Is My Correlation of Biological Origin?

Daniel B. Rowe, Ph.D.

Associate Professor
Department of Mathematics, Statistics, and Computer Science

Adjunct Associate Professor
Department of Biophysics

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Outline:

1. Biological Associations
   - Between Brain Regions
   - Within Brain Regions
   - Physiological Signals

2. Induced Correlation
   - Within Slice Local Correlation
   - Within Slice Distant Correlation
   - Between Slice Distant Correlation
   - Temporal Correlation

3. Discussion
1. Biological Associations: Between Discovered

Biological association between regions of brain have been seen.
1. Biological Associations: Between Discovered

Functional Connectivity in the Motor Cortex of Resting Human Brain Using Echo-Planar MRI

Bharat Biswal, F. Zerrin Yetkin, Victor M. Haughton, James S. Hyde


From the Biophysics Research Institute
Medical College of Wisconsin,
Milwaukee, Wisconsin

FIG. 3. (Left) FMRI task-activation response to bilateral left and right finger movement, superimposed on a GRASS anatomic image. (Right) Fluctuation response using the methods of this paper. See text for assignment of labeled regions. Red is positive correlation, and yellow is negative.
1. Biological Associations: Within Applied

Biological Associations within regions have been used to detect Neurological Disease.
1. Biological Associations: Within Applied

Alzheimer Disease: Evaluation of a Functional MR Imaging Index as a Marker

COSLOF = \frac{2}{K(K-1)} \sum_{i,j=1, i\neq j}^{K} c_{ij}

1 From the Biophysics Research Institute
Medical College of Wisconsin, Milwaukee, WI

Shi-Jiang Li, PhD
Zhu Li, MD
Gaohong Wu, PhD
Mei-Jie Zhang, PhD
Malgorzata Franczak, MD
Piero G. Antuono, MD
1. Biological Associations: Physiological Signals

It has been noticed that there are physiological signals that need to be subtracted.
1. Biological Associations: Physiological Signals

Image-Based Method for Retrospective Correction of Physiological Motion Effects in fMRI: RETROICOR

Gary H. Glover,¹* Tie-Qiang Li,¹ and David Ress²

¹Department of Radiology, Stanford University School of Medicine, Center for Advanced MR Technology at Stanford, Stanford, California.

Separating respiratory-variation-related fluctuations from neuronal-activity-related fluctuations in fMRI

Rasmus M. Birn,* Jason B. Diamond, Monica A. Smith, and Peter A. Bandettini

Laboratory of Brain and Cognition, National Institute of Mental Health, NIH, 10 Center Dr., Bldg. 10, Rm. 1D80 Bethesda, MD 20892-1148, USA
2. Induced Correlation:

It has been noticed that the data has an intrinsic correlation and is spatially dependent.
2. Induced Correlation: Within Local

Reducing inter-scanner variability of activation in a multicenter fMRI study: Role of smoothness equalization

Lee Friedman, a,* Gary H. Glover, b Diana Krenz, c and Vince Magnotta d
The FIRST BIRN 1

In summary, we have described important scanner differences in activation effect size and smoothness that will affect the results of multicenter fMRI studies. Vendor differences in image smoothness were documented and are likely due to differences in k-space filtering regimes. We have shown that smoothness equalization can reduce scanner differences in activation effect size within a field strength and also reduce the field strength effect on activation effect size.
2. Induced Correlation: Within Local

Integrated Local Correlation: A New Measure of Local Coherence in fMRI Data

Gopikrishna Deshpande, Stephen LaConte, Scott Peltier, and Xiaoping Hu

WHC Department of Biomedical Engineering, Georgia Institute of Technology and Emory University, Atlanta, Georgia

Mean spatial correlation functions. Left: brain tissue. Right: EPI phantom.
2. Induced Correlation: Within

Evaluating fMRI Preprocessing Pipelines

Review of Preprocessing Steps for BOLD fMRI
IEEE ENGINEERING IN MEDICINE AND BIOLOGY MAGAZINE  MARCH/APRIL 2006

The preprocessing steps interact with virtually every decision made in designing and performing an fMRI experiment.

Empirical Evaluation of Preprocessing.
2. Induced Correlation:

Efforts to precisely mathematically quantify the effects of processing.
2. Induced Correlation:

Signal at $t$

$$S(t) = \int\int_{-\infty}^{+\infty} \int\int_{-\infty}^{+\infty} \rho(x, y)e^{-i\gamma\Delta B(x, y)t} e^{-i2\pi(k_x x + k_y y)} dx dy$$

where $k_x(t) = \frac{\gamma}{2\pi} \int_0^t G_x(\tau)d\tau$ and $k_y(t) = \frac{\gamma}{2\pi} \int_0^t G_y(\tau)d\tau$ are known.

