Each time we open our eyes, we are confronted with an overwhelming amount of information. Despite this, we have the clear impression of understanding what we see. This requires selecting relevant information out of the irrelevant noise. Attention is what turns looking into seeing, allowing us to select a certain location or aspect of the visual scene and to prioritize its processing. Such selection is necessary because the limits on our capacity to absorb visual information are severe.

They may be imposed by the fact that there is a fixed amount of overall energy consumption available to the brain, and by the high-energy cost of the neuronal activity involved in cortical computation. Attention is crucial in optimizing the use of the system’s limited resources, by enhancing the representation of the relevant locations or features while diminishing the representation of the less relevant locations or aspects of our visual environment.

The processing of sensory input is facilitated by knowledge and assumptions about the world, by the behavioral state of the organism, and by the (sudden) appearance of possibly relevant information in the environment. For example, spotting a friend in a crowd is much easier if you are cued to two types of information: where to look and what to look for. Indeed, numerous studies have shown that directing attention to a spatial location or to distinguishing features of a target can enhance its discriminability and the neural response it evokes. Understanding the nature of attention and its neural basis is one of the central goals of cognition, perception, and cognitive neuroscience, as described in this entry.

Spatial Covert Attention

Attention can be allocated by moving one’s eyes toward a location, overt attention, or by attending to an area in the periphery without actually directing one’s gaze toward it. This peripheral deployment of attention, known as covert attention, aids us in monitoring the environment and can inform subsequent eye movements. Cognitive, psychophysical, electrophysiological, and neuroimaging studies provide evidence for the existence of overt and covert attention in both humans (including infants) and nonhuman primates. Many of these studies have likened attention to increasing visual salience.

Whereas covert attention can be deployed to more than one location simultaneously (“in parallel”), eye movements are necessarily sequential (“serial”); they can only be at one location at a given time. Many studies have investigated the interaction of overt and covert attention and the order in which they are deployed. The consensus is that covert attention precedes eye movements and their effects on perception, which in many cases are similar but in others they are not.

Hermann von Helmholtz is considered to be the first scientist to provide an experimental demonstration of covert attention (circa 1860). He experimented with a wooden box whose interior was completely dark. Looking into the box through two pinholes, he reported that he could concentrate on any part of the visual field so that when a spark came, he could focus attention independently of the position and accommodation of his eyes, and get an impression of objects in only the particular attended region. The similarities and differences between eye movements and deployment of spatial attention have been a focus for research ever since.

Many authors state that humans deploy covert attention routinely in many everyday situations, such as searching for objects, driving, crossing the street, playing sports, and dancing. However, other authors
think that covert attention is deployed mainly in social situations—for example, when deception about intentions is desired, in competitive situations (such as sports activities), or when moving the eyes would provide a cue to intentions that the individual wishes to conceal.

**Endogenous and Exogenous Covert Attention Systems**

A growing body of behavioral evidence demonstrates that there are two covert attention systems that deal with facilitation and selection of information: *endogenous* and *exogenous*. The former is a voluntary system that corresponds to our ability to willfully monitor information at a given location; the latter is an involuntary system that corresponds to an automatic orienting response to a location where sudden stimulation has occurred. Endogenous attention is also known as *sustained* attention and exogenous attention is also known as *transient* attention. These terms refer to temporal nature of each type of attention: Whereas observers seem to be able to sustain the voluntary deployment of attention to a given location for as long as needed to perform the task, the involuntary deployment of attention is transient, meaning it rises and decays quickly. The different temporal characteristics and degrees of automaticity of these systems suggest that they may have evolved for different purposes and at different times—the transient, exogenous system may be phylogenetically older.

**Behavioral Studies**

To investigate covert attention, it is necessary to make sure that observers’ fixation is maintained, and to keep both the task and stimuli constant across conditions while manipulating attention. Experimentally, the endogenous and exogenous systems can be differentially engaged by using distinct cues. Michael Posner devised a paradigm that has been widely used to study the endogenous and exogenous orienting of attention. It allows the comparison of performance in conditions where attention is deliberately directed to either a given location (attended condition), away from that location (unattended condition), or distributed across the display (neutral or control condition).

In the Posner cueing paradigm, observers have to respond as quickly as possible to a peripheral target, which is preceded by a central or peripheral cue. In the endogenous condition, a central cue—typically an arrow—points to the most likely location of the subsequent target. In the exogenous condition, a brief peripheral cue is typically presented at one of the target locations but does not predict the subsequent target location. In both endogenous and exogenous conditions, performance in detecting or discriminating a target is typically better (faster, more accurate or both) in trials in which the target appears at the cued location than at uncued locations. Central or symbolic cues take about 300 milliseconds (ms) to direct endogenous attention in a goal-driven or conceptually driven fashion. Central cues are small lines presented at fixation pointing to different locations of the visual field (e.g., upper left quadrant, lower right quadrant); symbolic cues include different numbers or colors that indicate different locations where the observer is to attend (e.g., #1 or a red circle indicates upper left quadrant, #3 or a blue circle indicates lower right quadrant). Peripheral cues, conversely, grab exogenous attention in a stimulus-driven, automatic manner within about 100 ms. Whereas the shifts of attention elicited by central cues appear to be under conscious control, it seems that it is extremely hard for observers to ignore peripheral cues. This involuntary transient shift occurs even when the cues are uninformative or may impair performance.

