REVIEW ARTICLE

The predicting role of the default mode neuronal network on sustained attention in k-12 students: a systematic review.

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ABSTRACT

The role of the Default Neural Network in the emergence of attention deficit disorder has received increasing scientific evidence in the last 20 years. This article aimed to systematize the empirical and quantitative evidence available in research on the role of the Default Neural Network in sustained attention and attention deficits in school children and adolescents; The methodology of systematic review of the scientific literature available between 2010 and 2020 was used. A sample of 13 studies was selected. The results showed that sustained attention is rhythmic and fluctuates along with working memory. Regarding children with attention deficit, anomalies in the availability of dopamine, thinning of the areas of the cerebral cortex interconnected with the Neural Network by Default, as well as hypo and hyper connectivity of the white matter tracts associated with this network are reported. These findings, interpreted as a whole, provide valuable evidence about the emerging role of the Default Neural Network in the underlying processes of sustained attention and the appearance of attentional deficits. These systematized findings can have profound implications in didactics and instructional design, due to the fact that there is sufficient and validated evidence to adapt the learning tasks to the rhythms of attention and rest since these processes obbey biological limitations and not to administrative requirements.

Key words: *focus of attention; default-mode network; attention deficit disorder; systematic review.*

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INTRODUCTION

Contemporary educational systems have been designed to be efficient and provide results on standardized assessments. This homogenization trend has put schools in a spiral of competition where those students with cognitive deficits are mostly absorbed by public schools that do not impose entry barriers(1). This situation of cognitive neuro diversity supposes an extra effort and stress for educators due to the diversity of diagnoses presented by students. Perhaps the most common cognitive disorder in the classroom is attention deficit disorder (ADHD) in its multiple types and degrees; At the present time, ADHD is the disorder that has been most documented for affecting the academic performance of those who suffer from it(2,3). Attention deficit in its base form is characterized by the inability to sustain attention on specific tasks compared to other subjects of typical development.(4)

Selective or sustained attention is described as the ability to focus on certain environmental stimuli while ignoring others(5), however sustained attention is not truly sustained; the brain periodically samples the environment (sampling), suggesting that working memory (and cognition in general) is more complex than a simple persistence of spikes and average spike rates of attention sustained over time(6). The available studies support the conclusion that sustained attention is a complex process, resulting from the interaction of multiple brain systems, however, the nature of these interactions has not yet been well characterized, and the temporal dynamics of the brain's functional response is yet not well understood.(7)

Maintaining attention is essential to mastering everyday life. Sustained attention is a multicomponent mental factor, not a unitary one, which implies an orchestrated work of recurrent processes that are at the service of maintaining attention and its maintenance. For this purpose, the brain is organized into a collection of networks with specialized functionalities that interact flexibly(8). Attention and working memory are clearly intertwined, as they show covariations in individual ability and recruitment of similar neural substrates. Both processes fluctuate over time, and these fluctuations may be a key determinant of individual variations in attention and memory spans.(9)

Attention deficit hyperactivity disorder (ADHD) is a neurodevelopmental disorder that affects healthy psychological functioning and is associated with mental health problems as well as poor academic and social functioning. The DSM-V characterizes ADHD by its three cardinal symptoms: inattention, hyperactivity, and impulsivity. Approximately 2.5% of the population meets the criteria for ADHD.(10)

From a neuroanatomical standpoint, the traditional foci of interest in ADHD included the insular cortices, frontal lobes, basal ganglia, and cerebellum. More recently, attention has been directed to the brain's Default Neural Network and its functional integrity in ADHD with a focus on the precuneus and parietal lobes and interactions with medial prefrontal cortices(11). The Default Mode Network, Negative Task Network or Default Neural Network -DMN- describes a set of functionally connected brain regions that are more active at rest than during externally oriented cognitive tasks. The DMN is a neural network that is activated mainly in the absence of cognitive tasks, moreover, as the demands for attention to external stimuli increase, the activation of DMN decreases and the activation of "positive task" networks increases.(12)

