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Oculomotor Convergence and the Dorsal Attention Network: A Neurophysiological Mechanism for Focused Attention

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Abstract

The ability to focus attention on particular stimuli is essential for many aspects of everyday life. Various aspects of the brain have been theorized to be essential to the development of focused attention, including both oculomotor convergence (the rotation of the eyes in order to enable near-vision fixation) and the Dorsal Attention Network (DAN). Through the review of existing research, this article investigates and explores the connection between oculomotor areas (like saccades and vergence) and areas of the DAN (like the frontal eye fields and intraparietal sulcus), as well as in what ways such a connection may contribute to or facilitate the development of focused attention. Additionally, a consideration of the Default Space Theory (DST) is also employed to help explain how such a relationship facilitates focused attention due to the DST explanation of the creation of a 3D internal simulation space, which is generated through thalamic fill-in of sensory data and is modulated according to cardiorespiratory oscillations. Through these investigations and discussions, a better understanding of focused attention and its underlying mechanisms can be developed.

Keywords

Oculomotor Convergence; Dorsal Attention Network; Focused Attention; Frontal Eye Fields; Intraparietal Sulcus; Default Space Theory; Vergence; Saccades; Thalamocortical Loops.

Introduction

The ability to focus attentively on a particular task is vital for concentrating on any specific job or activity. Such focused attention, or the ability to select and actively process specific information while suppressing irrelevant information, is essential for performing certain tasks, such as reading, decision-making, and the like [1]. Techniques for studying attention and focus have evolved since the early psychologists of the late 1800s studied the element of human focus and will be examined in this review. More recently, focused attention has been shown to be related to activity in the brain's dorsal attention network (DAN), a region comprising the frontal eye fields (FEF), the intraparietal sulcus and superior parietal lobule (IPS/SPL), and the motion-sensitive middle temporal area (MT+) [2,3]. Additionally, oculomotor convergence, which is the eye movement that allows individuals to focus on near objects in their environment, has been shown to play a role in attentional focus [4]. Oculomotor control and visual attention appear to be related, as eye movements predict activation of the dorsal attention network even in tasks that do not require visual attention [5]. Relatedly, theories like the Default Space Theory (DST) suggest that consciousness includes an element of focused attention, which is neurophysiologically facilitated not only by the DAN, but also by oculomotor convergence [6,1]. An exploration of these concepts regarding focused attention suggests that oculomotor convergence may act as a neurophysiological pathway through which the DAN facilitates its role in focused attention.

Methods

This narrative review will examine the relationship between oculomotor convergence and the DAN's role in enabling focused attention. To identify relevant research, databases such as PubMed, Google Scholar, Scopus, and Web of Science will be searched. Keywords and phrases like "oculomotor convergence," "dorsal attention network," "focused attention," and "frontal eye fields" will be used. Boolean operators will help refine the search, and filters for English language, human and animal studies, and peer-reviewed articles will be applied. The inclusion criteria will focus on studies that explore the anatomy, physiology, neuroimaging, and clinical implications of the convergence and DAN interaction. Studies that do not pertain to these topics or do not provide full research findings will be excluded. An estimated 1,500 articles might initially be found, from which a preliminary selection of 400 research papers may be made. From this sample, approximately 50 studies will be selected based on their relevance, quality (impact factor >5, citation count >50), and methodological rigor. The results from these articles will be qualitatively synthesized to identify patterns, relationships, and gaps in the literature regarding the physiological role of convergence in the DAN and how DST's premise integrates this physiological mechanism into a larger conceptual framework of attention networks in the brain. No meta-analysis will be conducted due to the qualitative nature of the synthesis and the expectation that the methodologies across relevant studies will be too heterogeneous for quantitative comparison.

Overview of oculomotor convergence

Another oculomotor mechanism, convergence, is mediated by the Edinger-Westphal nucleus and the supraoculomotor area [7]. Convergence triggers the simultaneous contraction of the medial rectus muscles and pupillary constriction and lens accommodation (collectively called the near triad) [8]. Convergence and other vergence eye movements are much slower (5-10 degrees per second) than

saccadic eye movements (200-800 degrees per second) [8]. The neurophysiological mechanisms of convergence involve a broad neural network spanning from the brainstem to the cortex [8]. From a neurophysiological perspective, convergence eye movements gate attention [9]. Convergence movements, according to eye-tracking studies, correlate strongly with the internal attentional focus, increased pupil diameter, and decreased microsaccades [5]. Within the DST, convergence gate attentional mechanisms may contribute to the creation of a default space by way of depth cues that oscillate along with cardiorespiratory rhythms to produce or maintain the oscillatory stabilization of the default space [10]. Clinical disjunctions in convergence such as convergence insufficiency (CI) manifest in symptoms related to blurred vision and attentional fatigue [11].

