University of Oregon

Institute of Cognitive & Decision Sciences

Attention

Michael I. Posner
Kevin A. Briand

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Address Correspondence to: Dr. Michael I. Posner
Department of Psychology
Straub Hall
University of Oregon
Eugene, OR 97403-1227
(503) 346-4939

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1. ATTENTION

Michael I. Posner and Kevin A. Briand
Dept. of Psychology, University of Oregon, Eugene, Or.

BACKGROUND

The problem of selective attention is one of the oldest in psychology. William James wrote at the turn of the century "Everyone knows what attention is. It is the taking possession by the mind in clear and vivid form of one out of what seem several simultaneous objects or trains of thought." This article deals with two aspects of attention. The first is the selection of information for conscious processing and action. The second is the maintenance of the alert state required for attentive processing.

The dominance of behavioral psychology postponed research into the internal mechanisms of selective attention in the first half of this century. The finding of Moruzzi and Magoun that the integrity of the brain stem reticular formation was a necessity to maintain the alert state provided some anatomical reality to the study of an aspect of attention. The quest for information processing mechanisms to support the more selective aspect of attention began following World War II with studies of selective listening. Broadbent proposed a filter, limited for information (in the formal sense of information theory), and located between highly parallel sensory systems and a limited capacity perceptual system.

Selective listening experiments supported a view of attention that suggested very early selection of a relevant message with non selective information being lost to conscious processing. However, on some occasions it was clear that unattended information was processed to a very high level, since there was evidence that a very important message on the unattended channel might interfere with the selected channel.

In the 1970's psychologists began to distinguish between automatic and controlled processes. It was found that words could activate their semantic associates even when the person had no awareness of the word's presence. These studies indicated that the parallel organization found for sensory information extended to semantic processing. Thus, selecting a word meaning for active attention appeared to suppress the availability of other word meanings. Attention was viewed less as an early sensory bottleneck and more as a system for providing priority for motor acts, consciousness, and memory.

Another approach to problems of selectivity arose in work on the orienting reflex. The use of slow autonomic systems, such as skin conductance as measures of orienting, made it difficult to analyze the cognitive components and neural systems underlying orienting. During the last 15 years, there has been a steady advance in our understanding of the neural systems related to visual orienting from studies employing single cell recording in alert monkeys. This work showed a relatively restricted number of areas in which the firing rates of neurons were enhanced selectively when monkeys were trained to attend to a location. At the level of the superior colliculus (midbrain), selective enhancement could only be obtained when an eye movement was involved, but in the posterior parietal lobe of the cerebral cortex, selective enhancement occurred even when the animal maintained fixation. An area of the thalamus, the lateral pulvinar, was similar to the parietal lobe in containing cells with the property of selective enhancement.

Until recently, there has been a separation between human information processing and neuroscience approaches to attention using non-human animals. The former tended to describe attention either in terms of a bottleneck which prevented limited capacity central systems from overload, or as a resource that could be allocated to various processing systems in a way analogous to the use of the term in economics. On the other hand, neuroscience views emphasized several separate neural mechanisms that might be involved in orienting and in maintenance of alertness. Currently, there is an attempt to integrate these two within a cognitive-neuroscience of attention. For example, studies of visual search have incorporated a modern neuroscience view of a multichannel visual system with separate mechanisms to dealing with color, form and motion with the cognitive idea of a separate visual attention system needed for integrating information from these channels when the target requires it. Below we place emphasis on this integrated viewpoint.

CURRENT STATE

Methods. An impressive aspect of current developments in this field is the convergence of evidence from various methods of study. These include performance studies using reaction time, recording from scalp electrodes, and lesions in humans and animals, as well as various methods for imaging and recording from restricted brain areas including individual cells.

Current progress in the anatomy of the attention system rests most heavily upon two important methodological developments. First, the use of microelectrodes with alert animals allowed evidence for the increase in activity of cell populations with attention. Second, anatomical (CT, MRI) and physiological (PET) methods of neuroimaging allowed more meaningful investigations of localization of cognitive function in normal persons. The future should see combined use of localizing methods (e.g. PET) with noninvasive methods of tracing the time course of brain activity in the human subject based on scalp electrical and magnetic recordings. This combination should provide a convenient way to trace the rapid time dynamic changes that occur in the course of human information processing.