In the context of traumatic brain injuries (TBI), images have been obtained through the diffusion tensor technique -or DTI-, which has made it possible to correlate a structural disconnection within the DMN with the appearance of deficits in the level of sustained attention in subjects previously classified as neurotypical. These results show that abnormalities in DMN function are a sensitive marker of attention deficits and suggest that changes in connectivity within the DMN are central to the development of attention deficits after TBI.[13]

In order to explore the etiology of attention deficit from childhood to adolescence, one study extracted extensive datasets from fMRI examinations of patients of different age groups diagnosed with attention deficit. The findings of brain activity patterns reveal, from a global perspective, an aberrant functional connectivity between several networks, such as the Default Neural Network (DMN), the attentional network and the executive control network[14]. Aberrations in the functional connectivity of these networks could directly contribute to symptom differences in childhood and adolescence in patients with ADHD and without ADHD.

The objective of this literature review was to systematize the functions of the Default Neural Network associated with sustaining attention and the etiologies of attention deficit in children and adolescents in school age. Having systematized information on the role of the DMN will allow teachers and health personnel to agree on the most appropriate cognitive strategies for neurotypical children diagnosed with ADHD according to the neuroanatomical limitations and advantages of each group.

METHOD

A systematic review of empirical-quantitative research indexed in the WOS and Scopus databases was carried out from 2010 to 2020, to obtain evidence on the role of the Default Neural Network -or DMN- in the maintenance of sustained attention, as well as the appearance of attentional deficits with and without hyperactivity. In the research identification stage, the search keywords were: Default Neural Network, DMN, Education, School, Student, K-12, Attention disorder and ADHD.

The inclusion criteria were: Children and/or young people in the school stage were selected from the sample, the study focuses on or includes relevant aspects of the Default Neural Network, the study is empirical, quantitative and/or mixed, the study focuses on relevant aspects of DMN in relation to sustained attention or attentional deficits and the study reports quantifiable results and its method is reproducible.

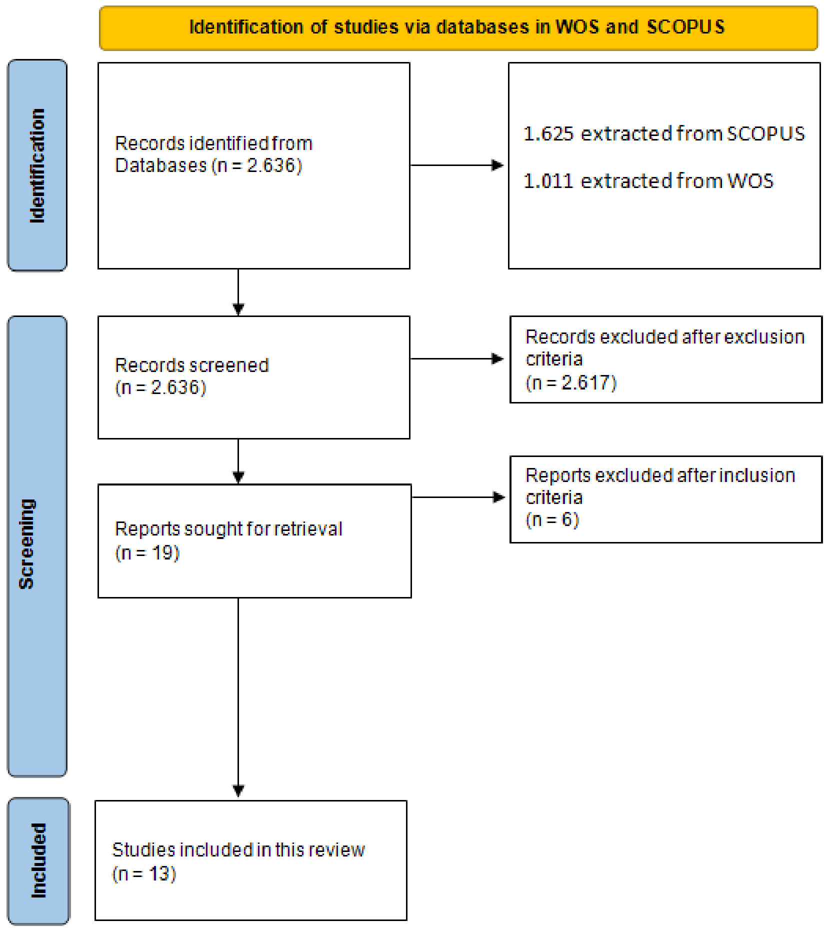
The exclusion criteria were: The sample subjects of the study are mainly outside the school stage, the study does not focus on or does not include relevant aspects of the Default Neural Network, the study is empirical but it is a literature review, the study is not quantitative, the study does not focus on relevant aspects of DMN in relation to sustained attention or attentional deficits, the study does not report quantifiable results or its method is not reproducible.