Overview of the dorsal attention network

Dorsal Attention Network: Includes frontal eye fields (FEF) and intraparietal sulcus (IPS) for visual attention [2]. This network plays a crucial role in voluntary/top-down attention and enhancing signals in sensory cortices. Neurotransmitters like norepinephrine and acetylcholine enhance the effects of the dorsal attention network [12]. Functional connectivity studies show the dorsal attention network interacts with the ventral attention network and the cerebellar lobules VIIb and VIIIa, which play a role in sustained attention [13]. Interestingly, research shows the dorsal attention network is active in auditory attention and predicts success with auditory tasks from eye movements [5]. According to DST, the dorsal attention network modulates the 3D default space and produces infraslow oscillations that coordinate sensory integration [1]. Lesion studies show that spatial neglect results from damage to the right dorsomedial frontal cortex area of the dorsal attention network [14].

Oculomotor convergence and DNA in focused attention

Several neuroimaging studies (fMRI combined with eye-tracking) have identified a strong relationship between convergence and the dorsal attention network (DAN) when an individual focuses their internal attention on a specific target. The DAN is a brain network involved in top-down, voluntary attention and oculomotor control; it includes regions such as the frontal eye fields (FEF) and the intraparietal sulcus (IPS) [9]. Studies have shown that as internal attention converges on a target, activity in visual networks decreases while activity associated with vergence and the DAN increase [12]. Other studies have also utilized brain mapping techniques like direct electrical stimulation (DES) and lesion-symptom mapping (LSM) to identify hubs within the DAN that pre-activate prior to eye movements and shifts in attention [14]. Relatedly, the DAN shows activity with increasing working memory load, illustrating its versatile role in attention, eye control, and cognitive functions [13]. In the context of the default space theory, the integration of visual input via convergence engages this hub to pre-activate the oculomotor system, which facilitates efficiently focused attention on the multisensory experience within default space. These findings of the DAN's involvement with oculomotor as well as cognitive and multisensory functions suggest that its nodes may be part of a generalizable mechanism that integrates sensory inputs into default space. Supporting the supramodal nature of such mechanisms, studies report that even auditory-focused attention can evoke oculomotor system responses [5].

Integration: A Neurophysiological Mechanism

The convergence-DAN pathway is also responsible for projecting midbrain vergence signals to the DAN. This feature enables the DAN to modulate the visual cortices for focused attention [15]. According to DST, cardiorespiratory synchronization with the alpha and beta waves of the DAN stabilizes the 3D space in which attention can be focused [10]. Higher states of consciousness such as meditation boost this feature by enhancing vagal tone, which expands the space in which sustained attention is possible [1]. This pathway aligns with the global workspace theory of consciousness. The attentional priority that the brain's oculomotor system generates is broadcast by the DAN [16]. Many disorders or injuries such as CI in conditions like ADHD or neglect after a stroke are disruptions to this mechanism. Based on this, vision therapy, DES, and other interventions have been proposed by neuroscientists to improve the function of this mechanism [14].

Discussion

Despite the unification this theory provides, it also has its limitations and criticisms. However, in seeing each of those limitations and criticisms, there are possibilities of future technologies that can overcome them. Some of those future technologies have the potential to validate DST. Additionally, with the understanding of DST, technologies have been theorized to make advancements in the treatment of neurological disorders.

Conclusion

The integration of these areas has significant implications regarding cognitive deficits and possible treatment options. Research developments can enhance and add to this theoretical model. One of the neurophysiological mechanisms essential to the DAN is oculomotor convergence, which relates to the 3D default space model's emphasis on focused attention and the sensory input to achieve this.

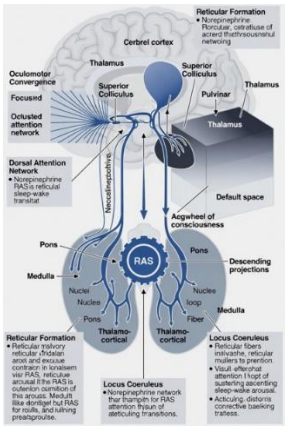

Figure 1: Neuroanatomical pathways of the Reticular Activating System (RAS) and arousal network.

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