

Cortical Arousal and Pediatric Attention-deficit/Hyperactivity Disorder (ADHD)

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Abstract

While the continued manifestation of Attention-deficit/Hyperactivity Disorder (ADHD) symptoms and cognitive impairments are documented well, the underlying physiological processes remain unknown. This review documents research linking arousal to ADHD-related cognitive impairments. Etiological models that attempt to associate arousal to ADHD-related cognitive impairments and behavioral manifestations of the disorder are reviewed. Finally, recommendations for future research will be explored with a particular emphasis on both research and clinical implications.

Keywords: Cognitive impairments; Clinical implications; Psychiatry; Attention-deficit/Hyperactivity Disorder (ADHD)

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Attention-Deficit/Hyperactivity Disorder

Attention-deficit/Hyperactivity Disorder (ADHD) is a complex neurodevelopmental disorder characterized by excessive and developmentally inappropriate inattention and hyperactivity/impulsivity levels [1]. The largest and most comprehensive randomized clinical trial in child and adolescent psychiatry, the Multimodal Treatment Study of Children with Attention-deficit/hyperactivity disorder (MTA), documents significant and continued impairment in children with ADHD into adulthood across multiple domains of functioning after 16 years despite receiving the most effective treatments available for the [2]. Children with ADHD earn lower grades and experience higher rates of special education placements, grade retention, and school dropout. Relative to typically developing children, children with ADHD score significantly lower on standardized math, reading, and spelling achievement measures even after controlling for individual differences in intelligence [3]. Approximately 70% children with ADHD meet criteria for a specific learning disability [4] and the annual academic-related impairment cost in the US is \$15-25 billion dollars [5].

Although the elevated health risks, social/interpersonal problems, and above-described academic/cognitive impairments are documented well [6], the underlying physiological processes remain unknown [3]. This review will outline research linking arousal to ADHD-related cognitive impairments. Additionally, the reviews highlight etiological models that attempt to associate

arousal to ADHD-related cognitive impairments and behavioral manifestations of the disorder. Finally, recommendations for future research will be explored with a particular emphasis on both research and clinical implications.

Meta-analytic reviews document moderate Executive Function (EF) impairments in children with ADHD across a number of domains including behavioral inhibition, short-term memory, verbal fluency, inhibition, problem-solving, and working memory [7]. Executive Functions (EFs) refer to a "suite" of related mental processes mediated by the prefrontal cortex. EFs are needed to sustain goal-oriented problem-solving. Moreover, EF-related processes include inhibition, working memory, planning, emotional or motivational regulation, and interference control [8]. Moreover, ADHD-related EF deficits have a central and secondary role in several theoretical models of ADHD [9]. EF deficits (i.e., executive dysfunctions) are linked to learning, particularly performance in language arts, mathematics, and science [10], comprehension, reasoning, and planning [8]. Research suggests that EF deficits may mediate the relationship between ADHD symptoms and grades [11]. Consistently large effects sizes are often associated with verbal and spatial working memory impairments. Working memory is a limited-capacity system for the simultaneous storage and processing of spatial and phonological (i.e., speech-based information). Rapport and colleagues conducted the first study to examine between-group

differences in working memory [12] for children with ADHD while systematically increasing working memory demands. Recent work suggests that working memory impairments are linked to behavioral inhibition deficits [13].

Conceptual ADHD models posit that activity level augments arousal necessary for performance on cognitive tasks, particularly tasks requiring higher-order executive functions such as working memory, inhibition, problem-solving [14]. Barkley's Behavioral Inhibition Model of ADHD posits that inhibition deficits, a core deficit of ADHD, are associated with four executive functioning impairments, namely working memory, self-regulation of affect, motivation, and arousal [9]. This model defines arousal as the ability of the central nervous system to be attentive and responsive to stimuli [9]. The cognitive-energetic model of ADHD [15] postulates that "state" factors such as effort, arousal, and activation influence components of cognitive processing; whereas executive functioning, effort, and task parameters are thought to impact arousal. This model defines arousal as physiological changes time-locked to stimuli [15]. Finally, the working memory model of ADHD [16] posits that activity level augments arousal necessary for performance on cognitive tasks, particularly tasks requiring sustained attention and higher-order executive functions such as working memory, inhibition, and problem-solving. Collectively, current ADHD models postulate a relationship between arousal and cognitive processes.

Electrodermal Activity (EDA) quantifies activity of the sympathetic nervous system by measuring the reduction in electrical resistance of the skin in response to stimuli [17]. EDA is quantified by measuring gradual changes over time (EDLs: Electrodermal Levels). Children with ADHD have demonstrated lower EDLs relative to children without ADHD during resting paradigms [18] tone discrimination paradigms [19] and reward-extinction paradigms [20]. With the exception of resting paradigms, these tasks require attention to simple stimuli (e.g. tones) by the child participants and restrict movement, the hallmark feature of ADHD. To date, however, assessing physiological processes in children with ADHD has proven problematic, as hyperactive pediatric samples are prone to producing motion artifact that may be related to the etiology of ADHD [21]. Historically, researchers were limited to simple listening tasks because of the capabilities of their physiological

recording equipment. Frequently, EDLs are studied in conjunction with electroencephalograms, which demand minimal movement and may be disrupted by spontaneous eye blinks. Traditional EDA measurement equipment inhibits freedom of movement, a hallmark feature of ADHD, which may create movement artifacts in the EDA data.

Measures for Cognitive Processes

It is important to understand the relationship between cognitive performance and physiological measures of behavior using (noninvasive) wireless technologies to investigate the unique contribution of both arousal and activity level to ADHD-related cognitive processes and academic impairments. Wireless sensors may have an advantage over traditional EDA measurement methods. In traditional measurement methods, electrolyte paste is applied to the skin to facilitate the circuit connection between the skin and the electrodes. This paste diffuses normally into the skin and hydrates the outer layer of skin. This hydration may mimic the hydration caused by perspiration and confound EDA measurements [22]. The wireless sensors eliminate this potential confound by reducing motor artifacts. In traditional EDA measurement, sensors are worn on the medial or distal joints of the index and middle fingers of a participant's non-dominant hand to minimize movement artifacts; however, significant reduction of artifacts is not always achievable and can reduce the amount of data available for analysis. Placing the sensors on a participant's non-dominant hand may further minimize motion artifacts and permit participants to use their dominant hand to complete cognitive tasks.

Conclusion

Children diagnosed with ADHD are in drastic need of innovative and effective treatments, particularly interventions targeting ADHD-related cognitive and academic impairments. While the continued manifestation of ADHD-related cognitive impairments and symptomatology into adulthood are documented well, the underlying physiological processes remain unknown [3]. Future research examining underlying physiological processes associated with ADHD-related cognitive impairments may inform the development of impairment-specific interventions for children diagnosed with ADHD.

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