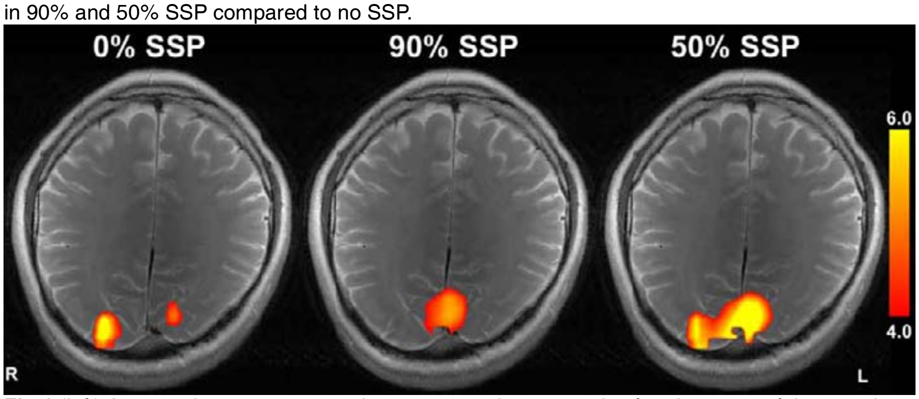
## METHODS

The assumption of noise suppression using Signal Space Projection (SSP) is that the spatial pattern of noise measured in channels of an RF coil array is uncorrelated with the spatial pattern of the signal to be detected. In studies of evoked functional responses, such as event-related fMRI, the characterization of noise spatial pattern can be implemented by concatenating the pre-stimulus baselines of the data $\mathbf{Y_b}$. Here rows of $\mathbf{Y_b}$ represent the time series from different channels in a RF coil, and columns of Y represent the spatial pattern of the pre-stimulus measurement at different time instants. To characterice the noise space, we compute the Singular Value Decomposition (SVD): $\mathbf{Y_b} = \mathbf{USV}^H$, where columns of **U** and V are orthogonal spatial and temporal patterns, respectively, **S** is a diagonal matrix whose elements are the corresponding singular values in decreasing order, and the superscript $^H$ denotes the Herimitian transpose. We select the noise space on the basis of the power spectrum of singular values in **S.** Subsequently, wecreate a projection operator $\mathbf{P} = \mathbf{I} - \mathbf{U}_m{}^*\mathbf{U}_m{}^H$ , where $\mathbf{U}_m$ is contains the first m columns **U** selected to the noise subspace and and **I** is an identity matrix. Noise-suppressed **D**' InI data can then be calculated as **D**' = **PD**, where **D** is the data matrix of InI measurements from all channels (columns) and all time points (rows).

We demonstrated SSP InI in an event-related visual fMRI experiment with 8-Hz checkerboard stimulus. In this experiment, 6-sec pre-stimulus baseline was followed by 2 seconds checkerboard flashing and then 20 seconds of fixation. A total of 40 repetitions were acquired. We used PRESTO sequence [4] to collect ultra-fast MR InI acquisitions with TE=30 ms, TR=20ms, Flip angle=20 degree on a 3T scanner (Trio, SIEMENS Medical Solutions, Erlangen, Germany) using 32-channel head RF coil array [5]. We used the 6 second pre-stimulus interval as the baseline to characterize the noise space. We selected the cut-off value *m* by including singular values until the sum of their squared moduli reached a given fraction, given below in percent, of the sum of the squares of the moduli of all singular values. After SSP, an Ini reconstruction was calculated using the minimum-norm estimate (MNE) approach followed by dynamic statistical parametric mapping (dSPM). Reconstructed data were finally spatially smoothed by a 6-mm Gaussian kernel.

## RESULTS

**Figure 1** shows the InI *t*-statistics maps of dSPM reconstructions using MNE with no SSP, 90% SSP and 50% SSP. The images were overlaid on a high-resolution Turbo-Spin-Echo (TSE) image to illustrate anatomical features. The time-series activation maps were averaged between 6 and 10 seconds after the onset of the stimulus to capture strong functional activation. Strong occipital lobe activations were observed in reconstructions, while 50% SSP provided the largest activation area (1335 $mm^2$). The time courses from the occipital region-of-interest were shown in **Figure 2**. We observed that 50% SSP showed higher longer-lasting activation peaks compared to no SSP and 90% SSP. Smaller pre-stimulus baseline variations were observed in 90% and 50% SSP compared to no SSP.



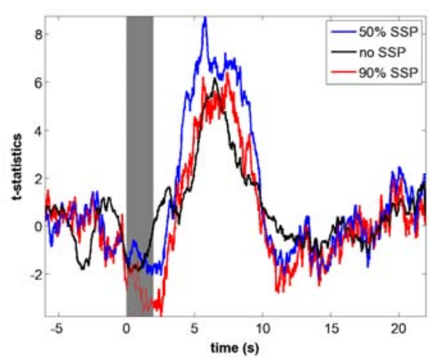




**Fig.1** (left) Averaged *t*-statistics maps between 6 and 10 seconds after the onset of the visual stimulus overlaid on TSE anatomical images
**Fig.2** (right) Time courses of average t-statistics in the occipital ROI

## DISCUSSION

We introduce the Signal Space Projection (SSP) method to suppress noise, particularly that of physiological origin, in InI data. Suppressed pre-stimulus fluctuation baseline after SSP demonstrated its capability to capture spatial noise patterns. If too many dimensions are included in the noise subspace, the detection power may be compromised because the noise and signal subspaces are not any more completely orthogonal. We found that 50% SSP provides a good compromise between suppression of noise and retaining the signal components in InI acquisitions and reconstructions.

## ACKNOWLEDGEMENT

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