

Attention, mechanisms of

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1. Brief history of attention

The problem of attention is the problem of selecting for active processing certain aspects of our physical environment (e.g., objects) or some ideas in our mind (which are stored in our memory). This problem is one of the oldest and most central issues in psychological science. Many great minds have wrestled with the definition of attention. In 1890, William James wrote: "Everyone knows what attention is. It is the taking possession of the mind in clear and vivid form of one out of what seem several simultaneous objects or trains of thought." James' account heavily joins attention with subjective experience. Moreover, James' effort to deal with both attention to objects and attention to "trains of thought" is important for understanding current approaches to sensory orienting and executive control. However, attention in the sense of orienting to sensory objects can actually be involuntary and can occur unconsciously, so attention is not, as the quote from William James implies, the same as being aware.

Behavioral psychology postponed research into the internal mechanisms of attention after 1900. The quest for attentional mechanisms was resumed after World War II by Donald Broadbent. Broadbent proposed a filter, limited for the amount of information (in the formal sense of information theory) that was located between highly parallel sensory systems and a limited-capacity perceptual system. This view was of immense aid in making possible objective studies of limitations in the human ability to deal with more than one signal at a time in a variety of practical tasks.

As psychology moved toward the study of cognitive mechanisms, the new objective methods made it possible to ask about the processes of selection. It was found that words could activate their semantic associates even when there was no awareness to the word's identity (i.e., priming). The highly parallel organization found for sensory information extended to semantic processing. The act of selecting a word meaning for active attention appeared to suppress the availability of other meanings of the selected item and of competing items. Attention was viewed less as a filter or bottleneck than as a mechanism for providing priority for motor acts, consciousness and some kinds of memory.

Whereas the psychology of attention furnished a number of interesting results about the limits of performance and of unconscious processing, there was no agreement on whether attention involved mechanisms separate from those used to process data, let alone any analysis of what these mechanisms might be in neural terms. Advances in our understanding of neural systems underlying attention developed from experimental paradigms involving selection of sensory information and more recently from the technological innovation of non-invasive tools for imaging the living brain.

Brain imaging has forged an impressive link between psychology and neuroscience. As early as 1990, some scholars suggested that the human brain entertains several attentional systems of different, though interrelated, functions (e.g., orienting, target detection, and alerting). More recently it has been demonstrated that distinct brain areas indeed mediate different attentional processes and that it is possible to examine selective attention as an organ system with its own functional anatomy, circuitry, and cellular structure. Although still incomplete, this information has illuminated multiple important questions in cognitive science and provided insights into neurological and psychiatric disorders of both children and adults. Attention allows us to exercise voluntary control over thoughts, feelings and actions. Variations in the operational efficiency of these attentional systems serve as a basis for differences in self-regulation and emotional control and promise to help describe mechanisms of volition and sustained effort.

2. Some basic characteristics of attention

Visual attention allows us to move attention around to various areas of the visual field and change the detail with which we look at any given area. For example, you can look at this page and pay attention to its setup as a whole, or you can zoom in on specific words and certain letters therein. If you are paying attention to single characters, you can glean a lot of information about punctuation marks, catch typos, and even spot minute imperfections on the physical sheet. But in that case, you might miss the idea a paragraph is trying to convey. One has the ability to change the location of attention and also to change the size of the attentional focus. This has been called the "zoom lens" idea or the "attentional spotlight," and it relates to our common experience concerning the kind of attention needed for reading versus proofreading.

Given a large visual array of individual features, you can have a choice of examining it globally or, instead, examining its specific features. You can shift back and forth between them by changing the focus. Some patients have difficulty examining the local features—these patients usually have damage to the left temporo-parietal lobe. Other patients may do fine with the local features but cannot get the overall contour; they usually have damage to the right temporo-parietal lobe. The parietal lobe tends to emphasize the shifting between local and global, while the temporal lobe seems to determine whether one can actually examine a local or global feature of the stimulus.

We usually foveate, or look at, exactly the thing that we are interested in, and that generally relates our attention to where we fixate. However, it is easy to dissociate the two: to cue people to attend to some location in space other than the center of gaze and then show that they are very sensitive (i.e., have a low threshold or fast response time) to information that occurs at the cued location and relatively slow or insensitive to information at the fovea. We believe that these covert shifts are used to select the part of the visual field to which one usually wants to move the eyes. In everyday life, one usually follows covert shifts of attention with an eye movement. Attention to visual elements can also apply to other modalities (e.g., auditory).

When multiple people talk simultaneously, it is sometimes necessary to select one out of these streams of conversation to follow in detail. We usually do that based on the location of the person—we often visually orient toward the person and/or hone in on their frequency of voice (e.g., it is easier to separate a male voice from a female voice than it is to separate two male voices) or the content of the information (e.g., following by content). When we attend to one stream, the other information goes into the background: it is present, but it does not reach focal analysis.

