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Individual differences in cognitive performance: relation to brain structure and function

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Lab Link

Laboratory of Working Memory and Cognition

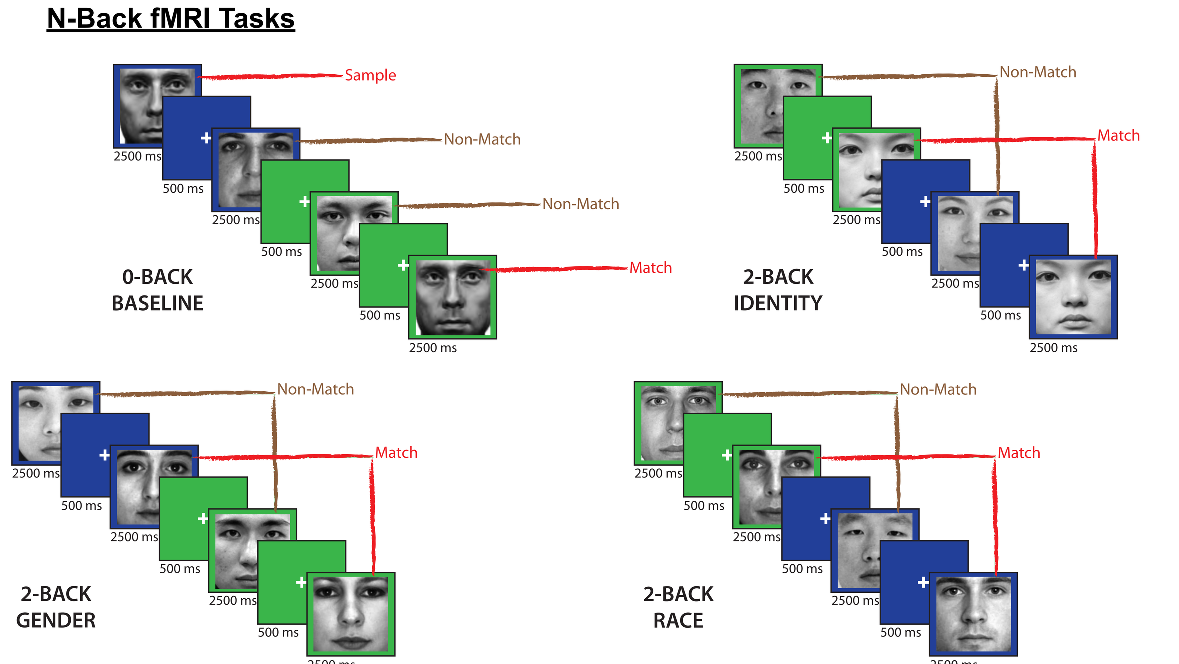
Background and Aims

- Functional neuroimaging and electrophysiological data have shown that working memory and other high-level cognitive tasks are mediated by sustained activity in frontal and posterior association cortices, as well as functional connectivity between these regions.
- Previous work has also suggested a relationship between object & spatial working memory performance and individual differences in the strength of long-range fronto-posterior white matter connections, even among healthy control subjects (Klingberg, 2006; Walsh et al., 2011).
- The aims of this study were to extend these findings by using a combination of neuropsychological testing, fMRI, and DTI, and employing:

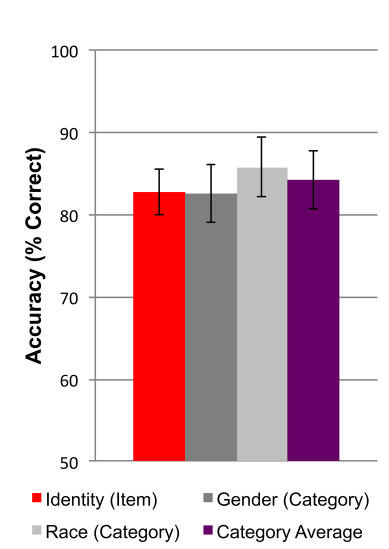
  1) different working memory tasks for items and categories,
  2) verbal working memory tasks,
  3) more specific white matter parcelations,
  4) new measures to assess tract-based microstructure, and
  5) alternative ways to control for non-tract specific changes.

