Endogenous Control in Algebraic Problem Solving: An fMRI Study

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We present an experiment exploring cognitive control in algebraic problem solving. Participants solved 128 four-term equations and followed the same three-step strategy to solve each problem. Problems varied along two dimensions: (a) Whether the intermediate state of each problem was displayed on the screen ("updated") or the equation remained the same ("non updated"); (b) Whether they contained only parametric or only numeric terms. Therefore, the demands for retrieval and maintenance of arithmetic and visual information were manipulated independently, while the demand for endogenous control increased as more representations had to be maintained.

Participants performed the task within a 3T fMRI scanner (Field of view 200mm, Repetition time 1,500ms, Flip angle 73°). The paradigm was slow event-related, with each trial lasting 22.5s. An exploratory analysis showed that right and left dorsolateral prefrontal regions and the left insula were insensitive to the equations being updated or not, but were selectively activated by arithmetic retrievals. A medial frontal region encompassing the dorsal cingulate was sensitive to control demands. Activity in parietal regions (BA7/39) was compatible with both control and mental imagery demands.

A confirmatory analysis using eight predefined ROIs confirmed that the head of the caudate nucleus was also sensitive to control demands. An ACT-R computational model for the task succeeded in reproducing both the behavioral and the hemodynamic data.

These results support our hypothesis that cognitive control is mainly achieved by medial and subcortical (and, possibly, parietal) regions, with other areas biasing response selection by holding task-relevant representations.