The investigations selected in the inclusion stage were disaggregated into their essential parts in a data matrix for the extraction of the following relevant information: definitions of sustained attention and attention deficit, the role of the DMN in sustained attention and attentional deficits, characteristics of the participants (age, sample, development -neurotypical or not- and country), and measurement instruments and main result of the study. Based on the main results of the studies, a percentage index of recurrences was created to establish: repetitive etiological patterns that would link the abnormal functioning of the Default Neural Network with the emergence of attentional deficits; the role of the DMN in the maintenance of sustained attention in the neurotypical population.

RESULTS

Of the 2,636 investigations identified in this systematic review (see Figure 1), 19 potentially relevant studies - that did not meet the exclusion criteria- were selected. Finally, only 13 studies were included because they met the inclusion criteria. Once the necessary data was dumped

Figure 1. Flowchart of identification, exclusion, inclusion and selection of research under the systematic review modality used in this review.



into the extraction matrix, the results of the investigations allowed us to arrive at the results presented below **(see table 1, 2 and 3)**.

Cortical thinning

23% of the investigations reported a thinning of the cerebral cortex in children with attention deficit. The cerebral cortex in regions of the right superior frontal lobe is thinner in children, adolescents and adults with ADHD, and there is also a correlation between the cortical thinning of these regions and the severity of the attention disorder 15; Consistently, recent research reported a general decrease in cortical thickness in subjects with ADHD compared to the neurotypical population.[16]

Failure of activation and/or suppression of the DMN

38% of the investigations reported a failure of activation and/or suppression of the Default Neural Network and Attentional Networks in children with attention deficit, which prevents satisfactory sustained attention spans. Children with ADHD have specific disorders in some brain functions during sustained attention, they experience deficits in fronto-striatal-parietal activation and suppression of the Default Neural Network.[17]

This last condition has been documented in another study as a lack of suppression of the DMN that is related to deficiencies in

Table 1. Main results of the investigations.

