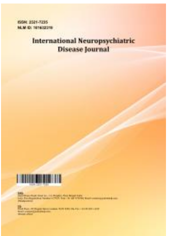

International Neuropsychiatric Disease Journal

Volume 22, Issue 6, Page 27-35, 2025; Article no.INDJ.147641
ISSN: 2321-7235, NLM ID: 101632319

Neurocognitive Deficits in Attention Deficit/Hyperactive Disorder (ADHD): Role of Sensory Processing, Visual Perception and Attention

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Authors' contributions

This work was carried out in collaboration between both authors. Both the authors were involved in the planning, conceptualization, literature review, writing and reviewing the manuscript. Author PK wrote the first draft of the manuscript. Both authors were involved in reviewing and revising the manuscript to its final form. Both authors read and approved the final manuscript.

Article Information

DOI: https://doi.org/10.9734/indj/2025/v22i6527

Open Peer Review History:
This journal follows the Advanced Open Peer Review policy. Identity of the Reviewers, Editor(s) and additional Reviewers, peer review comments, different versions of the manuscript, comments of the editors, etc are available here: https://pr.sdiarticle5.com/review-history/147641

Minireview Article

Received: 23/08/2025
Published: 12/11/2025

ABSTRACT

Attention-Deficit/Hyperactivity Disorder (ADHD) is one of the most common neurodevelopmental disorders characterized by symptoms of inattention and/or hyperactivity and impulsivity, and it affects mostly children and adolescents by causing significant impairment in their development and daily functioning. ADHD is associated with various neurobiological abnormalities and deficits, and this review article examines the current research evidence on the role of three neurocognitive domains in ADHD, namely sensory processing, visual perception and attention. Atypical sensory

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***Cite as:** Prakat Karki, and Rishabh Sharma. 2025. "Neurocognitive Deficits in Attention Deficit/Hyperactive Disorder (ADHD): Role of Sensory Processing, Visual Perception and Attention". International Neuropsychiatric Disease Journal 22 (6):27–35. https://doi.org/10.9734/indj/2025/v22i6527.*

processing in terms of increased or reduced neural thresholds for sensory modulation can explain the distinct symptoms of the various ADHD subtypes. In visual perception, structural and functional deficits in visual processing and perception can account for the vision related problems commonly found in ADHD. Finally, deficits in selective and sustained attention observed in ADHD can indicate underlying dysfunctions in other bottom-up and top-down processes. The interaction of sensory processing, visual perception and attention has also been discussed alongside other neurobiological processes and mechanisms implicated in ADHD. Although evidence of the role of these three neurocognitive domains has significant clinical implications, the wide range of experiences and symptom manifestations in ADHD warrants further research of these and other neurocognitive and neurobiological mechanisms, as well as reconsideration of current ADHD diagnostic protocols. The article highlights the need and further scope of better understanding the psychosocial, cognitive and biological underpinnings and mechanisms of ADHD, in order to formulate more effective diagnostic and treatment approaches.

Keywords: Attention-Deficit/Hyperactivity Disorder (ADHD); sensory processing; attention; visual perception.

1. INTRODUCTION

Attention Deficit Hyperactive Disorder (or ADHD) is a neurodevelopmental disorder characterized by two types of persistent and developmentally inappropriate behavioral patterns; inattention, and hyperactivity and/or impulsivity. ADHD is one of the most commonly diagnosed and prevalent mental health disorders worldwide, particularly among children and adolescents (Banaschewski et al., 2017). The incidence of ADHD has been steadily growing in recent decades in most societies worldwide and Its lifetime prevalence is between 6 to10 percent (Ayano et al., 2023; Salari et al., 2023). As a mental health disorder, it is generally classified as a 'neurodevelopmental disorder' in both the DSM-V and ICD-11 and the presentation of its symptoms are typically differentiated into three types; predominantly inattentive type, predominantly hyperactive/impulsive type and combined inattentive and hyperactive/impulsive type (American Psychiatric Association, 2013; Gomez et al., 2023; World Health Organization, 2022). Individuals with the inattentive subtype of ADHD (or ADHA-IA) have symptoms such as inability to pay or sustain attention or being easily distracted, lack of focus, high forgetfulness, etc. The hyperactive subtype (ADHD-H) is characterized by behaviors related to impulse control and motor functions with symptoms such as fidgeting, tapping, restlessness, disorganization, excessive talkativeness and general behavioral disinhibition (APA, 2013; Reynolds & Kamphaus, 2016). Individuals with the combined subtype of ADHD (or ADHD-C) tend to exhibit a mix of both inattentive and hyperactive/impulsive symptoms. Overall, individuals with ADHD are exhibit a range of problems in various cognitive, affective and behavioral domains, and these also lead to impairments in their academic, interpersonal and occupational functioning (Okuda & Germano, 2016).

