Evaluation of Effective Connectivity in the Visual System using fMRI

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Introduction

Images acquired using functional magnetic resonance imaging (fMRI) encompass multiple brain regions. From the resulting blood-oxygen level dependent (BOLD) signals, it possible not only to quantify physiologic activity in a single region (i.e. functional segregation) but also to look for statistical dependencies between BOLD signals arising from different spatial regions and, thereby, infer causal influences among different neural systems. This latter approach is defined in fMRI as effective connectivity [1]. Effective connectivity was explored in the visual system using a path analysis model. The human visual system is organized in a parallel and hierarchical fashion, making it ideal for evaluating connectivity models with fMRI. In the work summarized here, we explored the connectivity from primary visual cortex (V1) to dorsal V2 (dV2) and dV2 to MT, a cortical area known to contain neurons sensitive to motion.

Methods

Data was acquired from three subjects with normal vision in all respects. For two of the three data sets, three fMRI runs were acquired, including one retinotopic mapping experiment (TR=2000ms, TE=30ms, $\alpha=70^o$, 15 slices/5mm thick, 132 phases) that consisted of a flashing checkerboard wedge rotating around a fixation point, and two MT localizer experiments (same parameters as above with 128 phases) consisting of alternating blocks where the subject viewed stationary versus radially moving dots. For the third subject, only one of the latter runs was acquired. Data was initially processed using Brain Voyager (Brain Innovation, Maastricht, The Netherlands). The retinotopic mapping runs were spatially and temporally filtered and then spatially normalized in Talairach space. Volumes of interest (VOIs) for areas V1 and dV2 were determined using retinotopic analysis methods [2]. The MT localizer runs were also filtered and spatially normalized in Talairach space. Visual area MT was localized on the latter runs by correlating a hemodynamic response function with epochs of viewing stationary versus radially moving dots. An average time course in area MT from voxels that met the correlation activation criteria $p < 2.3e\text{-}017$ (uncorrected) was acquired from the left and right hemisphere MT regions. For the third subject, only the right MT area was localized. Using the VOIs determined from the retinotopic mapping experiment, an average time course from areas V1 and dV2 was also determined from the MT localizer runs.

The averaged time course data from V1, dV2 and MT were Z-score normalized, combined (for the first two subjects) and divided into sets consisting of time points where activity was present in MT when the subject viewed radially moving dots versus little or no activity in MT when the subjects viewed stationary dots. These two sets of observations were used to evaluate the effective connectivity between the visual regions during the two different states.

Effective connectivity for the unidirectional linear model V1 ➔ dV2 ➔ MT was assessed using 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 were calculated for both hemispheres (except subject three) using observations from both visual conditions (viewing stationary vs. moving dots). Significant differences between the model coefficients were determined using a χ^2 difference test [3,4].

Results

Path coefficients for each model are indicated in the table below. S indicates subject number and LH/RH indicates left/right hemisphere. Asterisks indicate significant differences between corresponding coefficients determined using both models. Note that in all three subjects, dV2 ➔ MT connectivity increased in all hemispheres when subjects viewed moving stimuli versus stationary stimuli. This result was significant in both hemispheres of subject two and one hemisphere of subject one. Also note that in two subjects, V1 ➔ dV2 connectivity was higher when subjects viewed stationary stimuli. This result was significant in three of four hemispheres.

Stationary Stimuli

	V1 → V2	V2 → MT
S1, LH	0.36	-0.09
S1, RH	0.52	-0.06
S2, LH	0.55	0.43
S2, RH	0.58	0.23
S3, RH	0.55	0.47

Radially moving stimuli

	V1 → V2	V2 → MT
S1, LH	0.21*	0.13*
S1, RH	0.43	0.07
S2, LH	0.43*	0.57*
S2, RH	0.15*	0.40*
S3, RH	0.58	0.53

Conclusions

Using time course data acquired during fMRI and SEM, effective connectivity was shown to exist between areas V1, dV2 and MT in the visual cortex. These results are consistent with what is known about the anatomic connections among these areas [5], providing some validation of our procedures. Other multi-directional and non-linear models will be evaluated with this data set to better determine reliable models for effective connectivity studies in the visual system using fMRI.

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