Ref.	Instrument for measuring sustained attention or brain activity.	Main results of each study.
15	1 cubic millimeter voxel MRI volumetric image.	1. The cerebral cortex in regions of the right superior frontal lobe is thinner in children, adolescents, and adults with ADHD [A]. 2. There is a correlation between cortical thinning of these regions and the severity of the disorder [A]. 3. In all three age groups (children, adolescents, and adults), a diagnosis of ADHD predicts cortical thinning in regions of the right superior frontal lobe, where statistical differences between healthy and ADHD subjects were observed [A].
16	Cortical thickness based on a set of MRI images obtained with time T1.	1. Convergence was found between autism and ADHD, (both conditions show a general decrease in cortical thickness compared to the neurotypical population [A]. 2. Divergence found between autism and ADHD (lower wiring cost in ADHD condition) [C].
17	Brain activation based on fMRI images during cognitive load.	1. Children with ADHD and ASD have specific and shared impairments in brain function during sustained attention (shared deficits were in fronto-striatal-parietal activation and Default Neural Network suppression) [B].
21	1 cubic millimeter voxel fMRI volumetric image.	1. The existence of prominent atypical brain connectivity was evidenced in the components of the default neural network, as well as in the insular cortex for cases of ADHD and its variants [C].
19	8 cubic millimeter voxel fMRI volumetric image.	1. In the group of children with methylphenidate treatment, children with ADHD exhibited greater activation of the right frontal cortex during the suppression of interference [E]. This finding suggests that the accentuated activation of this cortex compensates for the inability to deactivate the DMN in children with ADHD [B].
18	fMRI-based brain activation during cognitive load. 1 cubic millimeter voxel.	1. There is evidence of reduced negative connectivity between positive and negative task networks in ADHD [C]. 2. Unlike typically developing children, DMN continues to develop with age [D]. 3. DMN non-suppression defects are related to deficiencies in vigilance of attention during the execution of tasks [B].
24	RT or reaction time and skipped responses.	1. The presentation of an excitatory prestimulus provides a non-pharmacological mechanism to improve response control in ADHD.
26	fMRI-based brain activation during cognitive load with BOLD and ReHo signal for homogeneity analysis of brain activity.	1. Increased ReHo values were mainly concentrated in the left angular gyrus previously associated with ADHD. 2. The angular gyrus is also part of the frontal-parietal lobe network and is one of the nodes of the DMN network.
20	Brain activation based on fMRI without cognitive load, with an 8 cubic millimeter voxel and subsequent analysis with DTI or diffusion tensor.	1. White matter volume was significantly decreased in ADHD patients compared to normal control subjects [C] and the volume of brain structures was generally smaller in ADHD patients than control subjects except for the putamen and globus pallidus, a 9% reduction in cerebral cortex was also found [A]. 2. In the DMN of ADHD subjects, decreased functional connectivity was found for several of its components [C].
25	Spontaneous brain activity during DMN activation was monitored using fMRI and the BOLD signal according to blood-oxygen need in a group of neurons. Voxel size close to 1 cubic mm.	1. The evidence showed that 40 sessions of 20 minutes of neurofeedback -NFB- consolidated the DMN allowing an appropriate activation in the posterior cingulate, precuneus, the temporoparietal junction and the cerebellar tonsils in children with ADHD [B]. 2. Activation of normalized DMN improved subjects' adaptation to new cognitive challenges [B].
27	Brain activation based on resting state fMRI without cognitive load, with a 3x3x3mm voxel.	1. The use of machine learning in the diagnosis of ADHD is capable of identifying precise biological markers. Notably, most of the altered functional connections were located within or across the cerebellum, DMN, and frontoparietal regions, indicating that alterations in the brain connectome are involved in a large resting-state network [C].
22	Brain activity was measured with rs-fMRI and structural MRI images.	1. From the global perspective, aberrant functional connectivity between various networks, such as the DMN network, the attention network, and the executive control network, could directly contribute to symptom differences in childhood and adolescence in patients with ADHD [C]. 2. From a developmental perspective, there was a delay in the maturation of brain networks in the ADHD group, especially in DMN [D].
23	The brain activity was carried out with the massive analysis of connectomes of the human brain in resting state with the RS-fMRI technique. Variable Voxel Size.	1. Reduced dopamine transporter and decreased dopamine D2 and D3 receptor availability in the ventral and caudate striatum in unmedicated adults with ADHD were associated with inattention and lower motivation scores [E]. 2. The DMN was associated with stronger midbrain connectivity to the ventral tegmental area than to the substantia nigra. 3. Neuroimaging studies support the thesis that an increase in dopaminergic signaling of the DMN with drugs facilitates the deactivation of DMN during cognitive stimulation [B].

Total number of studies analyzed (N=13

Table 2. Frequent etiologies of attention deficit associated with failures of the Default Neural Network.