Data have shown that much of this unattended information is processed in subtle and complicated ways. Unattended information can suddenly get interesting because your name is mentioned, or because something happens that is related to the conversation you are following, and you find yourself orienting to the new information. These phenomena have been studied experimentally in some detail.

3. Substrates of attention

We have established that attention is a selective aspect of information processing: some things are privileged, and some things are ignored. A carefully crafted behavioral task is now able to probe and assess at least three distinct attentional networks: (1) achieving and maintaining the alert state, (2) orienting to sensory objects, and (3) selecting among conflicting actions. Behavioral and imaging data suggest that these networks are independent. It is further possible to identify the neuroanatomy subserving these attentional networks.

Alerting involves a change in the internal state in preparation for perceiving a stimulus. The alert state is critical for optimal performance in tasks involving higher cognitive functions. Neuroimaging studies have shown activity in the frontal and parietal regions particularly of the right hemisphere when people are required to achieve and maintain the alert state even for a brief period. Lesions of these areas will reduce the ability to maintain alertness. Right frontal lesions have been shown to impair ability to voluntarily sustain attention, producing more errors over time than are found for left frontal patients in tasks involving continuous performance. Right parietal patients show deficits in maintaining the alert state as well as difficulties in attentional orienting that together produce a profound neglect in the visual field opposite the lesion. Alerting is thought to involve the cortical distribution of the brain's norepinephrine system arising in the locus coeruleus of the midbrain.

The orienting network involves the selection of information from sensory input. Cholinergic systems arising in the basal forebrain play an important role in orienting. The pulvinar, superior colliculus, superior parietal lobe and frontal eye fields are often activated in studies of the orienting network. Orienting can be reflexive, as when a sudden target event directs attention to its location, or it can be more voluntary, as when a person searches the visual field looking for some target. Orienting typically involves head and/or

eye movements toward the target as in overt orienting. However, it can also be covert. A few dorsal brain areas, including the superior parietal lobe and temporo-parietal junction, serve as a common source of attention to sensory stimuli. They produce effects within a network of areas that depend on modality (e.g., ventral visual areas in the case of visual input). The strongest evidence for localization of mental operations stems from the area of attentional orienting toward sensory stimuli where a confluence of methods and experimental sophistication has demonstrated how separate brain areas can be invoked to organize a simple attentional shift. There is agreement that orienting of attention to a visual stimulus produces amplification in prestriate regions, which affects processing in all subsequent regions and feeds back to influence processing in the primary visual cortex (V1) and perhaps in the lateral geniculate nucleus of the thalamus.

Executive control of attention involves more complex mental operations in monitoring and resolving conflict between computations occurring in different brain areas. Executive control is most needed in situations that involve planning or decision making, error detection, novel or not-well-learned responses, conditions judged difficult or dangerous, and in overcoming habitual actions. The anterior cingulate and lateral frontal cortex are target areas of the ventral tegmental dopamine system. Brain imaging data have repeatedly shown that the anterior cingulate cortex (ACC) is an important node in this network. Toward that end, a number of neuroimaging studies have shown activation of the dorsal anterior cingulate in tasks requiring people to respond either to a prepotent response or to a rather strong conflicting dimension. For example, in the classic Stroop task, experienced readers name the ink color of a displayed word. Subjects are usually slower and less accurate in responding to the ink color of an incompatible color word (e.g., the word "RED" displayed in blue ink) than in identifying the ink color of a control item (e.g., "LOT" inked in red). Another such task involves subjects responding to the direction of a central arrow when flanking arrows could either point in the same (congruent) or opposite (incongruent) direction. The Attention Network Test uses the flanker task to measure conflict and shows strong activation in the dorsal ACC. These conflict tasks have been shown by neuroimaging studies to activate midline frontal areas (e.g., ACC), lateral prefrontal cortex and basal ganglia. These experimental tasks provide a means of fractionating the functional contributions of areas within the executive attention network. Chiefly, the ACC has been more active on incongruent than congruent trials. This result could reflect the general finding that lateral areas are involved in representing specific information over time (working memory), whereas medial areas are more related to the detection of conflict.

Patients with focal brain lesions of the ACC initially display deficits of voluntary behavior. The notion of ACC involvement in cognitive control and volition has been a topic of much interest lately. Based on behavioral, optical, and neuroimaging data it was recently reported that effective suggestion (i.e., verbal exhortation) prevented word reading and modulated focal brain activity in highly suggestible individuals. This top-down influence was both potent and selective in that it annihilated the Stroop interference effect and reduced ACC activity, respectively. Interpretation of these data implies that, at least in highly suggestibles, attentional manipulations can influence aspects of self-regulation by affecting neural activity in specific brain areas. Although attention and self-regulation have arisen within two different research traditions, there have been some recent efforts to integrate these two directions, considering hypotheses about specific neural mechanisms involved in both attention and cognitive control. These prospective approaches advocate a synthesis that is likely to be productive in linking brain systems to aspects of child socialization, for example.

4. See also

[Visual field](#)

[Arousal: the activation of behavior](#)

5. Further reading

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