<u>Principles</u> Three fundamental working hypotheses characterize the current state of efforts to develop a combined cognitive-neuroscience of attention. First, there exists an attentional system of the brain that is anatomically separate from various data processing systems that may be activated passively by visual and auditory input. Second, attention is carried out by a network of anatomical areas. It is neither the property of a single brain area nor is it a collective function of the brain working as a whole. Third, the brain areas involved in attention do not carry out the same function, but specific computations are assigned to different areas.

It is not possible to specify the complete attentional system of the brain, but something is known about the areas that carry on three major attentional functions: orienting to sensory stimuli most particularly locations in visual space, detecting target events, whether sensory or from memory, and maintaining the alert state.

<u>Orienting</u> Usually we define visual orienting in terms of the foveation of a stimulus. Foveation improves efficiency of processing

targets in terms of acuity, but it is also possible to change the priority given a stimulus by attending to its location covertly without any change in eye or head position. When a person or monkey is cued to attend to a location, events that occur at that location are responded to more rapidly, give rise to enhanced scalp electrical activity, and can be reported at lower threshold. This improvement in efficiency is found within the first 150 milliseconds after an event occurs at the location to which the subject is to attend. Similarly, if people are asked to move their eyes to a target, an improvement in efficiency at the target location begins well before the eyes move. This covert shift of attention appears to function as a way of guiding the eyes to appropriate areas of the visual field. Brain injury to any of the three areas that have been found to show selective enhancement of neuronal firing rates will cause a reduction in this ability to shift attention covertly. However, each area seems to produce a somewhat different deficit. Damage to the posterior parietal lobe has its greatest effect on the ability to disengage from attentional focus to a target located in a direction opposite to the side of the lesion. The effects of the parietal lobes of the two cerebral hemispheres are not identical.

Damage to the right parietal lobe has a greater overall effect than does damage to the left parietal lobe. There is dispute about the reasons for the asymmetries that are found. One account supposes that the right parietal lobe is dominant for spatial attention and controls attention to both sides of space, while the left parietal lobe plays a subsidiary role. According to another account, the right parietal lobe is influenced more by the global aspects of figure, while the left parietal lobe is more influenced by local aspect. A third view argues that the ability to disengage is handled symmetrically by each hemisphere, but the maintenance of the alert state is asymmetric. Testing these theories requires comparisons between separate populations of patients with left and right lesions, and thus it is difficult to arrive at a clear choice. And of course, more than one may be correct.

Lesions of the superior colliculus and surrounding midbrain areas also affect the ability to shift attention. However, in this case the shift is slowed whether or not attention is first engaged elsewhere. This finding suggests that a computation involved in moving to the target is impaired. In addition, patients with damage in this midbrain area also return to former target locations as readily as to fresh locations that have never been attended. Normal subjects and patients with parietal and other cortical lesions show a reduced probability of returning attention to an already examined location.

Patients with lesions of the thalamus and monkeys with chemical lesions of one thalamic nucleus (the pulvinar) also show difficulty in covert orienting. This difficulty appears to be in selective attention to a target on the side opposite the lesion, so as to avoid responding in error to distracting events that occur at other locations. A study of patients with unilateral lesions of this thalamic area showed a slowing of responses to a cued target on the side opposite the lesion even when the subject had plenty of time to orient there. This contrasted with the results found with parietal and midbrain lesions, where responses are nearly normal on both sides once attention has been cued to the location. Alert monkeys with chemical lesions of this area made faster than normal responses when cued to the side opposite the lesion and given a target on the side of the lesions, as though contralateral cues were ineffective in engaging their attention. They were also worse than normal when given a target on the side opposite the lesion irrespective of the side of the cue. Data from normal human subjects, required to filter out irrelevant visual stimuli, showed selective metabolic increases in the pulvinar.

These findings make two important points. First, they confirm the idea of anatomical areas carrying out individual cognitive operations. Second, they suggest a particular hypothesis of the circuitry involved in covert attention shifts. The parietal lobe first disengages attention from its present focus, then the midbrain is active to move the index of attention to the area of the target, and the pulvinar is involved in restricting input to the indexed area.

