Functional Magnetic Resonance Imaging Studies Investigating Prefrontal Cortex Function in Attention-Deficit Hyperactivity Disorder

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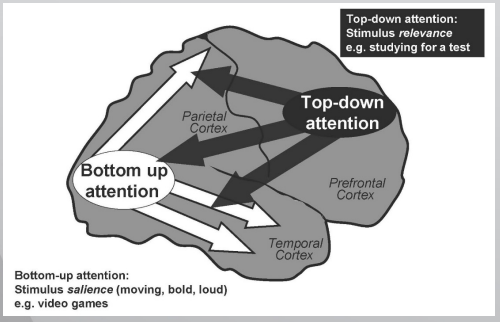
BACKGROUND

- Attention-deficit/hyperactivity disorder (ADHD) is one of the most common childhood neurodevelopmental disorders characterized by symptoms of inattention, hyperactivity, and/or impulsivity. While the exact cause of ADHD is still unknown, research has shown that individuals with ADHD often have lower levels of activity in the prefrontal cortex (PFC) compared to individuals without ADHD.[1]
- The PFC, which plays a critical role in regulating attention, behavior, and emotion, is frequently dysfunctional in individuals with ADHD. The PFC is also involved in the regulation of dopamine, a neurotransmitter that plays a key role in the brain's reward and motivation pathways. ADHD has been linked to abnormalities in the dopamine system, which may further contribute to PFC dysfunction.[2]
- Various neuroimaging studies have demonstrated that children and adults with ADHD have structural and functional abnormalities in the PFC, including reduced gray matter volume, altered neural activation patterns, and disrupted connectivity with other brain regions.[2] To assess differences in the brain systems that underlie ADHD, modern psychiatric research has increased the utilization of functional magnetic resonance imaging (fMRI) which measures brain activity by detecting changes in cerebral blood flow.[3]
- Understanding the role of the PFC in ADHD is important for developing effective treatments that target this brain region. For example, medication used to treat ADHD, such as stimulants, are believed to work by increasing dopamine levels in the PFC and other brain regions, thereby improving attention and impulse control. Non-pharmacological treatments, such as cognitive-behavioral therapy, also aim to improve PFC functioning by teaching individuals strategies to regulate their attention and behavior.[3]

METHODS AND MATERIALS

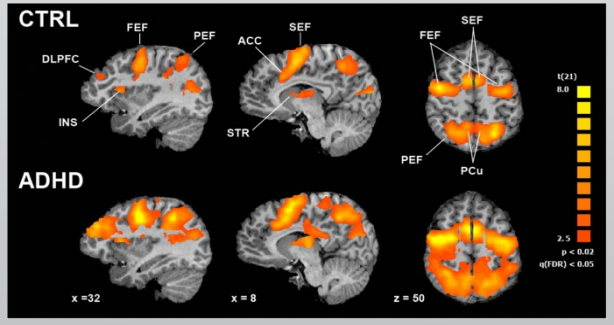
- A systematic literature search was conducted in electronic databases, including PubMed, ScienceDirect, and Google Scholar. Studies published between 2013 and 2023 that used fMRI to investigate PFC function in ADHD were included.
- The search terms included "attention-deficit/hyperactivity disorder," "fMRI," and "prefrontal cortex." The inclusion criteria were limited to human studies published in English. A total of 20 studies met the inclusion criteria and were included in this review.



The PFC regulates attention by directing resources based on stimulus relevance, known as "top-down" attention. This involves gating stimuli and sustaining attention on relevant information, mediated by PFC projections. Individuals with ADHD often have difficulties with top-down attention regulation, contributing to attentional deficits.[2]

RESULTS

- The results of this systematic review suggest that recent studies that have used various fMRI techniques, including resting-state fMRI, task-based fMRI, and connectivity-based fMRI, have shown consistent alterations in PFC function in ADHD.
- Resting-state fMRI (rs-fMRI) is a method of functional brain imaging that measures spontaneous fluctuations in blood oxygen level-dependent (BOLD) signals in the absence of an explicit task or stimulus.[3] Studies using resting-state fMRI have found altered PFC connectivity in individuals with ADHD compared to typically developing individuals, including reduced connectivity between the PFC and regions involved in attention and working memory. Authors found that individuals with ADHD had increased connectivity within the default mode network, a network involved in self-referential processing and mind-wandering, as well as reduced connectivity between the PFC and several other brain regions involved in cognitive control, attention, and reward processing.[4,5,6] Specifically, the authors found decreased connectivity between the dorsolateral prefrontal cortex (DLPFC) and the inferior parietal lobule (IPL) in children with ADHD. Additionally, the authors discovered reduced connectivity between the DLPFC and IPL was associated with greater ADHD symptom severity in children with the disorder.[7]
- Task-based fMRI (tb-fMRI) is a method of functional brain imaging that measures changes in BOLD signal during the performance of a specific cognitive task.[3] Studies using tb-fMRI have found altered PFC activation during cognitive tasks in individuals with ADHD, including reduced activation of the dorsolateral PFC during working memory tasks. Authors discovered that adults with persistent ADHD symptoms displayed underactivation in the PFC and striatum during interference inhibition and attention allocation tasks, while children with ADHD had reduced activation in the prefrontal cortex during tasks requiring working memory and cognitive control compared to typically developing children.[8,9,10]
- Connectivity-based fMRI (cb-fMRI) is a method of functional brain imaging that measures the functional connectivity between brain regions during task performance or at rest and is often used to investigate how different brain regions interact during cognitive processes.[11] Studies using cb-fMRI have found altered connectivity between the PFC and other brain regions in individuals with ADHD, including reduced functional connectivity between the PFC and regions involved in attention and working memory. ADHD-associated alterations of corticocortical connectivity and redistribution of regional nodes and connectivity involving the default-mode, attention, and sensorimotor systems correlated with behavior disturbances (e.g., inattention and hyperactivity/impulsivity symptoms) and exhibited differential patterns between clinical subtypes.[12,13]



Children with ADHD exhibited hyperactivity in the dorsolateral prefrontal cortex (DLPFC) during inhibitory control in the antisaccade task compared to control participants suggesting that hyperactivity in the DLPFC may be a key neural mechanism underlying inhibitory control deficits in children with ADHD.[14]

CONCLUSION

- To summarize, the use of fMRI in investigating PFC function in ADHD has led to consistent findings of altered brain activity and connectivity in specific PFC subregions that may have important implications for the development of targeted interventions and treatments for individuals with ADHD. However, more research is needed to fully elucidate the role of PFC dysfunction in ADHD and to explore the potential of emerging fMRI techniques for investigating this disorder.
- Overall, this systematic review underscores the value of fMRI as a tool for advancing our understanding of the neural basis of ADHD and for developing interventions to improve executive function in individuals with this disorder.

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