Differences between Boys and Girls in the Correlation of Functional Brain Connectivity and Intelligence

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Introduction

Recent volumetric MRI [1] and magnetic resonance spectroscopy (MRS) studies [2] have shown disparities between adult men and women in the neuroanatomical correlates of intelligence. To investigate the neuroanatomical bases for intelligence in children we used the functional MRI (fMRI) paradigm of silent verb generation. A data-driven analysis technique was used to investigate developmental aspects and sex differences in the association of functional connectivity with intelligence.

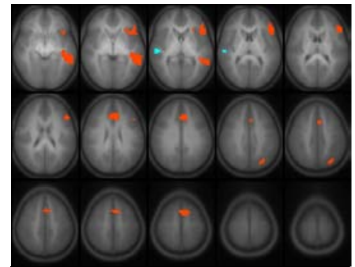

Figure 1. Regions with positive (red) or negative (blue) correlations of functional activation from silent verb generation with Full-Scale IQ (corrected $p < 0.05$).

Materials and Methods

Three hundred twenty-three children (156 boys, 167 girls) took part in the study using a Bruker 3T Medspec imaging system. EPI-fMRI scan parameters were: TR/TE = 3000/38 ms; BW = 125 kHz; FOV = 25.6 X 25.6 cm; matrix = 64 X 64; slice thickness = 5 mm. The fMRI paradigm consisted of a silent verb generation task detailed in [3]. A 30 second on-off block design was used. During the active epochs, the subjects silently generated appropriate verbs, such as “throw” or “kick”, to aurally-presented nouns such as “ball”. During the control epochs, subjects tapped their fingers when they heard a warble tone, designed to control for sublexical auditory processing. The General Linear Model (GLM) was used to analyze the data in order to find regions of activation associated with full-scale IQ (FSIQ). A within-group random-effects analysis was used to find all voxels activated by the task ($p <$ 1e-10, uncorrected). The fMRI activation intensities in those voxels were then correlated with FSIQ, with subject age (in months) included as a covariate. A data-driven analysis investigating brain functional connectivity was then performed in the following manner. For the five regions (Figure 1) with a positive correlation of BOLD activation with FSIQ in the left hemisphere (Broca’s area, medial temporal gyrus (MTG), cingulate, precuneus, and medial frontal gyrus (MFG)), ROIs were drawn around the activated regions, and the average time extracted from each subject for each ROI. For each subject, a connectivity coefficient *CC* was defined as a weighted sum of the pairwise covariances between regions: $CC_j = \sum_i W_i R_{ij}^2 \frac{R_{ij}}{|R_{ij}|}, W_i \geq 0$ where CC_j is the connectivity coefficient for the *j*th subject, R_{ij} is the correlation coefficient for the *i*th pairwise connection between regions for the *j*th subject, and W_i is a (positive-definite) weighting of each pairwise connection. The CC values were then analyzed using a three-way ANCOVA with the independent variables of FSIQ, subject age, and gender; the weights were optimized to maximize the T-score of the regression parameters from the ANCOVA for the FSIQ-X-gender-X-age interaction. To find the null distribution a Monte Carlo simulation was used, selecting the regression parameters for the ANCOVA from a random Gaussian distribution.

Results and Discussion

A network was found with a significant FSIQ-X-gender-X-age interaction (Figure 2; top). The T-score of the regression parameter was significant when compared to the null distribution (T = 3.26, $p < 0.025$). Separating out the data between boys and girls, binarizing the variable of age, and maximizing the age-X-FSIQ interactions as a function of cutoff age yielded a transitional age of 102 months for boys and 155 months for girls. Correlating the FSIQ for each subgroup with the CC (Figure 2; bottom), covarying for age, the association of connectivity with IQ is strong in boys under 9 (partial R = 0.52, $p < 0.005$), but diminishes thereafter (partial R = -0.11, NS), while the reverse effect is seen in girls; there is no association of connectivity with IQ for girls under 13 (partial R = 0.07, NS), but as girls mature connectivity becomes increasingly important (partial R = 0.36, $p < 0.002$). For boys age 13 and over (Figure 2), functional connectivity even becomes anti-correlated with IQ (partial R = -0.3, p = 0.03). There are four outlying data points in the young boys but the effect is still significant using a non-parametric test (Spearman’s R = 0.41, $p <$ 0.02) after removing age effects via stepwise regression. Previous studies support a greater dependence on functional connectivity in adult women for cognitive function as compared to adult men. Men appear to have more neurons and neuronal density relative to women, who exhibit a reciprocal increase in neuronal processes [4, 5]. We hypothesize that the transitional ages seen are related to the developmental trajectories of gray matter proliferation and pruning [6, 7], and the “growth-spurt” observed in girls from approximately age 8 through the early teen years [8].

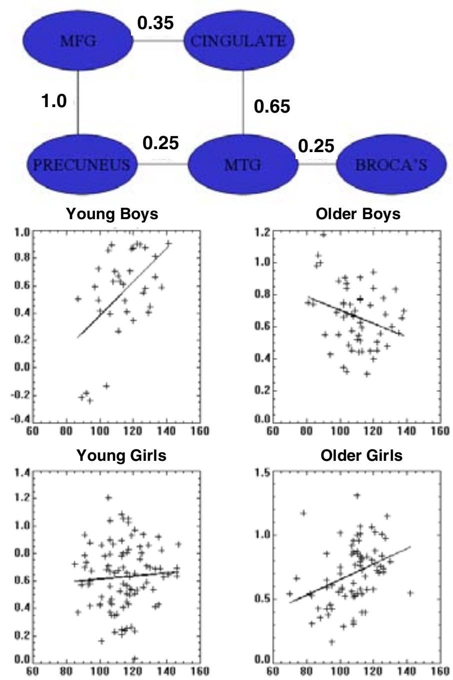

Figure 2. Functional network displaying a significant age-X-gender-X-IQ interaction effect (top; numbers represent relative connection strengths). Plots (bottom) of connectivity coefficients (vertical axes) vs. full-scale IQ (horizontal axes) for young (< 155 months) girls, older (> 155 months) girls, young (< 102 months) boys, and older (> 155 months) boys.

Conclusion

The neuroanatomical bases of intelligence in children were investigated using the fMRI paradigm of silent verb generation. The functional connectivity between the regions exhibiting a significant correlation between IQ and BOLD activation also displayed a significant gender-X-IQ-X-age interaction. The results indicate differing developmental trajectories between the sexes in the maturational processes related to intelligence.

References

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