While the circuitry described above remains speculative, it is clear that patients with parietal lesions have difficulties in pattern recognition, implying that somehow the parietal lobe damage comes to affect processing of patterns. The dorsal pathway extending from the primary visual cortex to the parietal lobe appears to mediate selective visual attention. Considerable anatomical data suggest that a second, ventral cortical pathway, leading from the striate cortex to the infratemporal cortex, is involved in processing color and form during pattern recognition. There is evidence from single cell recording in alert monkeys that visual spatial attention affects this pattern recognition system. Attention to a visual location affects the processing of stimuli within the receptive fields of V4 neurons. Area V4 lies along the ventral pattern recognition pathway known to be active when monkeys are processing color and form information. While it is not known how attention gains access to V4, one likely candidate is via the pulvinar, which has close connections both to the parietal system and to V4.

Cognitive studies of normal humans have been important in exploring how attention influences pattern recognition processes. A major distinction is between the processing of simple features (e.g., line orientation, color) and the processing of items defined by a combination of features (e.g., red vertical line). Simple features appear to be processed in parallel; that is, the search time is not affected by the number of non-target items in the display. When targets are defined by a combination of attributes (e.g., red vertical line) that are located within displays of highly similar non-targets (e.g. red horizontal lines and green vertical lines), the search appears to be a serial process and takes longer as the number of distractors increases. There is evidence that the visual orienting system described above is also involved in visual search.

One theory of how attention affects pattern recognition holds that it works to combine separate features into unitary percepts. According to this view, simple features are not combined until one orients attention to them. It is for this reason that attention is necessary to search for a conjunction of features. When a target is made of features that are also present in distractors, there can be illusory conjunctions due to an improper conjunction of elements from different locations. It is to avoid such illusory combination that one attends selectively to each item present in the array.

There is a second aspect to the visual orienting attention system. Just as we can attend to a spatial location, we can also attend to a small object or to a large object. If one views a large letter composed of small ones, it is possible to attend either to the overall form or to its constituents. The size of feature selected is related to the spatial frequency selected. When attending to local objects, people are relatively good at detecting high frequency probes, but when attending to global objects, they are relatively better for low frequency stimuli.

There is evidence from both normals and patients that the right hemisphere is biased toward global processing and the left toward local processing. When given a large letter made of small letters, patients with right parietal lesions copy the local letter but miss the global organization, while patients with left hemisphere lesions copy the global orientation while missing the local constituents.

We have concentrated upon visual orienting since that has been the area for which integration between cognitive and neuroscience studies have been most advanced. However, the earliest studies of selective attention used the two ears or the eyes and ears as channels for the presentation of sensory information. There is good evidence that one can bias processing toward one ear or one particular frequency. When this is done, the electrical signal from the selected channel is amplified with respect to information on unsolicited channels. When required to do so, subjects do quite well in attending to several channels at once. However, an exception to this generally good parallel processing arises when targets occur on more than one channel. The interference between targets can happen both between as well as within sensory channels, and the reasons for this form of sensory interference are discussed in the next section.

Cognitive Control A persistent issue in cognitive psychology is whether one should think of an executive exercising voluntary control. In one sense this raises the issue of a homunclus and the possibility of an infinite regress. Despite this problem, there appears to be little doubt that there is some central control over our behavior and thought patterns. In particular, the study of human expertise in problem solving and other behavior has always considered a central executive system that can describe at least a significant portion of the mental operations involved in problem solving.

More precisely, there is evidence of a limited capacity at some level of the system relatively close, but not identical to, motor actions. If a person must make two rapid responses, there will be interference between them even when the stimuli are in different modalities, and the responses differ so that one is vocal and the other manual. In fact, this kind of central interference does not depend upon any immediate response requirement. As described above, evidence suggests that a person can monitor several channels for rare targets with relatively little interference between the channels. However, if two targets occur at once, even if the subject's only task is to note whether there was one or two targets and need not make any immediate response, there is a great deal of interference between the targets. This finding underlies the idea that there is a limited capacity system which is involved whenever a signal (sensory or memorial) is to be consciously noted. There is also a good deal of evidence that the storage of recently presented information, generation of ideas from long term memory and other such acts, will interfere with the detection of new signals. In this sense, there does appear to be a unified executive system involved in many forms of cognitive and motor action.

Similar issues about attention arise in the study of the neural mechanisms underlying attention. Should attention be thought of as a unified system of many anatomical areas (as, for example, is found for the visual system), or are there many independent attentional systems. There are clearly close anatomical and behavioral ties between the posterior areas mediating visual spatial attention and areas involved in the control of eye movements and manual movements into the surrounding space. Although both cellular and performance studies argue that attention enhances the visual input in several posterior areas, it seems likely that much of its effect lies in differential access to more motor regions of the brain. Indeed, studies of patients with parietal lesions and of normals have examined whether a shift of covert attention can be performed when the person is engaged in an attention demanding language task. There is apparently very specific interference between the two tasks as though they involved a single system.