Working Memory Tasks

N-Back fMRI Tasks

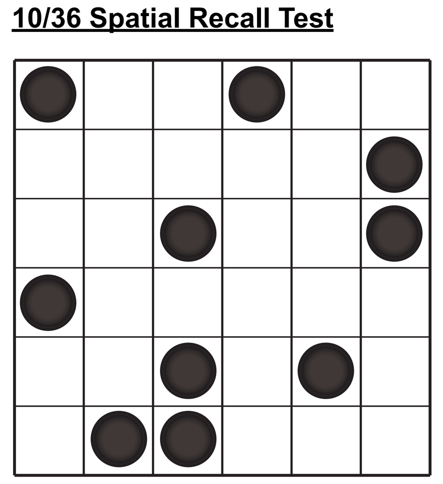


Item and Category Working Memory Tasks (performed inside the scanner)

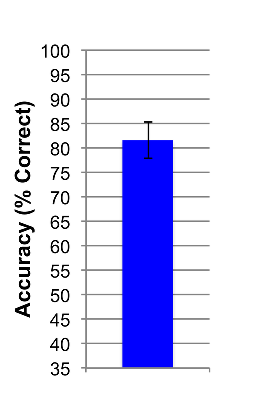


10/36 Spatial Recall Test

Spatial Working Memory Task (performed outside the scanner)



Pattern is displayed for only 10 seconds, and then the subject tries to replicate it (repeated a total of three times)

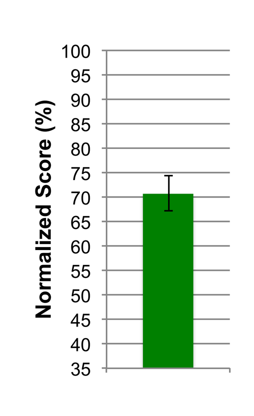


Selective Reminding Test

Verbal Working Memory Task (performed outside the scanner)

1. Direction
2. Memory
3. Owner
4. Mountain
5. Victim
6. City
7. Victory
8. Dream
9. Hotel
10. Wife
11. Virtue
12. Slave

Slowly read the entire list of words, and then have the subject repeat as many of them as possible. Remind them ONLY of the words that they missed before having them recall the ENTIRE list (repeated a total of six times).



Note: All error bars indicate standard error

fMRI and DTI Methods

25 healthy subjects (10 male; 28.2 ± 9.6 years) scanned at 3T

Acquisition Parameters

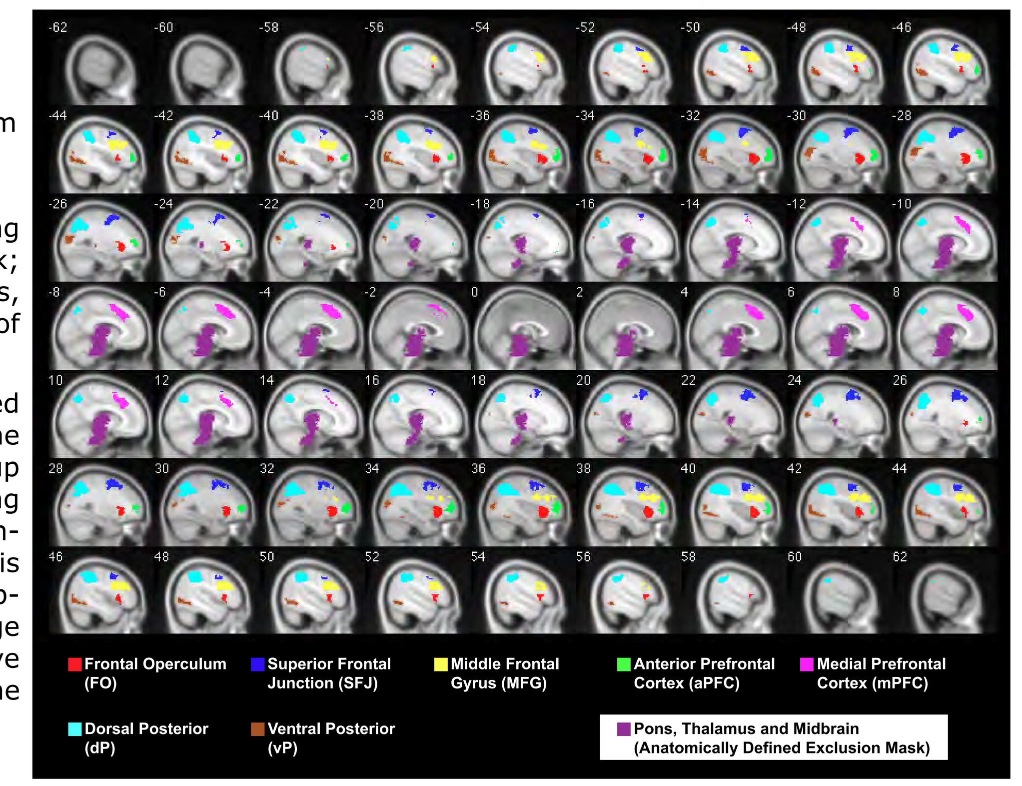
fMRI: GE-EPI; TE=30ms; TR=2s; 2.5mm x 2.5mm x 2.5mm

