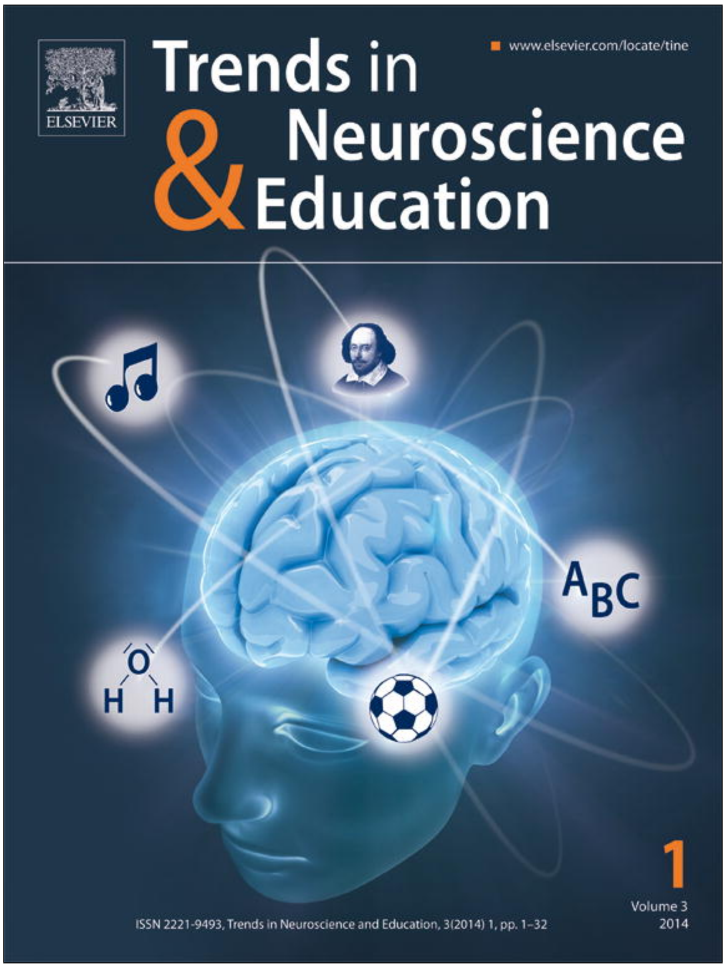
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Trends in Neuroscience & Education
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Volume 3
2014
ISSN 2221-9493, Trends in Neuroscience and Education, 3(2014) 1, pp. 1–32

Trends in Neuroscience and Education 3 (2014) 14–17

Contents lists available at ScienceDirect

Trends in Neuroscience and Education

journal homepage: www.elsevier.com/locate/tine

Review Article

Attention to learning of school subjects

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A R T I C L E I N F O

Keywords:
Alerting network
Anterior cingulate
Executive attention network
Expertise
Hippocampus
Orienting network

A B S T R A C T

In this brief comment we add to our previous discussion (Posner et al., 2013 [26]) about the importance of control mechanisms related to attention networks by dealing with how control influences what is learned and how wide the generalization of the learned information will be. A brain network connecting the anterior cingulate to the hippocampus appears to be important for the registration of new learning. This network provides a mechanism for how attention influences learning. Information coming to mind spontaneously or during testing activates a parietal area related to orienting of attention. Information about attentional control systems related to learning holds promise for new applications to acquire expertise related to all school subjects.

Contents

1. Introduction

Of all the factors that influence learning, attention to the learned material may be the most important (for a review see [7]). Modern psychology distinguishes between explicit learning (e.g., memorizing for recall), in which one has the goal of learning material so that it can be brought to mind consciously, and implicit learning, where performance of the skill is central (e.g., learning to ride a bicycle), and it is possible that being attentive at the time of learning is crucial for both [20]. In any case conscious recall is certainly important for many aspects of school learning. This paper reviews new data from neuroscience on the role of the executive attention network in explicit learning and recall and is designed to update our previous report in this journal on mechanisms of self regulation [26].

In recent years we have begun to understand the brain mechanisms by which attention controls what is learned and remembered [30,34]. These findings have great potential for education, where explicit learning and memory are central to success in school. In this paper we first consider how attention networks are related to learning and memory through connections to the hippocampus. We then review the development of these networks in infancy and childhood. Finally, we discuss how attention relates to the learning that is acquired in schools by considering expertise as it applies to skills important in elementary school and then to algebra as an example of skills acquired in secondary school.

2. Attention networks

Brain networks related to attention are: the alerting, orienting and executive network [22,24]. The alerting network involves the locus coeruleus, the source of the brain's norepinephrine, in conjunction with dorsolateral portions of the frontal and parietal lobes.

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http://dx.doi.org/10.1016/j.tine.2014.02.003
2211-9493

Achieving and maintaining the alert state are obviously important to school learning but play a smaller role in this paper.