Code	Concept	ID	N (%)
A	**There is thinning of the cerebral cortex in children with attention deficit.**	15,16,20	**3 (23%)**
B	**There is a failure of activation and/or suppression of the Default Neural Network and Attentional Networks in children with attention deficit, which prevents satisfactory sustained attention spans.**	17,19,18, 23,25	**5 (38,46%)**
C	**There is atypical or altered functional/anatomical connectivity between the Default Neural Network and frontoparietal regions in children with attention deficit disorder.**	16,21,18, 20,22,27	**6 (46,15%)**
D	**There is a dilated or delayed maturation of brain networks in children with attention deficit, especially in the Default Neural Network.**	18,22	**2 (15,38)**
E	**In unmedicated children with attention deficit disorder, lack of attention and motivation is associated with failures in the dopaminergic pathways (mainly lack of dopamine), which affect the components of the DMN and attentional networks, a situation that is susceptible to pharmacological treatment with methylphenidate .**	19, 23	**2 (15,38%)**

Total number of studies analyzed (N=13)

vigilance of attention during the execution of tasks(18). Plausible evidence has been obtained that pharmacological treatment with methylphenidate is capable of reversibly improving the activity of attentional networks and at the same time suppressing DMN during attentional processes.(19)

Atypical anatomical and/or functional connectivity

46% of the investigations reported an atypical or altered functional/anatomical connectivity between the Default Neural Network and frontoparietal regions in children with attention deficit. In an anatomical-functional investigation, white matter volume was significantly decreased in ADHD patients compared to normal control subjects, furthermore, in the DMN of ADHD subjects decreased functional connectivity was found in several of its components(20). In another investigation of functional brain connectivity, in subjects diagnosed with ADHD, the existence of prominent atypical connectivity was evidenced in the components of the Default Neural Network, as well as in the insular cortex, dlPFC and cerebellum(21). Similar results were obtained in a more recent investigation; A reduced negative connectivity is evidenced between the networks of positive and negative tasks in ADHD, that is, the subjects suffering from this disorder have a denser functional and/or anatomical connectivity than the neurotypical subjects between the DMN and Attentional Networks, which that inhibits adequate and mutually exclusive suppression of these networks during periods of attention or cognitive rest.(18)

Delayed brain maturation

15% of the investigations reported delayed maturation of brain networks in children with attention deficit, especially in the Default Neural Network. In typically developing and neurodiverse children, the DMN continues to develop with age 18, however, in certain neurodiverse children, the maturation of the DMN is slower and its maturation period is longer. From a developmental perspective, there is a delay in the maturation of brain networks in ADHD groups, especially in DMN.(22)

Failures in the dopaminergic pathways

15% of the investigations reported that, in unmedicated children with attention deficit, lack of attention and motivation is associated with failures in the dopaminergic pathways (lack of

Table 3. Individual results of the selected studies.

Ref.	Description of the role of the Default Neural Network in sustained attention and attentional deficits
15	The frontal cortex and its connections to various subcortical and brain structures (eg, the basal ganglia and thalamus) are involved in the control of selective motor activity and sustained attention, problem solving, and control of impulsivity. All these cognitive functions are altered in patients with ADHD.
16	The hypo and hyper connectivity of the DMN and TPN are responsible for the cognitive disorders present in autism and attention deficit hyperactivity disorder.
17	The DMN is turned off in normal subjects to maintain sustained attention without interruption.
21	The Default Neural Network is deactivated in the execution of tasks.
19	Children with ADHD and a history of medication have shown atypical brain activation in the prefrontal and striatal brain regions during cognitive challenge.
18	The DMN, also known as the negative task network, is a collection of brain regions whose activities are highly correlated during rest; during goal-directed tasks that demand attention, this network reduces its base level of activity.
24	Between the perception of a stimulus and the choice to respond to it depends on several critical executive function skills, including attention sustaining, rest-mode inhibition, and readiness to respond.
26	The angular gyrus is also part of the frontal-parietal lobe network and is one of the nodes of the DMN; it serves as an intermediate station for the integration of internal and external information, highlights the convergence of different multimodal inputs in the angular gyrus and interactions with different subsystems including memory and attention.
20	The DMN comprises medial brain regions that routinely exhibit decreases in activity consistent with the performance of attention-demanding cognitive tasks.
25	The DMN is a functionally homogeneous set of brain regions that is widely associated with internally directed cognition. During periods of rest, normal populations constantly activate DMN. The opposite seems to be the case with children who have ADHD.
27	Evidence has supported the hypothesis that the clinical symptoms of ADHD are the result of aberrant interactions in large-scale brain networks, such as the cerebellum, DMN, and frontoparietal regions.
28	ADHD patients may present a delay in the development of brain networks compared to typically developing subjects, especially in DMN.
23	During infancy, the DMN shows poor functional connectivity that increases with development. Abnormal DMN function has been associated with various psychiatric disorders including ADHD.

