<u>Weekend Educational Course Syllabus</u>

Session: **Introduction to Functional MRI**
Title of Talk: **Analyzing Data Using the General Linear Model**
Date/Time: Saturday, **30 May 2015, 1620-1650**
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Highlights

• Definition of a general linear model (GLM) and why it is useful in analyzing fMRI data
• How to construct a design matrix that also models other sources of variance (noise)
• Assumptions and limitations behind GLM analyses
• Scientific and ethical considerations on the presentation and interpretation of results

Target Audience

• Grad students, postdocs, and staff scientists who are familiar with the general concepts of fMRI but have little to no experience analyzing fMRI data.

Outcome

• After this talk, the target audience will know how to design and implement a GLM to analyze blood oxygenation level dependent (BOLD) fMRI data.

Purpose

• The GLM is commonly used to analyze fMRI data. However, its ease of use may obscure some of the underlying assumptions, which may results in suboptimal or opaque results. Therefore, it is important to know how to properly construct and implement a GLM analysis.

Methods

• As a starting point, simulated fMRI data of increasing complexity will be used to demonstrate the strengths and weaknesses of the GLM, and illustrate how to construct a design matrix of sufficient complexity to account for potential sources of variance.
• Once the basics have been discussed, a GLM analysis of real fMRI data will be performed.

Results

• A design matrix of appropriate complexity (one that considers task-related signal changes while accounting for multiple noise sources) is necessary to produce results that accurately reflect signal changes of interest (in both spatial location and amplitude/significance).
• Displaying the results of a GLM analysis (i.e., "activation maps") should control for type I and type II errors appropriately.

Discussion

- An interpretation of the results depends upon the analysis performed, so an important question to consider is: "How do the results change if the design matrix is changed?" A careful reanalysis of the data with changes to the original design matrix may reveal new insights into the data.
- *If an apparently minor change in the design matrix creates a significant change in the results, then this is important and should not be ignored*. The revised analysis may have revealed something new and interesting about the data, or perhaps there was an error in one of the design matrices. Either way, this observation is important and must be thoroughly investigated.

Conclusions

- Data analysis is extremely important – it starts at the scanner when data are being acquired (real-time data quality assurance), and can even continue after a manuscript has been published (as an example, note the 1994 paper listed in the References and its two follow-up papers).
- fMRI data should be analyzed in a thoughtful and careful manner, and sufficient details of the analysis methods should be clearly described in any submitted manuscript (the reviewers will appreciate it, even if they don't say it).

References (Note: this list highlights a few of the first papers to analyze fMRI data via a GLM, and represents a good starting point to learn more about GLMs. This list is by no means exhaustive as there are now ~~hundreds~~ thousands of papers that have analyzed a plethora of fMRI data using GLMs.)

- Friston, K. J., Jezzard, P., & Turner, R. (1994). Analysis of functional MRI time-series. Human Brain Mapping, 1, 153–171.
- Friston, K. J., Holmes, A. P., Poline, J. B., Grasby, P. J., Williams, S. C., Frackowiak, R. S., & Turner, R. (1995). Analysis of fMRI time-series revisited. NeuroImage, 2(1), 45–53.
- Friston, K. J., Frith, C. D., Turner, R., & Frackowiak, R. S. (1995). Characterizing evoked hemodynamics with fMRI. NeuroImage, 2(2), 157–165.
- Friston, K. J., Frith, C. D., Frackowiak, R. S., & Turner, R. (1995). Characterizing dynamic brain responses with fMRI: a multivariate approach. NeuroImage, 2(2), 166–172.
- Worsley, K. J., & Friston, K. J. (1995). Analysis of fMRI time-series revisited--again. NeuroImage, 2(3), 173–181.
- Worsley, K. J., Poline, J. B., Vandal, A. C., & Friston, K. J. (1995). Tests for distributed, nonfocal brain activations. NeuroImage, 2(3), 183–194.