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Research identifies changes in neural circuits underlying self-control during adolescence

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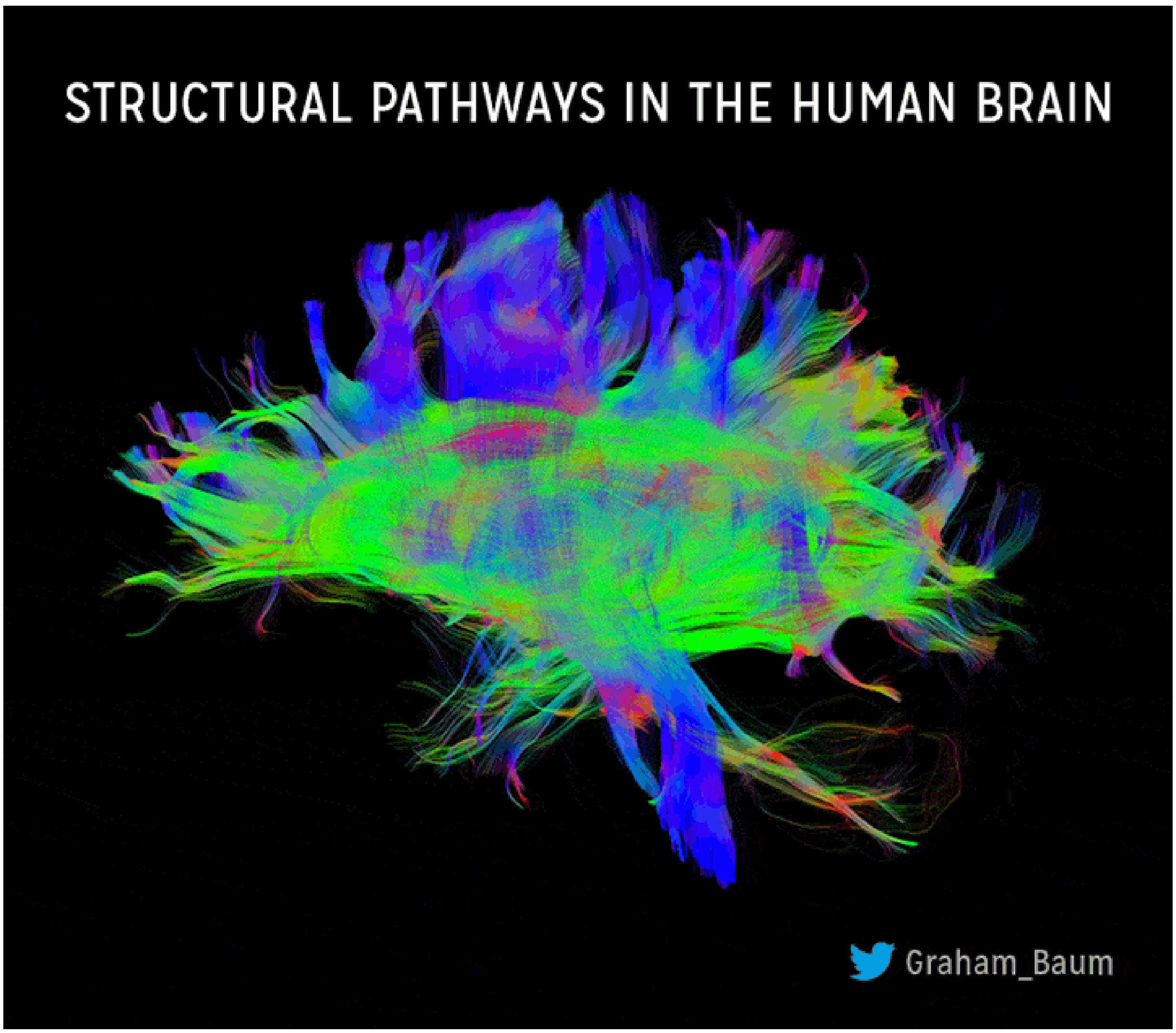

A study examining the relationship between structural and functional brain connectivity in 727 participants ages 8-23 years old revealed marked remodeling of structure-function coupling during youth. Credit: Graham Baum

The human brain is organized into circuits that develop from childhood through adulthood to support executive function—critical behaviors like self-control, decision making, and complex thought. These circuits are anchored by white matter pathways which coordinate the brain activity necessary for cognition. However, little research exists to explain how white matter matures to support activity that allows for improved executive function during adolescence—a period of rapid brain development.

Researchers from the Lifespan Brain Institute of the Perelman School of Medicine at the University of Pennsylvania and Children's Hospital of Philadelphia applied tools from network science to identify how anatomical connections in the brain develop to support neural activity underlying these key areas. The findings were published in the *Proceedings of the National Academy of Sciences*.

"By charting brain development across childhood and adolescence, we can better understand how the brain supports executive function and self-control in both healthy kids and those with different mental health experiences," said the study's senior author Theodore Satterthwaite, MD, an assistant professor of Psychiatry at Penn. "Since abnormalities in developing brain connectivity and deficits in executive function are often linked to the emergence of mental illness during youth, our findings may help identify biomarkers of brain development that predict cognitive and clinical outcomes later in life."

In this study, the researchers mapped structure-function coupling—the degree to which a brain region's pattern of anatomical connections supports synchronized neural activity. This could be thought of like a highway, where the anatomical connections are the road and the functional connections are the traffic flowing along those roads.

Researchers mapped and analyzed multi-modal neuroimaging data from 727 participants ages 8 to 23 years, and three major findings emerged.

First, the team found that regional variability in structure-function coupling was inversely related to the complexity of the function a given brain area is responsible for. Higher structure-function coupling was found in parts of the brain that are specialized for processing simple sensory information, like the visual system. In contrast, there was lower structure-function coupling in complex parts of the brain that are responsible for executive function and self-control, which require more abstract and flexible processing.

Results showed that structure-function coupling also aligned with known patterns of brain expansion over the course of primate evolution. Previous work comparing human, ape, and monkey brains has showed that sensory areas like the visual system are highly conserved across primate species and have not expanded much during recent evolution. In contrast, association areas of the brain, such as the prefrontal cortex, have expanded dramatically over the course of primate evolution. This expansion may have allowed for the emergence of uniquely complex human cognitive abilities. The team found that the brain areas which expanded rapidly during evolution had lower structure-function coupling, while simple sensory areas that have been conserved in recent evolution had higher structure-function coupling.

Researchers also found that structure-function coupling increased throughout childhood and adolescence in complex frontal brain regions. These are the same regions that tend to have lower baseline structure-function coupling, are expanded compared to monkeys, and are responsible for self-control. The prolonged development of structure-function coupling in these regions may allow for improved executive function and self-control that develops into adulthood. Indeed, the team found that higher structure-function coupling in the lateral prefrontal cortex—a complex brain area which plays important roles in self-control—was associated with better executive function.

"These results suggest that executive functions like impulse control—which can be particularly challenging for children and adolescents—rely in part on the prolonged development of structure-function coupling in complex brain areas like the prefrontal cortex," explained lead author Graham Baum, Ph.D., a postdoctoral fellow at Harvard University, who was a Penn neuroscience Ph.D. student during the time of the research. "This has important implications for understanding how brain circuits become specialized during development to support flexible and appropriate goal-oriented behavior."

More information: Graham L. Baum et al, Development of structure–function coupling in human brain networks during youth, *Proceedings of the National Academy of Sciences* (2019). DOI: 10.1073/pnas.1912034117

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