The orienting network, sometimes called the fronto-parietal network [9], is involved in attending to external signals regardless of sensory modality. It includes a ventral portion, the temporal parietal junction, that is involved in automatic orienting, when a strong unexpected signal occurs. A more dorsal portion includes the superior parietal lobe and frontal eye fields involved in voluntary orienting. During infancy, emotional and cognitive control primarily involve the orienting network [25,28]. While in later childhood and adulthood the orienting network continues to provide some form of control, as when we look away from a negative scene in order to control strong emotional response, the executive network is predominant in cognitive and emotional control for adults.

The executive network involves the anterior cingulate, anterior insula and ventral prefrontal cortex and their connections to the underlying striatum and autonomic nervous system [22,32]. Studies using fMRI show that this network is active during tasks involving conflict, but other forms of executive control also activate it [22].

3. Attention and the hippocampus

Recently studies have begun to examine the anatomy by which these attention networks influence the storage and retrieval of information from memory. Psychologists have long recognized the important role of mid-temporal lobe structures, in particular the hippocampus, in learning new information. Support for the importance of the hippocampus arose from lesion data in which the patient HM was unable to store new memories following bilateral excision of this brain area to reduce seizures. Animal and imaging data subsequently supported an important role for the hippocampus when conscious recall of stored memories was needed. Most studies of memory have examined the role of the hippocampus in the storage and retrieval of new memories. The hippocampus and neighboring structures appear to play a central role in storing new memories when they need to be recalled [30]. However, the role of the hippocampus is time limited in duration with its involvement in recent memories being more important than for remote memories [34]. It is thought that the consolidation of memory allows long term storage in cortical areas related to the sensory and motor aspects of the stored material, although the hippocampus may have an important role in indexing these memories.

While psychologists have long known that attention is crucial for the storage and retrieval of memories, little was known about the pathways by which attention interacted with the hippocampus. Studies on rodents have shown that the anterior cingulate is critical to the recall of information stored for a month or more [34]. In the case of hippocampal dependent memories involving fear conditioning, a pathway connecting the ACC to the hippocampus appears to be involved [34,36]. Not all memories studied in rodents depend upon the anterior cingulate. For example, in classical conditioning studies when the conditioned stimulus overlaps the unconditioned stimulus in time (delayed conditioning), the ACC is not involved in the storage process, but with the same time course if the conditioned stimulus is turned off before the unconditioned stimulus is presented (trace conditioning), there is ACC involvement in storing the trace [12]. However, whether or not the ACC is involved in storage, the anterior cingulate appears to be needed for recall [34]. Work with rats also shows single cell activity and the ACC reflects changes in reward contingencies and other external information that summon attention through surprise [6].

The ACC connection to the hippocampus pathway in mice appears to be critical for the rodent to obtain the proper level of generalization. After being conditioned to a shock in one context, mice with intact ACC is generalized to similar but not to dissimilar contexts. However, those with inactivated ACC show over generalization, and respond with fear to dissimilar contexts [36]. The authors argue that the ACC and mid prefrontal cortex via links to the hippocampus control the degree of generalization of memory.

Imaging studies with humans have revealed a role for executive and orienting networks in aspects of storage and retrieval. In one study undergraduate students are taught to attend closely to stimulus–response pairs when they are presented in green (think condition), but to avoid thinking about the association when presented in red (no-think condition). Subsequent tests and controls show that the instruction to avoid thinking produces a very poor memory of the paired relationship in comparison to the instruction to attend. Purging the item from memory activates the areas of the executive attention network including the ACC and lateral frontal areas, but reduces activity in the normally active hippocampus. The extent of the activity in lateral frontal areas is correlated with the reduction in the hippocampus as if the attention network was serving as a gain control for the storage system [3].

More recent studies ([17]; in process) with the same think no-think task described above found a role for posterior structures related to the orienting network in memory suppression. The participants were trained to report when despite the no-think instruction, they thought about the paired association. These intrusions on no-think trials were compared with no-think trials in which no intrusions were reported. This comparison showed activity in an area of the right angular gyrus. The right angular gyrus was shown to overlap with the area of the right temporal parietal junction found to be active in visual orienting tasks using spatial cues [9]. When people are instructed to rehearse an association during a test phase there is angular gyrus activation specifically related to the test session, this time in the left hemisphere [21]. Thus when thoughts come to mind, whether or not we are instructed to attend to them, they appear to activate the orienting network, while the effort to suppress the thought activates the executive network.

4. Development

These findings fit rather well with the development of attention in infants and children. We began our studies on 7 month old infants and have published results up to 4 years of age. We find that in infancy the orienting network is well developed and guides the child to critical behavior to be learned [25]. For example, we are familiar with the tendency to look at the eyes of a person with whom one is engaged in conversation. This eye to eye contact is fostered in infancy by the relatively high spatial frequency information that tends to lock the infant's eyes to the caregiver's gaze. However, between 4 and 12 months the infant more frequently looks at the mouth [16]; during that time the research has shown there is critical learning that tunes the infant's phonemic language structure [15,35]. Later on when infants are learning to name objects, they tend to focus on the objects to which their caregiver attends (this has been called joint reference, [4]). Thus attention fosters the learning of phonemes late in the first year and in the second year the names the caregiver gives to objects in the environment.

