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Review Article

Attention to learning of school subjects

Michael I. Posner*, Mary K. Rothbart

Department of Psychology, 1227 University of Oregon, Eugene, OR 97403, USA

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ABSTRACT

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.

* Corresponding author. Tel.: +1 541 3464939; fax: +1 541 3464914.
E-mail addresses: mposner@uoregon.edu (M.I. Posner), maryroth@uoregon.edu (M.K. Rothbart).

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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