Functional Magnetic Resonance Imaging & Diffusion Tensor Imaging: Applications and Promise for Developmental Research

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Noninvasive *In-Vivo* Imaging Methods

- Magnetic Resonance Imaging
- Functional Magnetic Resonance Imaging
- Diffusion Tensor Imaging

Promise for Cognitive Development- Examine the neural processes that underlie cognitive change in order to better understand the mechanics of cognitive development.
I. MRI - Brain Development

Figure 3. Regional growth of cortical gray matter ($n = 74$). There is a significant overall regional difference in slopes (inhomogeneity of slopes $F_{(3,248)} = 8.6, p < 0.0001$). There were significant differences between occipital and prefrontal ($F_{(1,289)} = 18.9, p < 0.0001$), occipital and frontal ($F_{(1,289)} = 5.8, p = 0.0166$), and parietal and prefrontal ($F_{(1,289)} = 17.8, p < 0.0001$) matter growth rates.

Gilmore et al., 2007

Gogtay et al., 2004

Motor and sensory systems involved in vision, motor response, audition.

Parietal and temporal association cortices support basic language skills and spatial attention.

Prefrontal and lateral temporal cortices integrate primary sensorimotor processes and modulate attention/language processes.
I. MRI - Brain Development

II. Can we examine whether these changes are experience driven or dependent on a predefined maturational program?
BOLD signal - Blood Oxygenation Level Dependent (BOLD) signal

↑ neural activity ➔ ↑ blood oxygen ➔ ↑ fMRI signal

(Logothetis et al. 2001)
II. Elucidating Brain/Behavior Relationships

FMRI provides a means by which to measure within-task change in behavior and neural activity as a function of experience i.e., learning, as well as how these interactions dynamically change across development.
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In both views, changes in connectivity between neural structures are as important as grey matter change in this view. This allows us to conceptualize the brain as a plastic evolving entity.
MRI technique for in-vivo characterization of 3D white matter microstructure.

DTI measures change in the microstructure of white matter based on properties of water diffusion. Diffusion of water in white matter tracts is constrained by myelin and the orientation and regularity of fibers.

Developmental Considerations

- Safety
- Performance differences between adults and children
- Informed Consent/Compliance - Acquisition
- Anatomical variability across development - Analysis
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Developmental Considerations: Informed Consent

Also helps with motion artifact and acclimates child to noise level to be expected.
Anatomical and functional variability exist, but are “small” after transformation of pediatric and adult brains into the same stereotactic space.

Comparison of primary sulcus location and general brain shape in children and adults.

Kang, Burgund, Lugar, Petersen, & Schlaggar (2003)
II. Converging Methods and Cognitive Development: What is the goal?

- Ultimately, it depends on your question. The real challenge is to use these techniques to allow brain to constrain behavior and theory.

- They should add a biological plausibility piece to what we think is happening and when used most effectively, they should shed light on issues that have been empirically elusive with behavioral data alone.
Thanks
Fig. 2. Bivariate scatterplot of the relationship of FA values for the bilateral average of left and right ACR (in red) and left SCR (in blue) to (a) Word ID and (b) Digit Recall. When correlated with Word ID (a), there exists a significant correlation in the SCR ($R^2 = 0.41, p = 0.001$) but an insignificant correlation with the ACR ($R^2 = 0.02, p = 0.48$). When correlated with Digit Recall (b) there exists a significant correlation in the ACR ($R^2 = 0.42, p < 0.001$) but an insignificant correlation with the SCR ($R^2 = 0.02, p = 0.43$).

Fig. 4. Fiber tractography of the (a) left SCR and (b) ACR. The red prism indicates a volume of interest defining the seed voxels. As seen here, the SCR contains primarily fiber tracts that run in the superior-inferior direction while the ACR contains fibers that run anterior-posterior in the frontal region of the brain. The white matter integrity of the fiber tracts of the left SCR correlate significantly with reading performance. White matter integrity of the fiber tracts of the ACR bilaterally correlate significantly with working memory. As seen here, the two white matter bundles are not connected and show specific relationships to different domains of cognitive ability.
**Figure 1.** fMRI study of infants’ speech processing. fMRI activation obtained in awake three-month-old infants listening to blocks of 20 s of normal (forward) or reversed (backward) speech relative to activity during silence are projected onto a 3D image (a) and axial slices (b) of a three-month-old human brain. From left to right the slices are taken from progressively more dorsal levels, and the front is to the top in each case. The color scales indicate the value of the z-score assessing the significance of the studied contrast (backward speech versus silence, forward speech versus silence, forward versus backward speech) in a random-effect group analysis at $P < 0.01$ corrected for voxel extent. Activation in response to forward speech (blue scale) occurred in superior temporal regions of the brain that are dorsal and posterior to areas activated by backward speech (orange scale). However, the regions significantly more activated by forward than by backward speech are the left inferior parietal region and the right dorsolateral prefrontal regions (blue-pink scale). This figure illustrates the complex cooperation between temporal, parietal and frontal regions in the recognition of native language (forward speech). Adapted from Ref. [61].
Figure 1: Top view of the streamline clusters on the whole brain. Streamlines within the same cluster share the same color. From the picture, the cingulum bundles can be easily identified in two clusters. Neural fibers along the corpus callosum are clustered into coherent bundles. Some of the U-fibers also form clusters.

Post-hoc grouping of participants on the basis of their performance (Schlaggar et al., 2002)

Parametric manipulations of task difficulty to identify where children and adults are performing equivalently. Only useful if task difficulty increases monotonically (Durston et al., 2002)