Our studies show that the anterior cingulate, a key node of the executive network, operates at 7 months when infants detect an error [5]. While the network is present in infancy it does not play as strong a role in control of behavior as later in childhood because of the lack of connectivity which only develops slowly. For example, the control that leads people to slow down after they have made an error and which also involves the anterior cingulate does not occur until 3 years later [13]. During that time the executive system is becoming connected to many additional parts of the brain that provide the basis for the control of voluntary behavior [11].

5. Learning in schools

How do these findings relate to the learning of school subjects? Multiple studies have shown that individual differences in self control make a major difference in school and in life outcomes [8,19]. However, we do not yet know how much of this relationship is mediated by connections to the hippocampus and how much by emotional and other pathways related to control. One relevant finding is that while effortful control, a measure of parental observation of their child's self control [27], is correlated with middle school performance in almost all school subjects, the measure of executive attention from the ANT only correlates with middle school mathematics, which is arguably a somewhat purer measure of domain specific learning than most other subject grades [8]. It may be that mathematics, which is more subject to objective grading, depends more upon the purely cognitive parts of the anterior cingulate related to the ANT, while other subjects may involve more emotional control systems.

A large literature in psychology argues that expertise involves sustained effort to acquire domain specific knowledge [31]. Studies of the biology of brain networks underlying expert performance suggest that training may not be the full story of who becomes an expert. The ability and persistence in the acquisition of such knowledge is subject to the constraints of genetics and brain efficiency as measured by executive attention [23]. This form of individual difference may well rest on the connectivity between the executive attention network and hippocampus, allowing for more efficient knowledge acquisition.

Neuroimaging has allowed us to understand mechanisms of expertise in particular domains. Some of these domains, such as perceiving faces, are common to most or all humans, while others, like reading words, are of critical importance for school. Both of these skills depend, in part, on highly specialized mechanisms within the brain's visual system. The efficient perception of faces depends on the right fusiform gyrus (fusiform face area; [14]). In the case of words there is an important computation involved in word recognition that depends upon the left fusiform gyrus [29]. The visual perception of words is clearly learned, and while face perception has innate components there is evidence that face perception differs greatly with the familiarity of the face. Moreover, improved recognition due to expertise in birds or dogs also modifies posterior visual brain areas [33]. Since the early stages of acquiring expertise involve high levels of directed learning, it seems likely that at early stages learning depends upon the links between executive attention and the hippocampus. After expertise is obtained evidence suggests that these posterior areas can operate without high levels of attentional control [23].

Many researchers have established the differences between those highly trained in physics (experts) and those untrained in the perception of motion (novices) [18]. For example, in judging how a yo-yo placed on its rollers and given a tug on its string extended leftward, novices frequently guess that it will roll clockwise away from the direction of the tug, while most experts correctly predict a roll counterclockwise in the direction of the tug. Listening to experts discuss how they make the judgment reveals that extensive semantic knowledge lies behind the judgment, but the ease and the speed of the judgment suggest that experts simply see the yo-yo differently. As discussed above studies of the neural systems that underlie high level skill for words or faces and for dogs (in dog experts) or birds (in bird experts) suggest that this knowledge alters posterior visual systems, so that the highly skilled person simply sees the face or word differently. The posterior localization is not merely for categories common to all people but can be obtained from expertise achieved by learning. These findings begin to provide a basis for understanding how the brain is changed during the estimated 10,000 hours of training necessary to obtain expertise in a domain [10].

An approach to the study of high level cognitive tasks learned in secondary school involves studies of high school Algebra. Using principles of cognitive science, John Anderson and his colleagues have developed an intelligent tutoring system which is currently used in 1000 schools in the U.S. involving more than 500,000 students [1]. Recently imaging studies have been used to connect brain areas with some of the functions performed by the tutor. In one study [2] fMRI was used to study changes in brain areas following 6 days of training. The study examined six brain regions identified in previous studies as important in carrying out Algebra problems [1]. Among these areas was the anterior cingulate, which was found to be active early in problem solution and was identified holding the subgoal used in solving the problem. The ACC operates in conjunction with the lateral prefrontal cortex in the storage and retrieval of declarative memories. Unfortunately this study did not examine concurrent activity in the hippocampus, so we do not know for sure that these frontal structures are using pathways described above to influence the hippocampus, but hopefully future studies using the intelligent tutor technology will examine this possibility.

Attention is clearly important for the learning of school subjects. In this paper we have reviewed recent information concerning the pathways by which attention controls what is learned. It is our hope that this improved understanding may illuminate the mechanisms involved in the achievement of high levels of skill needed in learning many areas studied in school.

Acknowledgments

This work was supported by NICHD grant HD060563 to Georgia State University subcontracted to the University of Oregon.

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