2. SENSORY PROCESSING IN ADHD

Scientific research on ADHD and its various aspects has grown exponentially in the previous decades, and there has been a growing consensus among clinicians and researchers that ADHD is primarily a neurobiological disorder. Although there is some agreement on the influence of various biological, developmental, environmental and social risk factors in the etiology and symptomatology of ADHD, more recent genetic, biomolecular, neuroimaging and neurophysiological studies provide credible evidence to suggest that ADHD is primarily a neurobiological condition (Tripp & Wickens, 2009; Thapar et al., 2012). Moreover, it has been consistently observed that children with ADHD have various neurocognitive impairments, in domains of executive functioning, visual perception, sustained attention and working memory, which manifest through the numerous behavioral symptoms that characterize ADHD (Okuda & Germano, 2016). This has led some researchers to believe that there are fundamental issues or deficiencies at the level of sensory processing or modulation among children with ADHD which further manifest as problems in visual and auditory perception, attention, working memory, executive functioning, etc. (Shimizu et al., 2014; Schulze et al., 2020). Individual differences in sensory processing across various sensory modalities can impair how children detect, modulate, interpret and respond to environmental stimuli in a number of ways (Ghanizadeh, 2010). Typical sensory modulation occurs through interaction between neural thresholds and individual self-regulation and for most neurotypical individuals, their neural thresholds are within a normal range that facilitates successful sensory processing in terms of appropriate detection and response to stimuli (Dunn, 2001). However, some individuals exhibit high neural threshold for detecting stimuli which can result in passivity or symptoms of inattention as triggering the typical neurological response requires stronger or more intense stimuli. There are also others who have low threshold for sensory stimuli such that neurological responses are produced for low intensity stimuli as well, and this can lead to individuals being overstimulated and easily distracted (Ghanizadeh, 2010; Schulze et al., 2020). These two conditions parallel the two subtypes of symptom profiles present in ADHD, and researchers have speculated whether ADHD is fundamentally a type of sensory processing disorder (Jung et al., 2014). This has been confirmed by studies comparing individuals with ADHD and healthy controls, which have found that individuals with ADHD have higher levels of sensory sensitivity or sensory avoidance, and also experience high sensory seeking and low sensory regulation and registration (Yochman et al., 2004; Jurek et al., 2025). These discrepancies in sensory processing can also have cascading effects on the various neurocognitive processes that follow sensory processing of stimuli among individuals with ADHD. However, the true nature of the mechanisms is not fully understood and research is ongoing (Jurek et al., 2025).

3. VISUAL PERCEPTION IN ADHD

Besides sensory processing, another related neurocognitive domain that has been repeatedly implicated in ADHD is visual perception as children and adults with ADHD often exhibit problems in detecting, organizing and responding to visual information (Jung et al., 2014). Issues in visual perception can also lead to further problems related to attention, working memory and executive functioning, which are characteristic of ADHD symptomatology. There is substantial research evidence at present that indicate various deficits at the sensory level that lead to the issues in visual perception observed in individuals with ADHD. They tend to exhibit a number of visual problems such as insufficient convergence, astigmatism, poor color and contrast sensitivity, insufficient focus, etc. (Lazarus, 2024; Villines, 2024). Individuals with ADHD also have higher prevalence of other vision related disorders such as hyperopia, hypermetropia and strabismus, all of which affect visual processing to some extent (Bellato et al., 2023). Various behavioral tendencies seen in children with ADHD in academic settings such as difficulties in tracking text, reading and writing, focusing in the classroom, paying sustained attention during lessons, etc. can be tracked back to impairments in the visual system and/or deficits in visual sensory processing (The Center for Vision Development, 2024). Due to these issues with vision, individuals with ADHD might often get overwhelmed, frustrated or dejected for not being able to plan and organize their work better or perform within the normative standards of classrooms or workplaces. Furthermore, studies have also found preference for auditory modalities over visual ones among individuals with ADHD further corroborating the presence of visual dysfunctions or impairments in ADHD (Nesplora, 2024; Rebon-Ortiz et al., 2024).

