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Strengthening Learning Capacities®

The Study

Exploring the Relationship Between Improvement in an Intensive Learning Intervention and Changes in Resting-state Functional Connectivity

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Subjects and Methodology

Students enrolled in the Arrowsmith Cognitive Intensive Program (CIP) in Toronto and Peterborough, ages 11 to 19, underwent Resting State fMRI imaging at the beginning and end of the 6 week program in the summer of 2017. Resting State fMRI is an imaging technique that is used to evaluate the brain's functional organization while the subject is not engaged in a task.

Researcher

Dr. Greg Rose, Director of Center for Integrative Research in Cognition and Neural Science at Southern Illinois University (SIU), was the lead researcher of this study and imaging was conducted at Sick Children's Hospital in Toronto.

Symbol Relations Cognitive Function

The cognitive function worked on over the 6 weeks of the study was Symbol Relations. This cognitive function is considered an 'association area of association areas' in the brain which simultaneously processes multiple stimuli - both external and internal - necessary to understand the world, oneself and others. As such, it is involved in processing concepts across all academic disciplines, understanding and quickly grasping what we read and hear, gaining insight, logical reasoning, seeing connections between ideas, analyzing abstract concepts, cause and effect processing, flexibility of thought, accepting and considering other points of view, thinking critically, making rational and considered decisions, deep semantic grasp of language and mathematical reasoning. These are critical abilities required for all aspects of learning. Given the unique role of this cognitive function as an association area, enhancement of this function has broad overarching impact on cognition. The resulting gains are generalizable to aspects of learning that require comprehension and conceptual understanding or reasoning.

Results

Improvement in the Symbol Relations (SR) cognitive function over the course of the six week program correlated significantly with increased connectivity in the following neural networks – the Salience Network, the Frontal Parietal Network and the Default Mode Network. These networks are involved in a number of processes, including attention, perception, self-awareness through the integration of sensory, emotional and cognitive information, planning, executive control or the ability to deliberately guide action based on goals, cognitive control, memory, ability to take the perspective of another, working memory, and comprehension.

Significant changes in cognitive processing speed, cognitive efficiency, letter pattern matching and pair cancellation on the Woodcock Johnson Tests of Cognitive Abilities were also seen with students in the Cognitive Intensive Program.

Implications of Study

Research on learning disabilities have identified that there is a neurobiological basis for these learning difficulties. Neuroscientists are studying the brain networks responsible for various behaviors such as reasoning, attention, memory and language processing. In education the approach to learning disabilities has been on finding ways for the brain to compensate for these neurological difficulties. This research conducted at SIU on the Arrowsmith Program has highlighted that brain networks responsible for reasoning, attention and memory can improve in connectivity through cognitive training, and thus compensation strategies, currently a focus in educational planning for those with learning disabilities, are not the only option. The implications of the SIU research is significant for the field of learning disabilities.

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Introduction

Resting-state functional imaging provides a quick and non-invasive assessment of brain activity, requiring little from an individual, cognitively or physically. We hypothesized that resting-state imaging would be an ideal method for studying brain-related state changes associated with a cognitive intervention. Our study asked the question: does improvement in an intensive learning/cognitive intervention modify resting-state functional connectivity?

Methods and Results

Participants

Participants (n = 16) were students in the Cognitive Intensive Program at the Arrowsmith School in Toronto, Ontario, Canada. Resting-state fMRI images were collected at the beginning and end of the six-week program using a Siemens 3T scanner at the Toronto Hospital for Sick Children. The average age was 14.59 years old (SD = 2.60). 10 were males, and all but 2 were right-handed.

