Epileptic focus localization using EEG-fMRI fusion

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Introduction

EEG triggered fMRI acquisition [1] and simultaneous EEG-fMRI acquisition [2] are becoming important tools for acquiring fMRI images corresponding to epileptic EEG waveforms (epileptiforms). In this study, we sought a systematic way to combine EEG and fMRI signals for epileptiform localization. To this end, we decomposed simultaneously acquired EEG and fMRI signals into their respective spatial and temporal patterns using singular decomposition (SVD), and combined them to obtain an estimate of the underlying brain activities in the form of a lattice of current dipoles.

Method

EEG data E and fMRI data F are represented by 2D matrices (collapsing three spatial dimensions into one), with columns representing spatial patterns and rows representing temporal patterns. An underlying current magnitude S has an fMRI spatial dimension and an EEG temporal dimension. EEG and fMRI forward equations can be written as follows.

$$E = COS \equiv AS, \quad F = SB \qquad \text{(1)-(2)}$$

In these equations, the current orientation matrix O is a diagonal tensor each of whose component is a 3D unit matrix representing the orientation perpendicular to cortical surfaces. The spatial filter C is computed according to [3] and the temporal filter B is computed from a hemodynamic response function, for which we used a Gamma function [4] with λ=9 seconds. These simple linear forms are amenable to a variety of analyses. For instance, it can be shown that the minimal norm form of (1) and (2) becomes a form known as a Sylvester equation. Here we show a different approach using the SVD. The SVD decomposes a spatiotemporal matrix into pairs of spatial and temporal singular vectors. The first step of the current method is to expand the data and coefficient matrices so that data matrices become zero-centered in spatial and temporal directions. Then the SVD of E and F is performed. Writing the SVD of S as LDR,

$$S = LDR, \quad E = ALDR = L_E D_E R_E, \quad F = LDRB = L_F D_F R_F . \qquad \text{(3)-(5)}$$

It is assumed that important temporal patterns in R are also captured in R_E from the EEG and important spatial patterns in L are also captured in L_F from fMRI. Then the problem of estimating S becomes the problem of finding best matching pairs of temporal vectors r_{Ei} (rows in R_E) and spatial vectors l_{Fj} (colums in L_F) and computing D. A match between r_{Ei} and l_{Fj} is computed from the similarity between l_{Ei} (colums in L_E) and Al_{Fj}, the similarity between r_{Fj} (rows in R_F) and $r_{Ei}B$, and associated singular values in D_E and D_F. Note that vectors Al_{Fj} are fMRI spatial patterns multiplied by the EEG spatial filter, and vectors $r_{Ei}B$ are EEG time courses multiplied by the fMRI temporal filter. After pairs are selected, D is computed to minimize error norms in the forward equations.

This method was applied to a data collected from an epileptic patient for epileptic focus localization. The fMRI parameters were:3T (Siemens Trio), EPI bold, TR=1.5 second, TE=30 milliseconds. The EEG data was recorded from 32 electrodes and was sampled at 500 Hz (Neuroscan Maglink / NuAmp). Two series of spikes (ten or more spikes) were observed during three, 11 minute runs. One of the series of spikes was chosen for analysis, and the 12 seconds of EEG and fMRI data were fused using the above method.

Results

Figure 1 shows an initial part of the EEG data, including recordings from four electrodes and two temporal singular vectors corresponding to the second and the third singular values of the estimated underlying activities. The first component was omitted because it corresponded to the average waveforms among electrodes. Figure 2 shows spatial singular vectors corresponding to the second and the third singular values of the estimated brain activities. It can be seen that the second component corresponds to a later superior medial frontal activity, and the third component corresponds to an initial posterior inferior temporal activity.

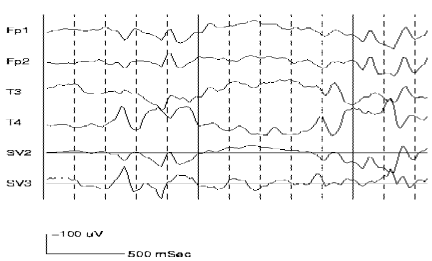

Figure 1. Some EEG data and temporal singular vectors

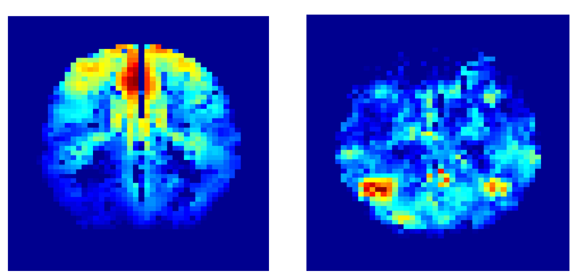

Figure 2. The second (left) and the third (right) spatial singular vectors

Conclusion

A method for EEG-fMRI data fusion has been presented and its application to epileptic focus localization. Application of SVD facilitates localization of fMRI activity corresponding to particular EEG time-courses.

References

[1] Warach S, Ives JR, Schlaug G, Patel MR, Darby DG, Thangaraj V, Edelman RR, Schomer DL. *Neurology* 1996; **47** (1):89-93.
[2] Lemieux L, Salek-Haddadi A, Josephs O, Allen P, Toms N, Scott C, Krakow K, Turner R, Fish D. *Neuroimage* 2001;**14**(3):780-7.
[3] Ary JP, Klein SA, Fender DH. *IEEE Trans Biomed Eng* 1981, **BME-28**:6, 447-452.
[4] Friston KJ, Jezzard P, Turner R. *Hum Brain Mapp* 1994, **1**, 153-171.