

Spatial & Temporal Independent Component Analysis of fMRI Data with Two Task-Related Waveforms

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Introduction

Independent Component Analysis (ICA) attempts to separate data into maximally independent groups in space or time, yielding spatial-ICA (SICA) (1) and temporal-ICA (TICA) (2) respectively. SICA has so far dominated the application of ICA to fMRI. The objective of these experiments was to apply both SICA and TICA to data with two predictable components present and to compare the results with those obtained using regression analysis.

Methods

Experimental Procedures

Four novel visual paradigms were designed, each consisting of two spatiotemporal components which were either spatially dependent, temporally dependent, both spatially and temporally dependent, or spatially and temporally uncorrelated, respectively. Two pairs of temporal waveforms were created, one pair that were uncorrelated (correlation = 0.0), and one pair that were highly correlated (correlation = 0.82) (see figure 1). An 8 Hz reversing checkerboard pattern with a spatial frequency of 1 cycle/degree was presented to different portions of the visual field: Stimulating the left or right visual field created spatially independent (non-overlapping) regions. Stimulating the right visual field or the entire visual field created overlapping regions (in which the contrast of the checkerboard pattern was increased). The temporal patterns were achieved by switching between the presentation of the spatial pattern (checkerboard) and a dark screen. Sketches of the paradigms are presented here.

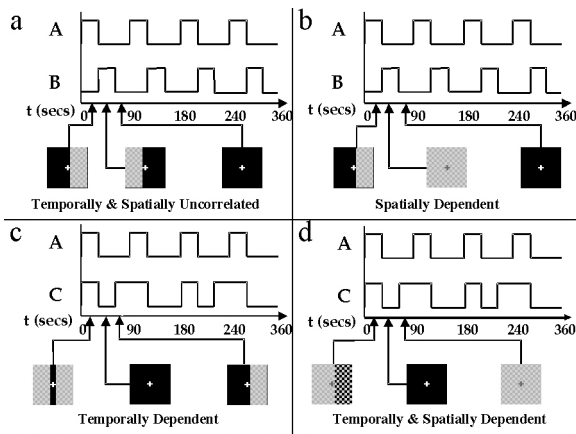


Figure 1. Schematic of four visual paradigms, each containing two spatio-temporal components (see text for details).

Five normal subjects were studied. All human studies were approved by the Institutional Review Board of Johns Hopkins University. BOLD fMRI data were acquired in a 1.5 Tesla Gyroscan NT PT-6000 (Philips Medical Systems) following acquisition of anatomic scans: Single-shot gradient-echo echo-planar (EPI) data (TR=1s, TE=39ms, FOV=24cm, matrix=64 x 64, FA=90 degrees, 9 slices, slice thickness=5mm, gap=0.5mm) were acquired over a 6-minute period for each of the four paradigms.

Data Analysis

The images were corrected for timing differences between slices (3,4). Next the data were imported into the Statistical Parametric Mapping (SPM99, Wellcome Department of Cognitive Neurology) under Matlab. Data were coregistered to a mean image, spatially smoothed (6x6x10 mm Gaussian kernel), spatially normalized into a standard space (5), and resampled to 3x3x4 mm voxels.

Regression Analysis

A linear model was constructed using the pairs of ideal time-signals (see waveforms in figure 1) convolved with a canonical hemodynamic response function. A high-pass (drift removal) filter was incorporated. The data were then regressed onto the model allowing for varying hemodynamic latencies in different brain areas (6).

Independent Component Analysis

Data were pre-whitened and reduced in dimension to twenty components (~99% of non-zero eigenvalues retained) using principle components analysis (PCA), after which ICA was performed. For the SICA analysis, all voxels inside the brain were used. For the TICA analysis, a smaller block of voxels including the visual cortex was used, to reduce computational demands. In both cases, ICA was performed using a fixed-point algorithm (7).

Results

Regression analysis (8) of data resulting from these novel paradigms yielded spatiotemporal components in good agreement with the paradigm design. SICA and TICA results were mixed: In all cases the algorithms either detected the two signals that were expected, detected only one of the two signals, or detected one or two components that were combinations of the expected signals. ICA performed well (detected both expected components) when expected (e.g., SICA "worked" when components were spatially independent) and "failed" (did not separate the two components) otherwise.

A comparison of the results from one subject, for the paradigm containing spatially and temporally independent signals, is presented here. The time courses from the ICA analyses are plotted along with the regressors used for regression analysis.

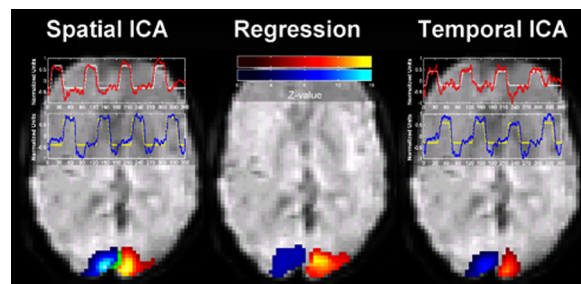


Figure 2. Single-subject results for the paradigm containing spatially and temporally independent components, analyzed using spatial ICA, regression, and temporal ICA.

Discussion

These data demonstrate that SICA and TICA can have diverging results, depending upon the characteristics of the underlying signals to be estimated: When the assumption of spatial or temporal independence is strongly violated, then ICA results do not agree with regression.

Regression analysis proved a useful way to analyze these data, because for this study strong hypotheses were available for primary visual areas. Such hypotheses will not always be available, and in fMRI a strength of ICA is that it can characterize data without making specific modeling assumptions. However, ICA is not completely free of assumptions and, as we have demonstrated, in certain situations the correct signals may be obtained only if the correct choice (between spatial and temporal independence) is made. In conclusion, the choice of spatial- or temporal- ICA should best be made with the knowledge of whether a given paradigm may reasonably be expected to be subserved by either spatially- or temporally- independent neuronal components.

References

1. Bell AJ, and Sejnowski TJ. *Neural Comput* 7:1129 (1995); McKeown MJ, et al., *Proc Natl Acad Sci USA* 95:803 (1998); McKeown MJ, et al. *Hum Brain Map* 6:160 (1998).
2. Biswal BB, Ulmer JL *J Comp Asst Tomog* 23:265 (1999).
3. van de Moortele PF, et al. *NMR Biomed* 10:230 (1997).
4. Calhoun V, Golay X, and Pearlson G. *Proc. ISMRM, 9th Ann. Mtg* 2000.
5. Talairach J, Tournoux P. *A co-planar stereotaxic atlas of a human brain*. Thieme, Stuttgart. 1998.
6. Calhoun V, Adali T, Kraut M, and Pearlson G. *Magn Reson Med*, In Press, 2000.
7. Hyvarinen A, and Oja E. *Neural Comp* 9:1483 (1997).
8. Worsley KJ, and Friston KJ. *NeuroImage* 2:173 (1995).