Total number of studies analyzed (N=13)

dopamine as the main cause), which affect the components of the DMN and attentional networks, a situation that is susceptible to pharmacological treatment with methylphenidate. In a study based on event-triggered brain activity, fMRI images provide evidence of greater activation of the right frontal cortex in children diagnosed with ADHD with active methylphenidate treatment, which allowed better suppression of interference from unsuppressed activity from the DMN[19]. In a study dedicated to obtaining evidence of damage to the dopaminergic pathways via rs-fMRI in neurotypical children diagnosed with ADHD, a reduction in the dopamine transporter and less availability of the dopamine D2 and D3 receptor in the ventral striatum and caudate were evidenced in adults with ADHD. Damage to dopaminergic pathways includes or extends to structures associated with DMNs. In unmedicated ADHD children, these dopaminergic pathway failures were associated with inattention and lower motivation scores.[23]

Role of the default neural network in sustained attention

The role of the DMN on sustained attention seems to be mainly associated with the ability of the subject to suppress the DMN during periods of activity of the prefrontal attentional networks[17], likewise, other authors have obtained evidence showing that the DMN is deactivated during the execution of tasks[21], or its activation is inhibited to give way to executive functions[24]. From a metabolic point of view, according to fMRI results, DMN reduces its BOLD signal -or oxygen consumption- during the execution of tasks that demand attention[18]. The evidence mainly points to a successful deactivation of the DMN in neurotypical subjects during the execution of cognitive tasks, on the contrary, subjects diagnosed with ADHD are not able to suppress its activity during periods of attention, nor are they able to activate it properly during rest periods.[25]

CONCLUSIONS

The Role of the Default Neural Network (DMN) in sustained attention is evidently indirect, in neurotypical subjects the activity of the DMN is suppressed during the activation of neural networks that support attentional processes[17], however, this deactivation is not successfully executed in subjects suffering from ADHD[25]. The causes that trigger a failure in the deactivation of the DMN during tasks that demand attention to externally directed events are varied: among them we have the thinning of cortical zones associated with attentional networks[15], a delayed maturation of brain zones, especially the DMN[22] and the classical etiology of attention deficit disorder associated with failure of dopaminergic pathways. A failure of the dopaminergic pathways involving attentional networks does not allow adequate activation of attentional networks or temporary suppression of DMN, a condition that is susceptible to pharmacological treatment with methylphenidate.[19]

Finally, a growing body of research has presented convincing evidence of aberrant anatomical and/or functional connectivity between DMN components in ADHD subjects[21], specifically hyper- and hypo-connectivity between the DMN and attentional networks[18], which would have as a correlate poor attention ability in subjects suffering from ADHD.

Future Recommendations

For the purposes of future literature reviews, whether narrative, systematic or meta-analyses, it is recommended to expand the search to other databases that, although they might not have the scientometric weight of those included in this review, their contributions could complement and supplement with other studies the roles of the Default Neural Network in attention processes and the emergence of different types of attention deficits with and without hyperactivity. Having incorporated only 13 studies is justified by only covering research that included children in school age.

Another relevant recommendation that emerges from this study, is that future research should incorporate correlations that links the functioning of the Default Neural Network with the academic performance of children with ADHD, this would make it possible to have background information that allows organizing the teaching-learning processes considering the characteristics and limitations in the functioning of the DMN, in order to design interventions that are adapted to the real educational needs that children present. Planning a lesson according to DMN limitations and functioning would have as a correlate the adequate response to the requirements of attention to neurodiversity that national and international regulations demand in terms of educational inclusion.

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