features. A bird watcher may look for a bluebird by looking for blue features of a particular size in the trees. The focus of attention reflects needs and priorities, here the goals of the bird watcher. Conversely, selective attention may be triggered by salient elements in the visual (or auditory) field. A salient item may be one that suddenly appears, or a sole moving object, or an item that is unique in color or some other feature. Selective attention may be drawn without our volition to such unique elements within the field. Even when focused on blue features of the bluebird, attention may be automatically refocused by the sight of a red cardinal. These two mechanisms for directing the action of selective attention work together. Goal-directed selective attention can alter the sensory processing of the selected inputs, and unique features in the field may draw or redistribute selective attention.

Selection, Flanker Effects, and Crowding

Selecting desired target(s) and filtering out other inputs are the central role of attention. Selection by location, or by source, is a fundamental aspect of attention in both audition and vision. However, the ability to focus solely on a specific location is often imperfect. Nearby objects may influence behavior, especially those that are similar in content to the target objects. For example, if you are asked to classify the middle of three shapes, similar flanking shapes may become confused with the target. This is especially true when the focus of attention is away from the fixation of the eye. This phenomenon can easily be seen if you look at a page and try to identify the middle of three letters some distance from the fixation in the periphery. The spacing between letters matters, as does the similarity of the flanking items. For example, identifying a middle letter as an E or F will be more difficult if the surrounding letters are also Es or Fs than if they are Os. Again, peripheral targets are hard to see precisely when covert selective attention is insufficient for accurate identification and where eye movements must be used to move the potential targets closer to fixation during visual search.

Significance of Selective Attention

Selective attention is an important aspect of how we process incoming sensory information from the world. Deficits in attention, often measured as deficits in selective attention, are disrupted or altered in a range of mental conditions, including attention deficit disorder, schizophrenia, and stress and anxiety disorders, and is an aspect of aging. Further research in selective attention may have implications for understanding the changes in perceptual and cognitive processing in these conditions.

Barbara Dosher and Zhong-Lin Lu

See also Attention: Covert; Attention: Divided; Attention: Object-Based; Attention: Selective; Change Detection; Psychophysics: Detection

Further Readings

Dosher, B. (1998). Models of visual search: Finding a face in the crowd. In D. Scarborough & S. Sternberg (Eds.), *Invitation to cognitive science: Methods, models, and conceptual issues* (Vol. 4, pp. 455–521). Cambridge: MIT Press.

Dosher, B., & Lu, Z.-L. (2000). Noise exclusion in spatial attention. *Psychological Science, 11*, 139–146.

Egeth, H. E., & Yantis, S. (1997). Visual attention: Control, representation, and time course. *Annual Review of Psychology, 48*, 269–297.

Logan, G. (2004). Cumulative progress in formal theories of attention. *Annual Review of Psychology, 55*, 207–234.

Palmer, J., Verghese, P., & Pavel, M. (2000). The psychophysics of visual search. *Vision Research, 40*, 1227–1268.

Serences, J., & Yantis, S. (2006). Selective visual attention and perceptual coherence. *Trends in Cognitive Sciences, 10*, 38–45.

Strasburger, H. (2005). Unfocussed spatial attention underlies the crowding effect in indirect form vision. *Journal of Vision, 5*, 1024–1037.

Wolfe, J. M. (2003). Moving towards solutions to some enduring controversies in visual search. *TRENDS in Cognitive Science, 7*, 70–76.

Wundt, W. (1924). *An introduction to psychology* (R. Pintner, Trans.). London: George Allen and Unwin. (Original work published 1912)

Attention: Spatial

One of the fundamental properties of our environment is that it is composed of a multitude of sensory information. Given such richness of input, humans are faced with the problem of having limited capacity for processing information, on the one hand, and the need to analyze as much of the sensory input as possible, on the other hand. Attention is the cognitive mechanism that allows effective selection of relevant information (e.g., the letters that you are reading right now) and an inhibition of "at the moment" irrelevant information (e.g., the humming sound of your computer).

Effective selection of information from the surrounding environment depends on the ability to select information in the most efficient manner and to distribute attentional resources in a systematic fashion based on the properties of the input. One fundamental property that describes our environment is its spatial nature—everything in our environment can be described by a set of unique three-dimensional coordinates (i.e., no two objects ever occupy the same location in space). Given that space is a unique descriptor, it is reasonable that the human attentional selection has evolved to use space as its fundamental unit of selection. Spatial orienting is not the only mode of attentional selection, however. Other units of attentional orienting are considered as possible candidates for attentional selection (e.g., object-based, feature-based, and modality-based orienting) on the grounds that spatial selection alone cannot account for the efficiency of attentional selection. This entry describes behavioral characteristics of spatial orienting, biased competition, attentional modulation, and sources of spatial attention.