By changing $G_x$ and $G_y$ over time . . . we cover $k$-space.

Adapted from Haacke et al., 1999.
2. Induced Correlation: Representation

Signal and noise of Fourier reconstructed fMRI data

Daniel B. Rowe\textsuperscript{a, b}, *, Andrew S. Neenka\textsuperscript{a}, Raymond G. Hoffmann\textsuperscript{b}

\textsuperscript{a} Department of Biophysics, Medical College of Wisconsin, Milwaukee, WI, USA

\textsuperscript{b} Division of Biostatistics, Medical College of Wisconsin, Milwaukee, WI, USA

\[(\Omega_{yR} + i \Omega_{yI}) \times (S_R + i S_I) \times (\Omega_{xR} + i \Omega_{xI})^T = (V_R + i V_I)\]
2. Induced Correlation: Representation

\[
(\Omega_{yR} + i \Omega_{yI}) \times (S_R + i S_I) \times (\Omega_{xR} + i \Omega_{xI})^T = (V_R + i V_I)
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2. Induced Correlation: Representation

Signal and noise of Fourier reconstructed fMRI data

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\textsuperscript{a} Department of Biophysics, Medical College of Wisconsin, Milwaukee, WI, USA
\textsuperscript{b} Division of Biostatistics, Medical College of Wisconsin, Milwaukee, WI, USA

If $E(s) = s_0$

and

$\text{cov}(s) = \Gamma$

then if

$y = \Omega s$,

$E(y) = \Omega s_0$

and

$\text{cov}(y) = \Omega \Gamma \Omega'$.

$\Omega \sigma^2 I \Omega' = \frac{\sigma^2}{P_x P_y} I$

Now we can do statistics!
2. Induced Correlation: Data Processing

Apodization  Zero-filling  Homodyne  IFT and permute  Phase shift rows

\[ OS = A \quad F \quad H \quad P_{R}^{-1} \quad \Omega_{\text{row}}^{-1} \quad \Phi \]

\[ \Omega_{\text{row}} \quad P_{R} \quad P_{C} \quad R \quad C \]

FT each line  Re then Im each row  Segregate Re and Im  Reverse alternating lines  Censor

And there are MANY more!
2. Induced Correlation: Representation

\[
\text{cor}(y) = \begin{bmatrix}
    & & & & \\
    & & & & \\
    & & & & \\
    & & & & \\
    & & & & \\
\end{bmatrix}
\]

5x5 image

5x5 correlation matrix

5x5 correlation image

D.B. Rowe, Ph.D.
2. Induced Correlation: Within Local

A Mathematical Model for Understanding the Statistical effects of k-space (AMMUST-k) preprocessing on observed voxel measurements in fMRI and fMRI

Andrew S. Nencka\textsuperscript{a}, Andrew D. Hahn\textsuperscript{a}, Daniel B. Rowe\textsuperscript{a,b,*}

\textsuperscript{a} Department of Biophysics, Medical College of Wisconsin, Milwaukee, WI, USA
\textsuperscript{b} Division of Biostatistics, Medical College of Wisconsin, Milwaukee, WI, USA

\[ y = S_m \Omega_a \Phi H P_R^{-1} \Phi_{row} P_R P_C RCS \]

\[ y = OS \]

\[ E(y) = OS_0 \]

\[ \text{cov}(y) = O \Gamma O' \]

\[ \text{cor}(y) = D^{-1/2} O \Gamma O' D^{-1/2} \]

smoothing

processing & reconstruction

spatial frequencies
2. Induced Correlation: Within Distant

A statistical examination of SENSE image reconstruction via an isomorphism representation

Iain P. Bruce\textsuperscript{a}, M. Muge Karaman\textsuperscript{a}, Daniel B. Rowe\textsuperscript{a, b, *}

\textsuperscript{a}Department of Mathematics, Statistics, and Computer Science, Marquette University, Milwaukee, WI 53201, USA
\textsuperscript{b}Department of Biophysics, Medical College of Wisconsin, Milwaukee, WI 53226, USA

For each voxel: \[ y = (S'\Psi^{-1}S)^{-1}S'\Psi^{-1}a = ua \]
\[ \nu = P_U U \]

\[ = P_U \]

Images can insert processing on unfolded image vector

\[ P_{CS} \]

permute to by folded voxel

\[ \Omega \]

reconstruct \( N_c = 4 \) images

\[ s \]

\( k \)-space vector of \( N_c \) images

D.B. Rowe, Ph.D.