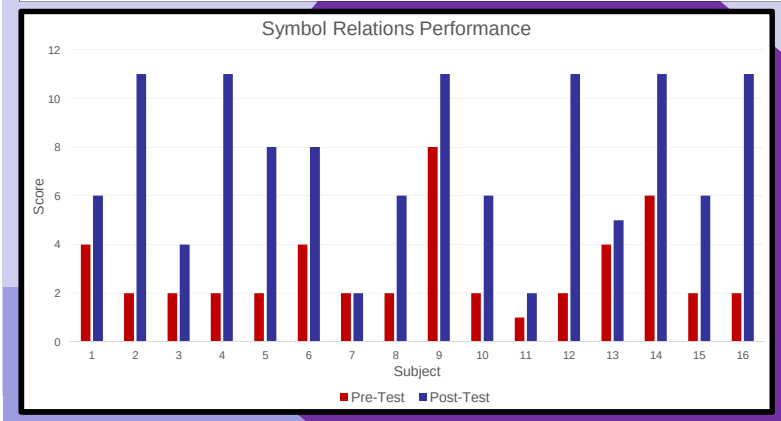
Training

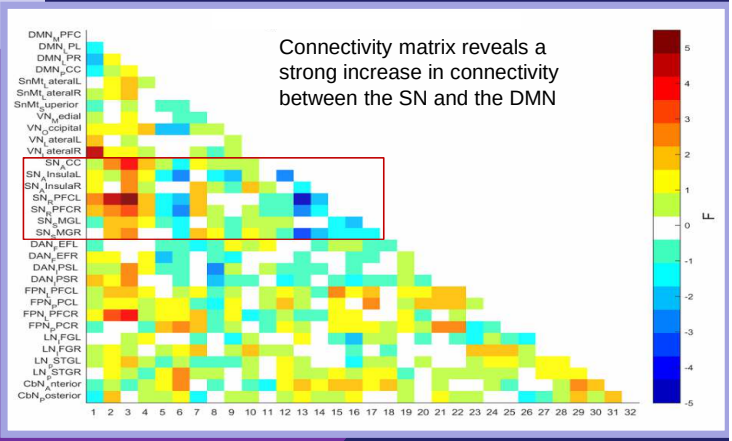
The training took place as part of the Summer Cognitive Intensive Program (CIP) held by the Arrowsmith School in Toronto. During the CIP, the students practiced the Symbol Relations Task. The Symbol Relations Task is a computer-based sustained visual-spatial processing task of progressively increasing difficulty. Subjects are presented with an analog clock face, initially showing only one hand. The subject uses a keyboard to enter a value for the hour shown. Feedback on the computer screen indicates whether the response is correct or incorrect. If the response was incorrect, the subject continues to respond until the correct response is entered. After this, a new clock face is shown. Once subjects reach a criterion of 90% accuracy over a series of consecutive responses, an additional hand is added to the clock face (e.g., hours and minutes). This process continues until up to 10 hands have been added to the clock differentiated by a combination of thickness, length, and color. Students in the CIP work 30 to 40 minutes per session on this task with a break and up to five hours per day, five days per week, for six weeks. Subjects are assigned a level of proficiency (1-12) based upon an assessment of their accuracy at the various levels of the task.

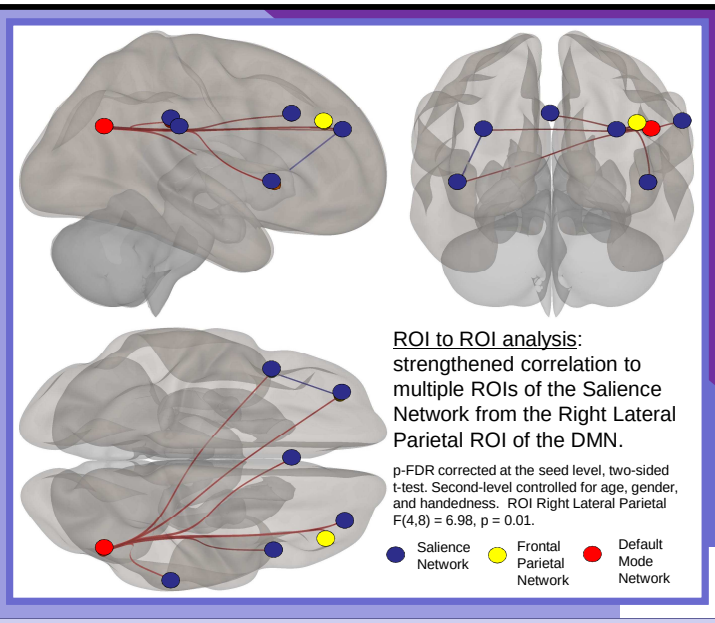
Imaging

During the 8 minute resting-state scan (TR = 4 sec, TE = 30 msec; 120 volumes) participants were told to keep their eyes open to view a cross hair on a screen and to think of nothing in particular. The scans were pre-processed and analyzed using the CONN toolbox (www.nitrc.org/projects/conn, RRID:SCR_009550).

