Developmental fMRI Changes Associated with Relational Reasoning

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Introduction: Models of human intelligence have distinguished crystallized knowledge from fluid reasoning abilities, with a rising trend in fluid reasoning over the past 100 years which may be linked to changes in math education that emphasize instruction of fluid cognitive functions and working memory[1]. We hypothesized that increases in fluid and relational reasoning during development results from sculpting of prefrontal-parietal neural networks associated with working memory, executive functions, and visual perceptual analytical abilities[2,3]. fMRI studies were undertaken to investigate the dynamic changes in brain activity in these neural regions while typical children and adolescents solved relational reasoning problems.

Methods:

Human Subjects Sixteen normal healthy children and adolescents (8-19 years of age) were studied. All subjects and parents of the subjects under 18 years old gave informed written consent prior to participation. Out of magnet cognitive tests showed average to above average levels of general intellect, math, reading, and attentional abilities for the sample.

Cognitive fMRI Task During fMRI scanning on a Philips 3T magnet, participants completed relational reasoning problems through a pair of LCD goggles. The paradigm includes alternating baseline (pattern matching, 78 s) and experimental (pattern solving, 78 s) trials 3 times (see Figure 1 for examples). Responses were recorded through a 2-button (left, right) handheld device. A series of T_2*-weighted EPI images (TR / TE / FA = 3000 ms / 35 ms / 90º, 25 5-cm-thick axial slices with no gap between slices, FOV = 23 ×23 cm^2, matrix = 80 ×80, 177 repetitions) were obtained for functional data acquisition.

Data processing and analysis Images were processed using SPM2 software. Brain activations associated with the pattern matching (baseline) task were subtracted from the experimental pattern solving task, isolating cognitive processes of relational reasoning. Average activation maps and regression analysis of negative and positive age effects were computed.

Results: Average activation maps showed significant brain activity in a network of interconnected structures including the occipital-parietal cortex bilaterally, the occipital-temporal cortex bilaterally, and the prefrontal and anterior cingulate cortices. Age regression analysis showed that the left and right superior parietal regions became progressively more active with developmental age ($R^2 = 0.52$ and 0.49, $p < .002$, respectively), while multiple frontal cortical, cingulate and basal ganglia areas became progressively less active with developmental age (R^2 range 0.44 to 0.70, $p < .006$). Figure 2 shows the specific clusters and age regression curves for the left superior parietal cortex and right cingulum.

Discussion: Average activation maps across the developmental sample indicated that significant brain activity occurred during relational reasoning in a network of structures including the occipital-parietal cortices (functionally associated with visuospatial perception and knowledge), the occipital-temporal cortex bilaterally (functionally associated with visual pattern perception), and the prefrontal and anterior cingulate (functionally associated with working memory, relational reasoning, conflict resolution, and decision-making). These regions are strongly interconnected cortical association areas often implicated in higher cognitive processing. Age regression analyses revealed an increasing role for the superior parietal cortices in relational reasoning abilities with developmental age, and a decreasing role for prefrontal, anterior cingulate, and subcortical brain regions. Younger children appear to work harder and engage more widespread neural networks while solving relational reasoning tasks, but become more efficient and focal in brain activation with increasing knowledge, experience and expertise.

References:

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3. Waltz JA, et al. *Psychological Science* 10: 119-125, 1999.

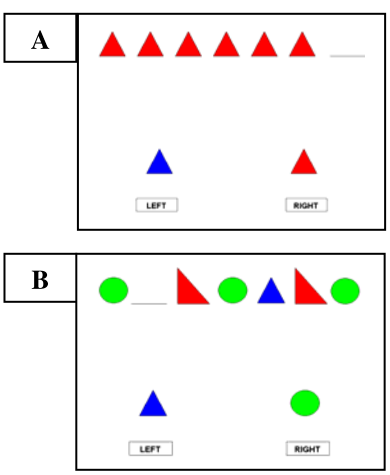

Figure 1. Examples of baseline pattern matching (A) and experimental pattern solving (B) problems.

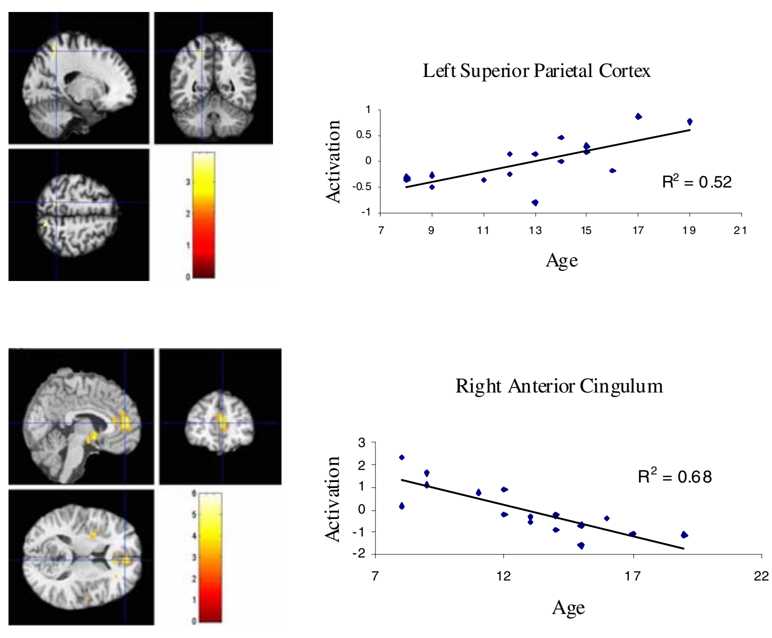

Figure 2. Regression analyses showed a strong positive correlation between increasing age and left superior parietal cortex activity and a significant negative correlation between increasing age and right anterior cingulum activity during the relational reasoning task.