DTI: SE-EPI; b=700s/mm²; 30 directions; 2.2mm x 2.2mm x 2.2mm

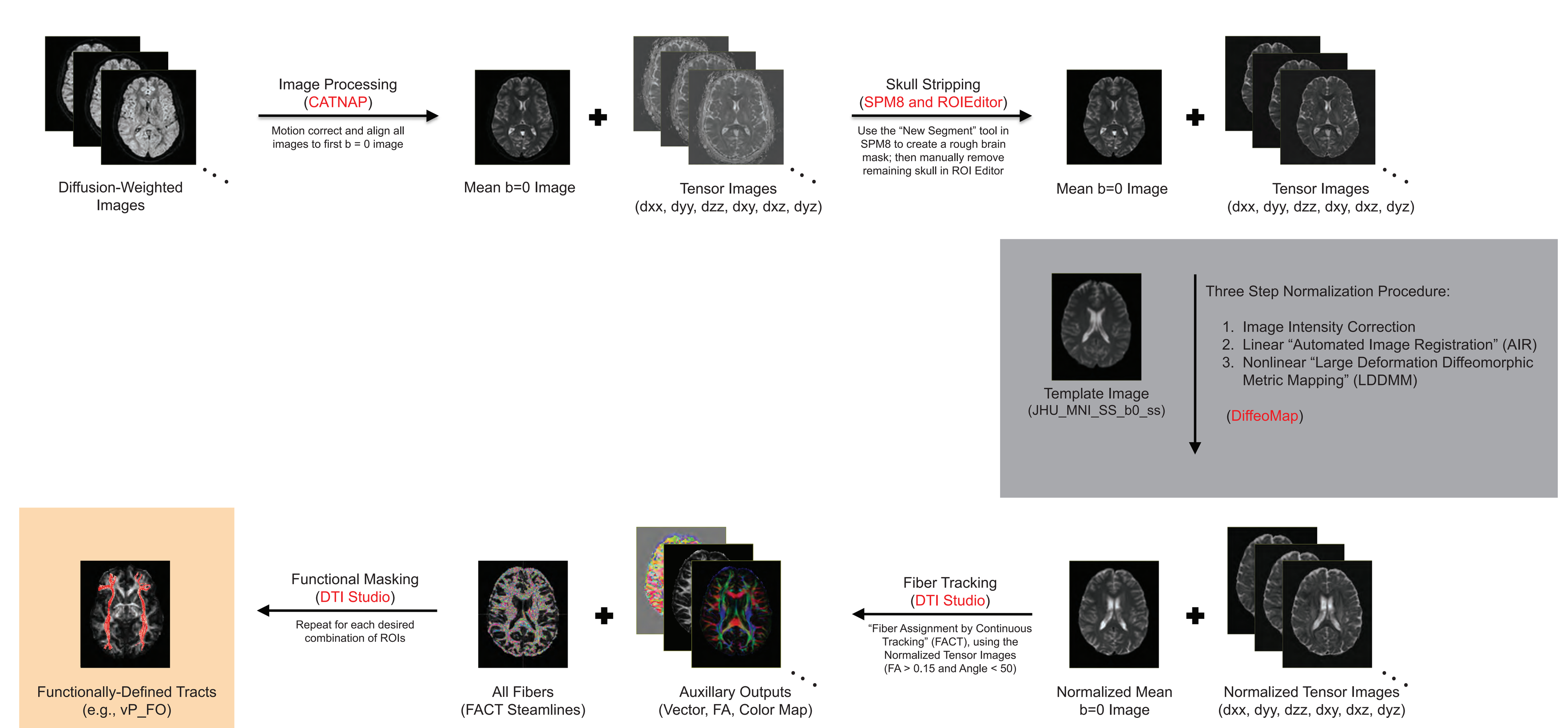
Analysis Pipeline

fMRI: Group data were first analyzed to create a mask of working memory regions (i.e., Item OR Race OR Gender 2-Back > 0-Back; p_{FDR}=0.005). This mask was then segmented into 2 posterior regions, 5 prefrontal regions, and an anatomical exclusion mask consisting of the pons, thalamus and midbrain **[Figure on Right]**.