Behavioral Characteristics of Spatial Orienting

Early models of attentional selection suggest that attention is directed to spatial locations in a manner analogous to a graded spotlight (or a zoom lens), selectively enhancing the perception of items that happen to occupy those spatial locations. An intuitive way to imagine how such a spotlight of attention might operate is to envision an image that has been blurred. An attentional spotlight is then moved around this blurred image bringing into focus spatial locations falling within its circumference. Consequently, items within the spatial spotlight are processed faster and more accurately than are those that fall outside of it.

One source of support for the existence of space-based attentional selection are the findings demonstrating that when a specific spatial location is attended, target detection at that spatial location is faster compared with targets that appear elsewhere on the screen. In such studies, subjects are typically seated in front of the screen and are asked to fixate their eyes on the small plus sign positioned at the center of the screen. Targets, flashes of light, or alphanumeric characters are then presented in various positions to the left and to the right of the fixation point. Participants are asked to respond with a button press once the presence of the target stimulus is detected. Of main importance is that the target flashes are preceded by a spatial cue—usually a flash of light—that is somewhat predictive (probability of 0.6 or higher) of the target location. Such design yields two types of cues: (a) valid—those that appear in the same location as the target, and (b) invalid—those that appear in locations other than the location of the target. The main finding from such behavioral cueing paradigms is that subjects respond faster to targets appearing in the same location as the cue (valid trials) compared with reaction times to invalidly cued targets. These results are interpreted in terms of a spotlight theory of attentional selection, such that spatial locations are selected in a manner analogous to a spotlight (i.e., only stimuli illuminated by the spotlight are selected), and that there are both costs and benefits to sharing attentional resources between spatial locations.

Space-based attentional orienting is not unique to the visual system (although it has been studied most extensively within the visual modality). Actually, early studies on spatial attentional orienting were conducted within the auditory domain. In a typical auditory spatial attention experiment, subjects are presented with two auditory streams (one in each ear, or dichotic presentation) simultaneously and are asked to shadow (i.e., repeat what is being spoken) one of the streams thereby focusing spatial attention on the sensory input within the left or the right ear. The first interesting observation emerging from such studies is that participants are able to perform this task at all! In addition, it is observed that subjects know surprisingly little (or almost nothing) about the ignored stream except that the sound is present. Subjects fail to notice such striking changes as language switches (e.g., from English to German), speech streams playing backward, or changing the gender of the speaker. Interestingly, not everything in the ignored stream is missed, and some stimuli can capture auditory spatial attention. In 1959, Neville Moray presented his subjects with a similar dichotic shadowing task, but in some cases, the experimenters inserted subject's own name in the ignored auditory stream. It was observed that the presence of one's own name could be detected within the ignored stream. As a result of such auditory spatial capture, however, subjects could no longer shadow the stream that was supposed to be attended. The results from these experiments suggest that in audition, just as in vision, stimuli that fall outside spatial attention are suppressed and fail to enter consciousness.

Biased Competition

The term *spotlight of attention* is merely a metaphor for changes in neural processing that follow spatial attentional orienting. The spotlight of attention is said to enhance an early sensory representation of the selected stimulus. Such enhancement can be viewed as a result of biased competition among neural representations. The biased competition model of selective attention proposes that items presented in a multielement scene are not processed independently, but rather interact in a mutually suppressive way. Such suppressive interactions have been observed behaviorally (e.g., harder to see an item when it is embedded among other items) as well as with neurophysiological and neuroimaging techniques. This neural competition, however, can be resolved via a biasing signal that is either bottom-up (e.g., red item among blue items) or top-down (e.g., looking for an apple in a supermarket's fruit aisle). To the extent that the biasing signal is spatially imprecise, its benefits spread within a local region, falling off with distance from the epicenter of the attended region. This could account for the distance effects as measured by both speed and accuracy in attentional paradigms in which items that appear closer to the cued location tend to be processed more efficiently (though not as efficiently as the valid location) than do those positioned further away.

The framework of biased competition consists of two general components: the source that generates the spatial bias and the effects of that attentional modulation bias on early sensory representations. The following two sections describe the neural mechanisms of each of these components in turn.

Attentional Modulation

When an item is attentionally selected (via the source signal), its representation is biased (i.e., enhanced) compared with the representation of this same item when it is not attended and/or is presented among other items (thus resulting in an attentional effect).