There are also distinct neurobiological deficits and structural abnormalities among individuals with ADHD which provide some indication regarding the etiology of the visual processing and perception issues. Anomalies have been reported in the development of the eye and other ocular structures such as the retinal nerves and ganglion cells among individuals with ADHD (Li et al., 2021). This can significantly impair visual processing and lead to a number of vision disorders stated earlier, which can further cause issues in attention and visual-spatial memory. Abnormalities have also been found in the noradrenergic, serotonergic and dopaminergic pathways from the retina to the visual cortex among people with ADHD (Cortese et al., 2018; Bellato et al., 2023). Retinal dopaminergic neurons in particular play a significant role in color, contrast and light perception and sensitivity, and they are crucial in spatial and temporal processing (Witkovsky, 2004). Through studies using various visual discrimination tasks, researchers have found that individuals with ADHD show particular processing impairments in the blue-yellow color continuum (Banaschewski et al., 2006; Fuermaier et al., 2018). Deficiencies or dysfunctions related to the retinal dopaminergic neurons can significantly affect the neural thresholds for sensory processing and lead to reduced stimuli detection or increased background noise, which can manifest as inattention or distractibility respectively (Bubl et al., 2015). In fact, children with ADHD exhibit a lot of similarities with people who have visual disorders, and scientists have also noted that a significantly higher proportion of individuals with visual problems are diagnosed with ADHD (DeCarlo et al., 2016; Cho & Ro, 2020). This raises further questions regarding the nature and validity of the ADHD diagnosis itself and the possibilities of misdiagnosis. Furthermore, not all individuals with ADHD exhibit impairments in visual processing and perception, and other distinct characteristics of ADHD related to self-regulation, motivation, disorganization and behavioral disinhibition are also not reliably associated with impairments in visual processing and perception. Hence, it suggests impairments and deficiencies in other neurocognitive mechanisms as well among people with ADHD. Nonetheless, visual perception remains an integral avenue for further research on ADHD and although it may not account for the symptoms among all individuals with ADHD, remedial programs and interventions related to visual perception may still be beneficial in alleviating symptoms for some (Dove Rehab Services, 2021; Rebon-Ortiz et al., 2024).

4. ATTENTION IN ADHD

Attention is another neurocognitive domain that is significantly implicated in ADHD. Deficiencies or problems in various aspects of attention have been found in ADHD, most commonly in functional domains of selective and sustained attention, response precision and inhibition, working memory, and information processing (Mueller et al., 2017). Within the attention research paradigm, the attention system theory by Posner and Peterson (1990) is regarded as instrumental in pioneering research into various aspects of attention among individuals with ADHD. According to Posner and Peterson (1990), attentional networks consist of three distinct systems of alerting, orienting and conflict resolution which are involved in processes related to self-regulation, visual orientation, vigilance, arousal, response inhibition, etc. (Fabio & Urso, 2014). It has generally been found that attentional processes are impaired among individuals with ADHD compared to healthy controls; however, the three subtypes of ADHD also differ on various aspects of the three attention systems, which suggests differential neurocognitive bases for the inattentive, hyperactive and combined subtypes of ADHD (Johnson et al., 2008). Individuals with the inattentive subtype (ADHD- IA) commonly have difficulties in orientation which is important in both selective and sustained attention, whereas those with hyperactive subtype (ADHD- H) show difficulties in conflict resolution or executive functions more evident in sustained attention only (Alava Sordo et al., 2021). Another model by Sergeant (2005) suggests three distinct stages of attention in characterizing ADHD; that of attention computation involving encoding and organization, various state functions such as arousal, affect and motivation, and an executive system involved in planning and monitoring (Xia et al., 2014). According to this cognitive-energetic model, the impairments in ADHD is a result of dysfunction in both bottom-up and top-down processes in attention and information processing, and the variability between the two systems leads to the heterogeneity of symptoms associated with ADHD (Sergeant, 2005). This indicates that bottom-up processes related to sensory processing and visual perception in encoding and organization are instrumental in attention and equally significant to top-down processes of executive functioning more commonly associated with attention. This has been confirmed through experimental studies on attention among individuals with ADHD, which have found mixed results suggesting that the different attentional deficits present in the three subtypes of ADHD can also be considered along a continuum of bottom-up and top-down attentional processes (Kratz et al., 2011; Bieleninik et al., 2023). A great deal of intra individual variation in performances on attention tasks has also been observed and individuals with ADHD tend to perform poorly on some tasks but perform normally or even excel at others (Bush, 2010). These mixed results of studies on attentional processes along with the ambiguous state of the ADHD combined subtype has led to the increasing notion that ADHD is largely a heterogenous cluster of diverse symptoms and clinical presentations. Although there are distinct neurocognitive impairments associated with ADHD, the varying levels of deficiencies in top-down and bottom-up processes related to sensory processing, visual perception, attention and executive functioning has hindered efforts in defining a consistent clinical profile and also uncovering its true etiology.