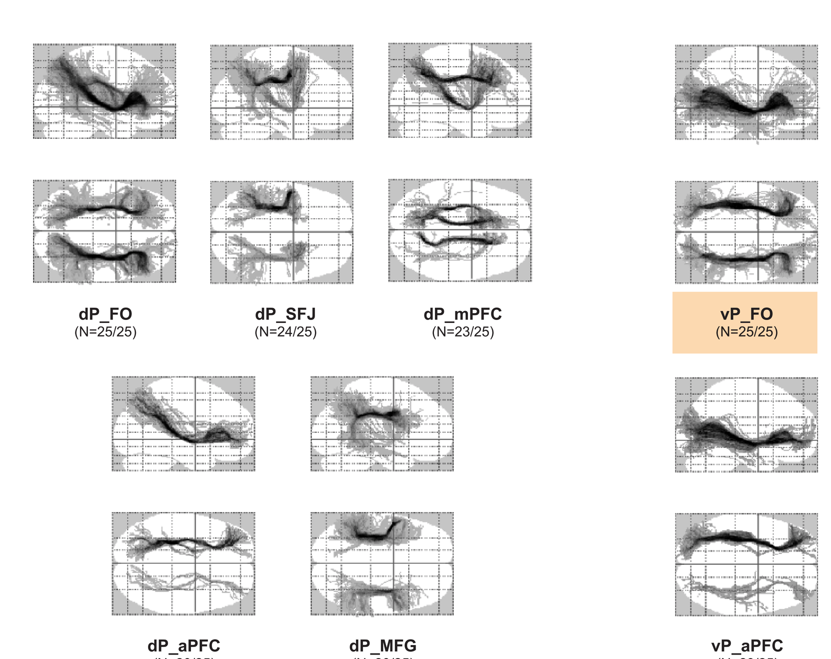
DTI: Individual subject data were first preprocessed and normalized before performing deterministic tractography between each of the posterior and prefrontal masks (i.e., 10 tracts per subject). Group probabilistic masks were then generated for each tract by averaging the relevant subject masks. Finally, probability-weighted fractional anisotropy (FA) values were extracted along the anterior/posterior axis of each of the group masks to create a quantitative curve for each subject. This allowed each subject's FA data to be: 1) fit to the average curve (minus the subject in question), 2) fit to the maximum curve (i.e., the highest FA across subjects), and 3) analyzed to compare the area under the individual vs. maximum curve **[Figure Below]**.



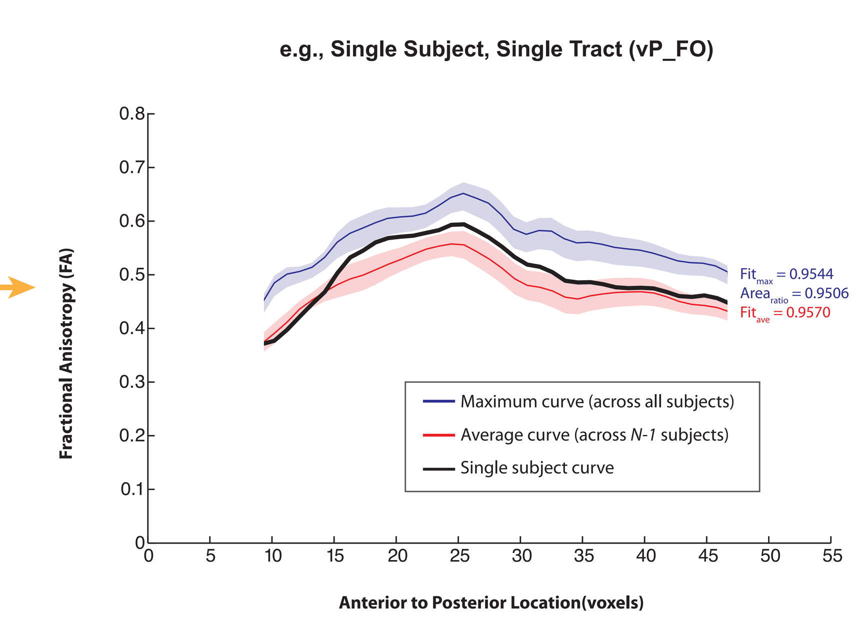
DTI Processing (repeated for each subject)



