Transitive Reasoning and Developmental Changes in Parietal Cortex

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Abstract

This study utilizes voxel-based morphometry to examine the neural basis of developmental changes in transitive reasoning in parietal regions. Two groups of participants (young adolescents and adults) performed a transitive reasoning task, subsequent to undergoing anatomical MRI brain scans. Behaviorally, adults performed better on the transitive reasoning task than the young adolescents. Grey matter analysis of their brains showed the expected thinning/pruning of grey matter in BA 7 and a significantly greater correlation between the performance of the adults and grey matter density than the performance of adolescents and grey matter density in this area. These results support the idea that developmental anatomical changes in parietal cortex facilitate developmental changes in transitive reasoning.

Keywords: transitive reasoning; VBM; parietal cortex; development

Introduction

Relational reasoning is the ability to consider and manipulate relationships between multiple mental representations, and has been shown to improve throughout childhood and adolescence (Ferrer, O'Hare, & Bunge, 2009). One important manifestation of relational reasoning is transitive inference, that is, the process of examining and comparing a number of relational pairs in order to understand overall group hierarchy (e.g. Ralph is braver than Celia, Tim is braver than Ralph; therefore Tim is braver than Celia). A number of neuroimaging studies, and at least one patient study indicate that the parietal lobes, in particular Brodmann area 7 (BA7) and Brodmann area 40 (BA40), play a critical role in transitive inference in adult populations (Goel, 2007; Goel & Dolan, 2001; Goel, Makale, & Grafman, 2004; Prado, Chadha, & Booth, 2011; Waechter, Goel, Raymont, Kruger, & Grafman, 2013).

We undertook a Voxel-Based Morphometry (VBM) study to track developmental changes in grey matter density in parietal cortex and its correlation with performance in transitive reasoning tasks in adolescent and adult populations. Based upon previous research on relational reasoning in the developmental literature (Ferrer, et al., 2009), we expected to find improved performance in transitive inference in the adult group. Given the consistent activation of parietal cortex reported in a number of imaging studies on transitive reasoning (see above), we expected that the behavioural changes would be associated with neuroanatomical changes in BA 7 and BA 40.

Methods

Participants

Two groups of participants took part in the experiment. The first group consisted of young adolescents with an age range of 11 years and 2 months to 16 years (N=35, 18 male, 17 female). The second group consisted of adults with an age range of 20 years and 1 months to 24 years and 4 months (N=41, 22 male, 19 female).

Stimuli

Twenty three-term relational arguments were generated (e.g. premise1: 'the stapler is inside the drawer'; premise 2: 'the staples are inside the stapler'; conclusion: 'the staples are inside the drawer'). Arguments were presented randomly on a computer screen. The beginning of every trial was signaled by a fixation cross in the middle of the screen. The sentences appeared on the screen one at a time with the first sentence appearing at 1 s, the second at 4 s, and the last sentence at 7 s. All sentences remained on the screen until the end of the trial. Subjects had 24 s after the presentation of the third sentence to respond. The response button triggered the following trial.

Task

Subjects were required to determine whether the given conclusion followed logically from the premises (i.e. whether the argument was valid). Subjects responded 'yes' or 'no' by pressing a key on a computer keypad after the appearance of the last sentence. Subjects reviewed example stimuli prior to the start of the task to ensure that they understood it.

MRI Acquisition and Analysis

High resolution sagittally oriented whole brain T1-weighted images were collected using a 3 Tesla GE-Medical System MRI scanner. A 3D fast spoiled-gradient-recalled pulse sequence was acquired (TR=8.7 msec, TE=1.7 msec, flip angle=12º, matrix size=250×250 pixels, 0.976×0.976 mm in plane resolution, spacing between slices=1 mm, slice thickness=1mm).