The Symbol Relations Task



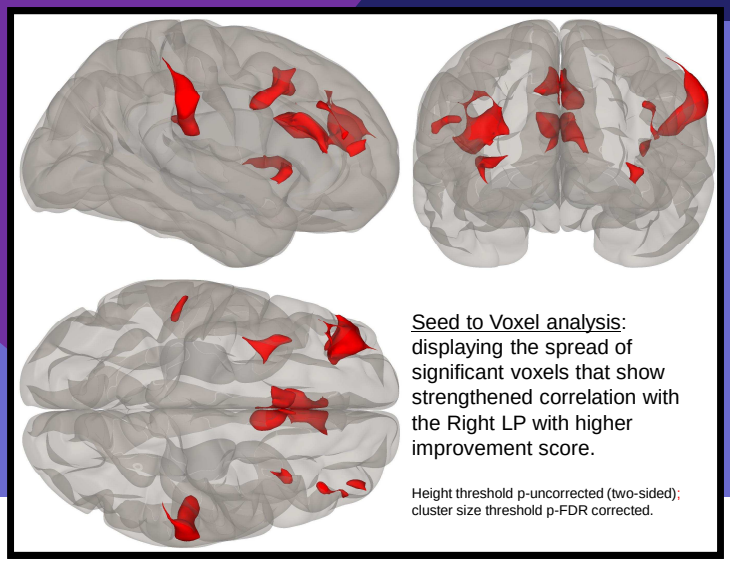




ROI to ROI analysis: strengthened correlation to multiple ROIs of the Salience Network from the Right Lateral Parietal ROI of the DMN.

p-FDR corrected at the seed level, two-sided t-test. Second-level controlled for age, gender, and handedness. ROI Right Lateral Parietal $F(4,8) = 6.98$, $p = 0.01$.

Salience Network | Frontal Parietal Network | Default Mode Network



Seed to Voxel analysis: displaying the spread of significant voxels that show strengthened correlation with the Right LP with higher improvement score.

Height threshold p-uncorrected (two-sided); cluster size threshold p-FDR corrected.

Discussion

Participants in the six-week Cognitive Intensive Program (CIP) improved their performance in the Symbol Relations Task that were correlated with changes in resting-state brain connectivity. The most notable change was increased connectivity between the Default Mode (right lateral parietal) and the Salience Networks (bilateral rostral Prefrontal Cortex, bilateral Anterior Insula, right Supra-marginal Gyrus, and the anterior cingulate), and the Frontoparietal Network (right lateral Prefrontal cortex). Sustained attention tasks (e.g., SART task (Smilek et al. 2010) or the grad-CPT (Esterman et al., 2013) activate similar brain regions. Sustained attention appears to be trainable (DeGutis & Van Vleet, 2010) and has been implicated in many developmental, psychological, and neurological disorders (see review by Fortenbaugh, DeGuits, and Esterman, 2017). Whether the observed changes in resting state network connectivity affects sustained attention or other cognitive domains is currently under study.

Smilek, D., Carriere, J. S. A., Cheyne, J. A. (2010). Failures of sustained attention in life, lab, and brain: Ecological Validity of the SART. *Neuropsychologia, 48,* 2564-2570, doi: 10.1016/j.neuropsychologia.2010.05.002
Esterman, M., Noonan, S.K., Rosenberg, M. (2013). In the Zone or Zoning out? Tracking behavioral and neural fluctuations during sustained attention. *Cerebral Cortex. 23,* 2712-2723, doi: 10.1093/cercor/bhs261
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