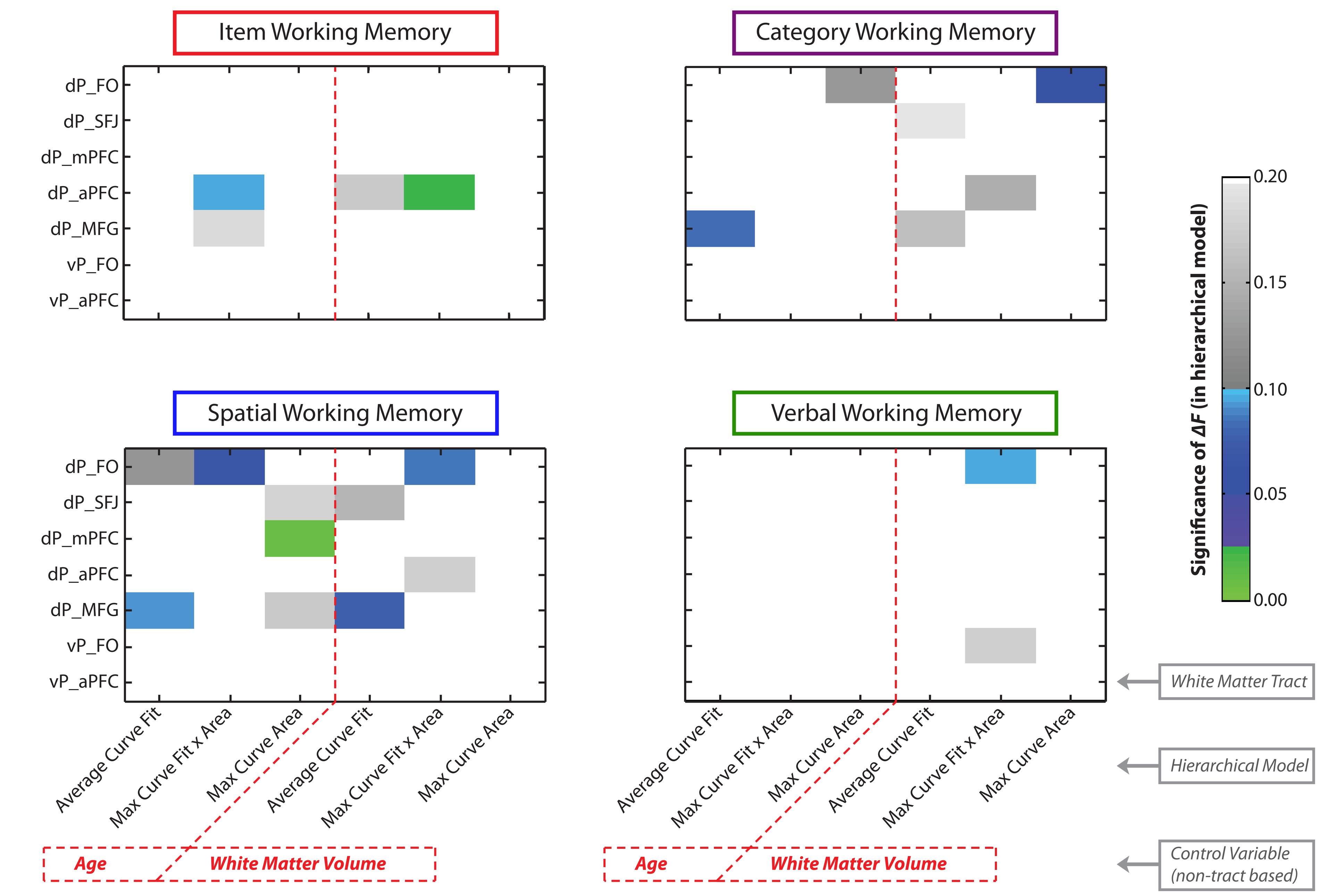
Probabilistic DTI Masks (from all subjects)



Quantitative Curve Fitting (repeat for all subjects/tracts)



Results and Discussion



- Based on our analyses, individual differences in white matter microstructure appear to be at least moderately predictive of working memory performance for items, spatial locations, and perhaps categories, but not necessarily for verbal working memory. This effect seems to be related almost exclusively to connections between the prefrontal and parietal cortices (as opposed to more ventral posterior regions).
- The most consistent results, across both white matter tracts and hierarchical models, were found for the spatial working memory task. These findings tend to support previous claims that spatial working memory is correlated with long-range fronto-posterior white matter connectivity (Klingberg, 2006; Walsh et al., 2011).
- Our results also show that the choice of analysis method has a major influence on the outcome of the hierarchical models, both in terms of the:

  1) tract-based changes (i.e., correlating subject curves with either the average curve or the maximum curves, and whether curve-fitting and/or area measures are used), and
  2) non-tract based changes (i.e., using age or total white matter volume as covariates).

- Although the relationship between these tract-based methods and individual differences in cognitive performance are admittedly modest, the fact that they show correlations among healthy subjects bodes well for future patient studies (e.g., Multiple Sclerosis), where a greater distribution of cognitive performance and tract-based structural measures would be expected.

Thanks for stopping by. If you have any questions or comments, please email me at cfigley@jhu.edu

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