The structural MRIs were preprocessed and analysed using Statistical Parametric Mapping software in Matlab2013a (SPM12b; Wellcome Trust Centre for Neuroimaging at UCL). The images were segmented and normalised to MNI space using Dartel nonlinear registration. The spatially normalised grey matter images were then smoothed with a Gaussian kernel of 8mm full width at half maximum and then taken forward to a SPM group analysis. Statistical analyses were performed using a full factorial design investigating the interaction between the factor age group and the covariate transitive reasoning. Gender and total intracranial volume were also included as regressors of no interest in order to reduce variance unrelated to the transitive reasoning variable of interest. After specifying the SPM model, we used the MarsBar toolbox (Brett et al, 2002) for region of interest (ROI) analysis. This way, differences in grey matter density between age groups, and interactions between age group and reasoning, were tested in four anatomical ROIs: two regions placed in the superior parietal cortex (LBA7, RBA7) and two regions placed in the inferior parietal cortex, comprising the supramarginal gyri (LBA40 and RBA40; see Figure 1).

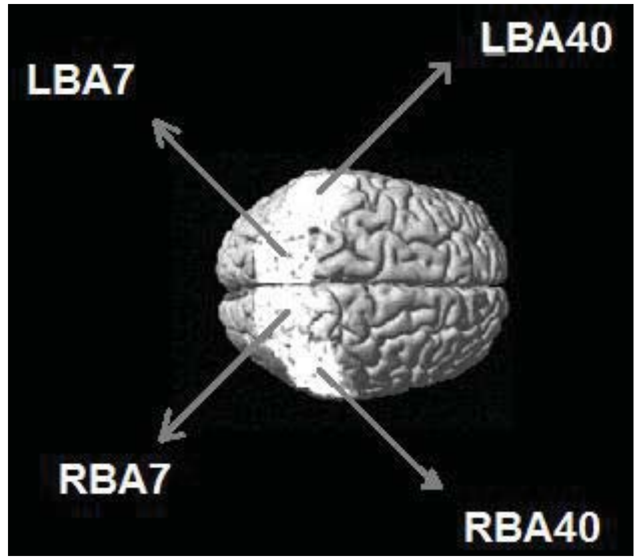

Figure 1. In white, the regions of interest used in this study

Results

Behavioural

An independent samples t-test showed that transitive reasoning scores were significantly higher for the adults (M = .85, SD = .11) than for the young adolescents (M = .76, SD = .13), $t(74) = -3.316$, $p = .001$).

Neural

Analyses were restricted to the pre-identified regions of interest (Figure 1). LBA7 and RBA7 showed significantly lower grey matter density in the adult group compared to the adolescent group. Subsequent ROI analysis (Table 1) showed a significant interaction between age (adults > young adolescents) and transitive reasoning in RBA7. A trend towards significance for this interaction was also found in LBA7.

Table 1. ROI analysis (contrasts and p-values; Bonferroni corrected for multiple comparisons)

Contrasts	Superior parietal (LBA7)	Superior parietal (RBA7)	Supra-marginal gyrus (LBA40)	Supra-marginal gyrus (RBA40)
GM young > GM adults	.012	.006	.228	.423
Interaction: age group x reasoning (adults > young adolescents)	.084	.050	1	1

Discussion

The present Voxel-Based Morphometry work studies the neural correlates of developmental change in transitive reasoning. At the behavioural level we found that adults performed better in the transitive inference task than the young adolescents. This result is consistent with previous studies with other relational reasoning tasks, e.g. the Raven's progressive matrices task (Crone et al., 2009).

At the neural level we found less grey matter density in the adults than in the young adolescents in the left BA7 and the right BA7. Decrease in grey matter after puberty is a known issue, and it has been attributed to synaptic pruning (Giedd et al., 1999). More interestingly, the ROI analysis showed a significant interaction between age group and transitive reasoning in right BA7, meaning that improved performance in the reasoning task was more related to grey matter density in the adults than in the young adolescents. A trend to significance was also present for the same interaction in the left BA7, but we did not find any significant result in BA40. This may be related with a lack of statistical power that perhaps could be overcome by using a larger sample size. Another possible explanation is that the developmental changes that happen in BA40 have a different timing than those that happen in BA7.

Taken together, these results support the idea that during development, regions in the parietal cortex are pruned and fine-tuned, resulting in greater efficiency. The structural brain changes lead to improved performance in transitive reasoning.

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