5. NEUROPHYSIOLOGY OF ADHD

The scientific evidence related to impairments in sensory processing, visual perception and attentional networks in individuals with ADHD provide some indication of how the various neurocognitive modalities interact and lead to the numerous psychological, social and behavioral symptoms. Sensory processing and perception can be regarded as the initial steps in activating various attentional processes, and deficiencies at various stages of visual perception can greatly offset attentional capacity and the higher cognitive processes that follow. While structural or functional abnormalities at the level of visual sensory processing can create cascading effects on the cognitive processes that follow, deficiencies in psychological mechanisms involved in visual perception can also lead to similar effects, but are more within reach of psychological or behavioral interventions aimed at correcting the processes. However, for both these variations in the top-down and bottom-up processes related to ADHD, there are also some evidences of deeper underlying deficits at the molecular level of the central nervous system which can also lead to variabilities in just not visual perception, but also other aspects of attention, memory, executive functioning, etc. Various neuroimaging and neurophysiological studies among individuals with ADHD have implicated dysfunctions in the prefrontal-striatal-cerebellar circuits in the brain which can account for a number of neurocognitive impairments seen in ADHD (Krain & Castellanos, 2006; Castellanos & Proal, 2012). Among individuals with ADHD, there is also reductions in grey and white matters, and lower volumes and mass of various brain structures (Qiu et al., 2011). These evidences better account for the system wide disruptions observed in ADHD compared to explanations related to specific disruptions in particular neurocognitive processes. Moreover, it can also account for the multiple deficits in ADHD at various levels of sensory processing, visual perception and attention, and also provide better explanations for the significant heterogeneity of symptoms observed in ADHD. However, a comprehensive understanding of the etiology and psychophysiology of ADHD, and the associations between the various neurocognitive domains and their biological underpinnings is still inconclusive.

6. CONCLUSION

A complete understanding of Attention Deficit/Hyperactivity Disorder (ADHD) and its etiology remains elusive despite decades of scientific research. Although there is credible evidence of neurocognitive impairments in sensory processing, visual perception, attention, memory, and executive functioning among individuals with ADHD, the heterogeneity in symptom presentations and issues in diagnostic validity undermine the true extent of its incidence and impact (Schlenker, 2021). Moreover, there have also been documented evidence of significant sociodemographic correlates of ADHD and its symptomatology with regard to sex, socio economic status, ethnicity, race, social class, family dynamics, academics, etc., which further raises doubts regarding the conceptualization of ADHD as a clinical or neurodevelopmental disorder (Reyes et al., 2013; Martel, 2013; Kofler et al., 2017). Nonetheless, there are millions of individuals, mostly children, who suffer from behavioral, psychological and interpersonal impairments considered within the definition of ADHD, and face challenges in carrying out their daily lives. However, among these neurodivergent populations, there is still significant individual differences in the manner in which the condition is manifested as well as their experiences of the conditions. While the diagnostic label of ADHD helps in screening, monitoring and treatment of individuals who face significant impairments, it can also be viewed as reductionist in terms of labelling a diverse range of individual differences, which otherwise might not lead to impairments, as psychopathological. This also raises some ethical challenges in terms of the experimental procedures that individuals are put through as part of ADHD assessment, and the clinical, interpersonal and occupational implications of the diagnostic label, which might lead to more harm than benefits. Although, examining neurocognitive and neurobiological differences in individuals with ADHD might aid in its understanding, it is also important to consider the fact that there are some variations in these domains between almost all people owing to differences in learning and knowledge, upbringing, cultural background, social context and other factors. The various advancements in clinical and research techniques have certainly allowed scientists to examine the complexities of ADHD; however, the efforts remain ongoing and with further scope for more deliberation.

CONSENT

It is not applicable.

ETHICAL APPROVAL

It is not applicable.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

The authors hereby declare that NO generative AI technologies such as Large Language Models

(ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

COMPETING INTERESTS

The authors have declared that no competing interests exist.

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Peer-review history:
The peer review history for this paper can be accessed here:
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