Studies of the effects of visual attentional selection demonstrated behavioral facilitation and enhanced cortical responses to attended locations. Neurophysiological studies investigating the effects of spatial attentional bias demonstrated that when a stimulus is presented in a neuron's receptive field (RF) the response to that stimulus is increased when spatial attention is directed to it compared with when attention is either unfocused or diverted elsewhere. For example, in their seminal study, Jeffrey Moran and Robert Desimone first identified the classic receptive field of a V4 neuron and its corresponding preferred and ineffective (not response eliciting) stimuli for that neuron. Monkeys were then trained to attend to stimuli in a specific location within the visual field while ignoring stimuli in other locations. Both effective and ineffective stimuli were then presented within the classic RF of a V4 neuron to elicit competitive interactions in a multielement display. The authors found that the responses of the V4 neurons were strongly modulated by the locus of the monkey's attention. The firing rate to the preferred stimulus was only one third as great when the monkey did not attend to it (i.e., attending to the ineffective stimulus) compared with when the preferred stimulus was attended. What is particularity interesting about this study is that when attention was directed to one of two stimuli in the RF of a V4 cell, the effect of the unattended stimulus was attenuated, as if the RF had contracted to only include the attended stimulus. Effects of attentional orienting are observed even when only one stimulus is present in the display.

Several neuroimaging studies, mainly event-related potentials (ERP) and functional magnetic resonance imaging (fMRI), also observed early sensory enhancement following spatial attentional selection. Studies employing neuroimaging techniques take advantage of the fact that visual stimuli presented to the left of the center are processed within the right primary visual cortex, whereas stimuli presented to the right of the center are processed within the left primary visual cortex. When one presents stimuli to the left and to the right of the fixation point, similar to the cueing paradigm discussed earlier, it is observed that directing spatial attention to the left hemifield results in the increased stimulus evoked neural activity of the early visual areas in the right hemisphere (and the converse is true for attention directed to the right hemifield).

Sources

Complementing studies that demonstrate the effects of attentional modulation is research that aims to determine the source of the attentional signal itself. Evidence from multiple methodologies has been accumulating that implicates a network in the posterior parietal and frontal cortices as likely candidates for the control of spatial attention.

Some of the first studies that investigated the role of the parietal cortex in the control of spatial attention have come from the neuropsychological literature. Certain forms of brain damage produce perceptual deficits in attending to regions of space. The most common of such deficits are extinction and unilateral visual neglect, both of which result from unilateral brain damage primarily in and around the parietal cortex. In extinction, the patient is able to respond to and recognize events and objects when they are presented in isolation anywhere in the visual field. When two items are presented simultaneously, however, one in the contralesional field (opposite to the location of the lesion) and one in the ipsilesional field, the contralesional object often is not reported or responded to. In unilateral neglect, the deficit is more severe in that even a single object in the contralesional field tends to be ignored in the absence of competition from other objects. Unilateral neglect tends to be a more debilitating condition in everyday life than does extinction, and some have argued that extinction amounts to a mild form of neglect. As such, the deficit in spatial orienting that is exhibited by unilateral neglect patients has been taken as evidence that the parietal cortex is involved in control of spatial attention.

Recent neuroimaging findings propose that control of spatial attention is likely subserved by the frontoparietal network of regions in the human cortex. Voluntary deployments of spatial attention are associated with neural activity in regions of the dorsal parietal cortex (intraparietal sulcus [IPS]), superior parietal lobule (SPL), and frontal eye fields (FEF). Conversely, the temporoparietal junction (TPJ) and ventral frontal cortex (VFC) are recruited when spatial attention is captured by a stimulus presented in an unexpected location (e.g., one's own name inserted within the unattended auditory stream).

Sarah Shomstein

See also Attention: Effect of Breakdown; Attention: Effect on Perception; Attention: Object-Based; Attention: Physiological; Attention: Selective; Attention and Consciousness; Visual Search

Further Readings

Bisiach, E., & Vallar, G. (1988). Hemineglect in humans. In F. Boller & J. Graffman (Eds.), *Handbook of neuropsychology* (pp. 195–222). Amsterdam: Elsevier.

Cherry, E. C. (1953). Some experiments on the recognition of speech, with one and with two ears. *Journal of the Acoustical Society of America, 25,* 975–979.

Connor, C. E., Gallant, J. L., Preddie, D. C., & Van Essen, D. C. (1996). Responses in area V4 depend on the spatial relationship between stimulus and attention. *Journal of Neurophysiology, 75,* 1306–1308.

Corbetta, M., & Shulman, G. L. (2002). Control of goal-directed and stimulus-driven attention in the brain. *Nature Neuroscience, 3,* 201–216.

Kastner, S., & Ungerleider, L. (2000). Mechanisms of visual attention in the human cortex. *Annual Review of Neuroscience, 23,* 315–341.

Moran, J., & Desimone, R. (1985). Selective attention gates visual processing in the extrastriate cortex. *Science, 229,* 782–784.

Moray, N. (1959). Attention in dichotic listening: Affective cues and the influence of instructions. *Quarterly Journal of Experimental Psychology, 11,* 56–60.