**Neurophysiological Studies**

**Single-Unit Recording Studies**

The development of techniques to record the electrical activity of single neurons in awake-behaving animals (e.g., monkeys) has enabled researchers to probe the biological foundations of endogenous
(sustained) attention while monkeys perform attention-demanding tasks. Such studies have provided detailed, quantitative descriptions of how endogenous attention alters the responses of neurons in the extrastriate visual cortex, yielding attentional facilitation and selection. Attentional facilitation results when spatial attention enhances the responses evoked by a single stimulus appearing alone in a neuron's receptive field, so that neurons respond to an attended stimulus much as they would were its luminance increased. Given that stimuli rarely appear in isolation, attentional selection of behaviorally relevant targets from among distracters arguably serves a more ecologically relevant purpose. When multiple stimuli appear within a neuron's receptive field, the firing rate is characteristically determined primarily by the task-relevant stimulus. Numerous studies have compared the response when attention is directed either with one of the two stimuli in the receptive field or outside the receptive field while fixation is maintained. Attending to the preferred stimulus (for which the neuron is tuned) increases the neuron's response evoked by the pair of stimuli whereas attending to the non-preferred stimulus (for which the neuron is not tuned) decreases such response.

**Neuroimaging Studies**

Neuroimaging has yielded information on the integrated brain activity underlying perception and cognition in humans. Studies documenting the neural correlates of covert attention have used several techniques, among them event-related potentials (ERPs) and functional magnetic resonance imaging (fMRI).

ERPs are electrophysiological responses that arise during sensory, cognitive, and motor processing, which provide precise information about the time course of information processing. ERP recordings can help reveal the timing and organization of stimulus selection processes in the brain's attentional network. ERP studies provide support for a mechanism of early sensory facilitation, at the level of the extrastriate visual cortex, during the spatial cueing of attention.

fMRI measures hemodynamic processes not invasively in the human brain by providing temporally integrated maps of regional cerebral blood flow across the whole brain. It is based on the increase in blood flow to the local vasculature that accompanies neural activity in the brain. There is wide agreement that attention increases fMRI responses in visual cortical areas in a retinotopically specific manner, corresponding to attended spatial locations, both for endogenous and exogenous attention. There is no consensus, however, about whether common neurophysiological substrates underlie endogenous and exogenous attention. Whereas some fMRI studies have found no difference in the brain networks mediating these systems, others have reported differences. For example, endogenous attention is cortical in nature, but exogenous attention also activates subcortical structures. Moreover, partially segregated networks mediate the preparatory control signals of both systems. For example, endogenous attention is mediated by a feedback mechanism involving feedback from frontal and parietal areas, whereas these regions are not necessarily involved in exogenous attention.

**Feature-Based Attention**

**Behavioral Studies**

Most studies of overt or covert attention (with or without eye movements, respectively) have examined the effects of spatial attention at different locations in the visual field. Both types of attention, however, can also be allocated to specific visual features, such as orientation or direction of motion or color. Feature-based attention is the ability to enhance the representation of image components throughout the visual field that are related to a particular feature. This type of attention is considered to play a central role when human or nonhuman primates search for a stimulus containing that feature. This ability
to detect a target or relevant item among distracters is the basis of a widely used paradigm in visual attention research: visual search.

Many psychophysical studies have shown that feature-based attention improves detection and discrimination performance across the visual field. A visual stimulus always occupies a certain spatial location, so it is important to control spatial selection. Thus, studies of feature-based attention generally use compound stimuli that contain multiple features superimposed over the same spatial location, and observers are required to attend to one of those features. For instance, attending to one motion direction in a compound motion stimulus produces a motion aftereffect consistent with the attended direction, and attending to one orientation in a compound orientation stimulus produces an orientation aftereffect consistent with the attended orientation.

**Neurophysiological Studies**

Because feature-based attention is independent of location, it is well suited to selectively modify the neural representations of stimulus features within visual scenes that match the currently attended feature. For example, feature-based attention can enhance the neural responses to a given attended feature; e.g., vertical orientation regardless of the locations where vertical orientations appear in the scene.

**Single-Unit Recording**

Some studies using single-unit recordings to investigate feature-based attention have shown that the responses of individual neurons that are selective for an attended feature (for example, vertical orientation, upward motion direction, or red color) can be selectively enhanced when the monkey attends to that particular feature (for example, upward motion while seeing a stimulus containing both upward and downward motion). Other studies have shown that attending to different feature dimensions (e.g., color or orientation) modulates activity in cortical areas specialized for processing those dimensions.

**Neuroimaging**

fMRI studies requiring participants to attend to specific features of stimuli have revealed that the neural activity evoked by the attended feature is enhanced both within the retinotopic cortical regions representing the spatially attended location and at other unattended regions that were stimulated by the same feature. Enhanced activation has even been observed at spatial locations where no stimuli were present. These studies suggest that feature-based attention is activated across the visual field. This representation enables the visual system to concentrate its limited processing resources on the most relevant sensory inputs regardless of where in the visual field they are located.

**See also**


**Further Readings**

- Corbetta, M.; Shuiman, G. L. Control of goal-directed and stimulus-driven attention in the brain Nature


Carrasco, Marisa

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