There is some evidence that areas of the frontal lobe are active during both language and spatial tasks. Studies of blood flow and metabolism have shown frontal activation during tasks involving language and spatial imagery. Studies of normal subjects processing individuals words show changes in blood flow for frontal midline areas, including the cingulate gyrus and supplementary motor when subjects were required to process the input actively. Moreover, experimental studies show that the degree of blood flow in the anterior cingulate increases regularly as the number of targets to be detected increases. Thus, this area appears to be sensitive to the mental operations of target detection.

The anterior cingulate has an internal organization that shows alternating bands of cells with close connections to the dorsolateral frontal cortex and with the posterior parietal lobe. This organization suggests an integrative role because studies have implicated the lateral frontal cortex in semantic processing while, as we have seen, the posterior parietal lobe is important for spatial attention. The anterior cingulate might provide an important connection between as widely different aspects of attention, such as attention to semantic content and to visual location. Unfortunately, both cognitive and anatomical theories of this type of cognitive control remain highly speculative.

Alerting. The earliest anatomy of attention involved the maintenance of the alert state. Cognitive psychologists have studied changes in alerting, both by using long boring tasks with low target probability, and by use of warning signals to prepare for a target. In both of these situations, there is evidence that an increase in alertness will improve the speed of target processing, and in some conditions, alertness also serves to reduce the accuracy of responding to the targets. The tradeoff between improved speed and reduced accuracy with warning signals has led to a view that alerting does not act to improve the buildup of information concerning the nature of a target, but instead acts on the attentional system to enhance the speed of actions taken toward the target.

There has been some improvement in our understanding of the neural systems related to alerting over the last few years. Patients with lesions of the right frontal area have difficulty in maintaining the alert state. In addition, experimental studies of blood flow in normals during tasks that demand sustained vigilance show right frontal activation.

The neurotransmitter norepinephrine (NE) appears to be involved in maintaining the alert state. This NE pathway arises in the midbrain, but the right frontal area appears to have a special role in its cortical distribution. Among posterior visual areas in the monkey, NE pathways are selective areas that are involved in visual spatial attention. At least one study shows that during the maintenance of vigilance the anterior cingulate is reduced in metabolic activity over a resting baseline. These anatomical findings would support the subjective observation that while waiting for infrequent visual signals, one has to be prepared to orient, but also empty the head of any ideas lest they interfere with detection.

APPLICATIONS AND FUTURE DIRECTIONS

Much remains unknown concerning the macroanatomy of attention, particularly the anterior portions of the system. Studies of blood flow and metabolism in normal persons should be adequate to provide candidate areas involved in aspects of attention. It will then be possible to test further the general proposal that these constitute a unified system and that constituent computations are localized.

We have a start on the circuitry that underlies the posterior attention system. However, more detailed cellular studies in monkeys will be necessary to test these hypotheses, and to understand more completely the time course and control structures involved in covert shifts of attention. Even more fascinating is the possibility that the microstructure of areas involved in attention will be somehow different in organization than those areas carrying out passive data processing. Such differences could give us a clue as to the way in which brain tissue might relate to subjective experience.

Even in our current state of knowledge, ideas about attention have proven useful in integrating aspects of social, developmental psychology with psychopathology.

The idea of attention as a network of anatomical areas makes relevant study both of the comparative anatomy of these areas and their development in infancy. In the first few months of life, infants develop nearly adult abilities to orient to external events, but the cognitive control produced by the anterior attention system requires many months or years of development. Studies of orienting and motor control are beginning to lead to an understanding of this developmental process. As more of the maturational processes of brain and transmitter systems is understood, it should be possible to match developing attentional abilities with changing biological mechanisms. The neural mechanisms of attention must support not only common development among infants in their regulatory abilities, but also the obvious differences between infants in the rate and success of attentional control.

There are many disorders that are often supposed to involve attention. These include neglect, closed head injury, schizophrenia and attention deficit disorder. The specification of attention in terms of anatomy and function may be useful in clarifying the underlying bases for these disorders. The development of theories of deficits may also foster the integration of psychiatric and higher level neurological disorders, both of which might affect the brain's attentional system.

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