Comparisons Between Effective and Functional Connectivity in fMRI

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Introduction

Functional MRI (fMRI) can be used to determine activation in multiple brain regions and explain causal relationships or connectivity between neural systems. Effective connectivity, which is typically determined while a subject performs a task, and functional connectivity, which is assessed during resting scans, are two techniques used to evaluate brain networks. Three subjects were studied with both methods to explore the relationship between cortical areas activated during a simple motor task. This preliminary data suggests that although connectivity indices are derived from different image sets and analyses, there exists a relationship between these two measurements.

Methods

Data was acquired from three subjects with no motor deficits. Two fMRI scans (GE 1.5T, TR=2000ms, TE=60ms, matrix=64 X 64, $\alpha = 90^0$, phases=200, slice thickness=7mm/1mm gap, FOV=24cm) were acquired, one during rest and one consisting of alternating blocks where the subject performed self-paced finger tapping with their dominant hand versus rest (40 seconds each). Both data sets were motion corrected with SPM99 [1]. Finger tapping data was also spatially and temporally filtered using Brain Voyager (Brain Innovation, Maastricht, The Netherlands). Regions of interest (ROIs) were identified during the finger tapping scan using a maximum correlation to detect supplementary motor area (SMA), primary motor cortex (MC) and ipsilateral cerebellum (CER).

For effective connectivity, an average time course from each ROI extracted from the finger tapping scan was Z-score normalized and divided into sets of either rest or tapping. These two sets of observations were used to evaluate the effective connectivity between the regions in different states. The sets were segregated based on the full-width half max of the hemodynamic response function used to determine activation in each region.

Effective connectivity for the unidirectional linear model SMA ➔ MC ➔ CER was assessed using the structural equation modeling (SEM) software LISREL (Scientific Software International, Lincolnwood, IL). A unidirectional model was used to ensure mathematically robust estimates of connection strength. Path coefficients, an indicator of effective connectivity, were calculated using observations from both conditions (tapping vs. resting). Significant differences between the model coefficients were determined using a χ^2 difference test [2,3].

For functional connectivity, the ROIs were registered to the resting scan and the time courses for each pixel in each region was extracted. Using IDL software (Research Systems, Inc., Boulder, CO), the time course of each pixel was low pass filtered at a cutoff frequency of 0.08 Hz using a fifth order Butterworth filter in order to remove cardiac and respiratory fluctuations [4]. The correlation coefficient of every pixel in one region of interest with every pixel in another region of interest was then calculated. To reduce all of the correlations to one parameter per connection of interest, the mean correlation coefficient was determined and used as an indicator of functional connectivity.

Results

The columns in the table at the right indicate path coefficients for the effective connectivity model during the tapping condition (ECt), the effective connectivity model during the resting condition (ECr), and an index for functional connectivity (FC) for all three subjects. The asterisks indicate significant differences between different paths within the same subject, and the crosses indicate significant differences between the same paths during different conditions in the same subject.

The results indicate:

- EC coefficients tend to be higher during task performance vs. rest.
- Subject 1 EC coefficients from MC➔CER were significantly smaller than SMA➔MC, a result which was also indicated in the FC index.
- Subjects 2 & 3 did not show significant differences between SMA➔MC and MC➔CER in either EC or FC.

	ECt	ECr	FC
Subject 1			
SMA ==> MC	0.80	0.73	0.12
MC ==> CER	0.53*	0.50*	0.04
Subject 2			
SMA ==> MC	0.84	0.74+	0.10
MC ==> CER	0.88	0.82	0.14
Subject 3			
SMA ==> MC	0.66	0.41+	0.14
MC ==> CER	0.69	0.64	0.10

Conclusions

The results suggest that effective connectivity measured during a task and functional connectivity measured during rest in fMRI show similar relative results within the same subject. Other models will be evaluated with an expanded data set to further elucidate the relationship between these effective and functional connectivity methods.

[1] http://www.fil.ion.ucl.ac.uk/spm/spm99.html
[2] McIntosh & Gonzalez-Lima. *Human Brain Mapping*. 2:2-22, 1994.
[3] Raykov & Marcoulides. *A First Course in Structural Equation Modeling*. Lawrence Erlbaum, 2000.
[4] Lowe MJ, et al. 1998. *Neuroimage* **7**:119-132.