Bruce, Karaman, Rowe: MRI, 1267-1287, 2011.
2. Induced Correlation: Within Distant

A statistical examination of SENSE image reconstruction via an isomorphism representation

Iain P. Bruce\textsuperscript{a}, M. Muge Karaman\textsuperscript{a}, Daniel B. Rowe\textsuperscript{a, b, *}

\[
y = O_I P U P_S P_C (I_{nC} \otimes \Omega) O_K s
\]

\(O\) \quad processing & reconstruction

\(O_t = S_m\)

\[
\Sigma = \text{cov}(y) = O\Gamma O'
\]
2. Induced Correlation: Within Distant

GRAPPA: Submitted Unpublished Results

Iain P. Bruce¹ and Daniel B. Rowe¹,²
¹Marquette University, ²Medical College of Wisconsin

\[ y = O_I C(I_n \otimes \Omega O_K) P_{C2} P_{G2} G P_{G1} P_{C1} s \]

\[ y = O_s \]

\[ \Sigma = \text{cov}(y) = O \Gamma O' \]

\[ O_I = S_m \]

\[ O \leftarrow \text{processing & reconstruction} \]

k-space vectors for all voxels
2. Induced Correlation: Between

Separation of Two Simultaneously Encoded Slices with a Single Coil

Daniel B. Rowe¹ ², Andrew S. Nencka², Andrzej Jesmanowicz², and James S. Hyde²

¹Department of Mathematics, Statistics, and Computer Science, Marquette University

\[
\begin{pmatrix}
    y_R \\
    y_I
\end{pmatrix} =
\begin{pmatrix}
    1 & 0 & 1 & 0 \\
    0 & 1 & 0 & 1
\end{pmatrix}
\begin{pmatrix}
    \rho_1 \cos \theta_1 \\
    \rho_1 \sin \theta_1 \\
    \rho_2 \cos \theta_2 \\
    \rho_2 \sin \theta_2
\end{pmatrix} +
\begin{pmatrix}
    \epsilon_R \\
    \epsilon_I
\end{pmatrix}
\]

Aliased Image  Aliasing Matrix  True Unaliased Images


Multiband
2. Induced Correlation: Between

Rowe, Jesmanowicz, Bruce, Hyde, Nencka
In Submission, 2013.

\[ \text{cov}(y) = \Sigma \]

\[
\Sigma = \frac{\sigma^2}{4} \begin{pmatrix}
1 & 0 & 1 & 0 \\
0 & 1 & 0 & 1 \\
1 & 0 & 1 & 0 \\
0 & 1 & 0 & 1
\end{pmatrix}
\]
2. Induced Correlation: Temporal

\[ \nu_T = \text{IRK} * S_T \]

\[ \nu_1 \text{ image 1 vector} \]

\[ \nu_n \text{ image } n \text{ vector} \]

\[ \begin{bmatrix} O_{I1} & \Omega_{a1} & O_{k1} & 0 \\
0 & \Omega_{\nu} & O_{In} & 0 \\
0 & 0 & O_{kn} & \Omega_{an} \end{bmatrix} \]
2. Induced Correlation: Temporal

\[ y_T = T \]

\[ y_1 \]

\[ P \]

\[ v_T \]

\[ \cdots \]

\[ v_1 \]

\[ \cdots \]

\[ v_n \]

\[ y_p \]

\[ y_T \]

\[ y_1 \]

\[ y_p \]

\[ P_1 \]

\[ P_p \]

\[ O_{T1} \]

\[ P \]

\[ v_T \]

\[ \cdots \]

\[ v_1 \]

\[ \cdots \]

\[ v_n \]

\[ O_{Tn} \]

ordered by voxel

D.B. Rowe, Ph.D.

Karaman, Nencka, Rowe: In Progress.
2. Induced Correlation: Temporal

TEMPORAL PROCESSING OF FMRI DATA INDUCES FUNCTIONAL CORRELATIONS AND POTENTIALLY ALTERS FUNCTIONAL ACTIVATIONS

M. Muge Karahan¹, Andrew S. Neacka², and Daniel B. Rowe¹²

¹Department of Mathematics, Statistics, and Computer Science, Marquette University, Milwaukee, WI, United States, ²Department of Biophysics, Medical College of Wisconsin, Milwaukee, WI, United States

\[ s_T = (s'_1, \ldots, s'_n)' \]
\[ y_T = O_T s_T \]
\[ O_T = TIRK \]
\[ E(s_T) = s_{T0} \]
\[ \text{cov}(s_T) = \Gamma \]
\[ E(y_T) = O_T s_{T0} \]
\[ \Sigma = O_T \Gamma O_T' \]
3. Discussion

Neuroscientists rely upon Statisticians to model and analyze their data.

Statisticians aim for a model that best describes the data.

Statisticians get data that is processed without their knowledge.

The results and interpretations are confounded by induced correlations that are of no biological origin.

The preprocessing needs to be characterized and accounted for when making biological interpretations.

We should model and analyze the original data that we measure, not a processed version of our data.