orientation stimulus (consisting of right-tilted and left-tilted lines), attending to one orientation (right-tilted lines) produces an orientation aftereffect consistent with the attended orientation. Psychophysical and neuroimaging studies have shown that the effects of feature-based attention occur at the spatially attended location as well as at non-attended locations across the visual field.

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See also Attention: Covert; Attention: Object-Based; Attention: Physiological; Attention: Selective; Attention: Spatial; Attention: Theories of; Eye Movements: Behavioral; Psychophysical Approach; Visual Search

Further Readings

Carrasco, M. (2009). Visual attention alters appearance: Psychophysical studies of subjective experience. In T. Bayne, A. Cleeremans, & P. Wilken (Eds.), *Oxford companion to consciousness*. New York: Oxford University Press.

Carrasco, M., Ling, S., & Read, S. (2004). Attention alters appearance. *Nature Neuroscience, 7,* 308–313.

Itti, L., Rees, G., & Tsotsos, J. (Eds.). (2005). *The encyclopedia of the neurobiology of attention.* Amsterdam: Elsevier.

Kinchla, R. A. (1992). Attention. *Annual Review of Psychology, 43,* 711–742.

Pashler, H., Johnston, J. C., & Ruthruff, E. (2001). Attention and performance. *Annual Review of Psychology, 52,* 629–651.

Posner, M. I. (1980). Orienting of attention. *Quarterly Journal of Experimental Psychology, 32*(1), 3–25.

ATTENTION: OBJECT-BASED

Efficiently representing visual information requires that the observer select only a fraction of the multitude of information that is available to the visual system at any one instant in time. Attentional selection is the mechanism by which a subset of incoming information is extracted from the complex sensory environment. The selection can be achieved in a top-down, goal-directed fashion (e.g., when one sets out to find one's keys on the kitchen counter), or in a bottom-up fashion in response to highly salient or novel stimuli in the input (e.g., a red strawberry among greener strawberries on a bush captures the viewer's attention). Early models of attentional selection suggested that attention is directed to particular regions or locations in space (the region of the keys or the region of the red strawberry), enhancing perceptual processing of information appearing in the attended location, whereas more recent models have also included object-based representations as possible candidates of attentional selection (i.e., the keys or the red strawberry as objects of attention themselves). This entry considers this latter, object-based form of attentional selection in which attention is guided or influenced by object structure.

Behavioral Phenomena

The primary signature associated with object-based attention is the enhanced processing of information belonging to or appearing within the confines of one object that is selectively attended. Numerous behavioral studies have confirmed this *single object advantage*. For example, in a now-classic study demonstrating the advantage in processing features from a single object conducted by John Duncan in 1984 (see Figure 1a), subjects were shown displays consisting of an outline box upon which a diagonal line was superimposed, thereby occupying roughly the same spatial region as the box (so that spatial attention could not enhance just one of the two "objects"). Subjects were required to make judgments about two features that appeared on the same object (e.g., line orientation and texture from the line, or box size and gap side from the box) or, in a second condition, when one feature appeared on each of the two different objects (e.g., line orientation and box size). The critical result was that subjects were less accurate in reporting two features when they came from the two different objects (one feature from each) than when they came from a single object. Indeed, under simple conditions, subjects identified two properties of a single object just as accurately as they identified one feature. These results were taken as favoring a view that the visual field can be segmented or parsed into separate objects and that attention can then be directed selectively to a single object, thereby facilitating the processing of all of its features.

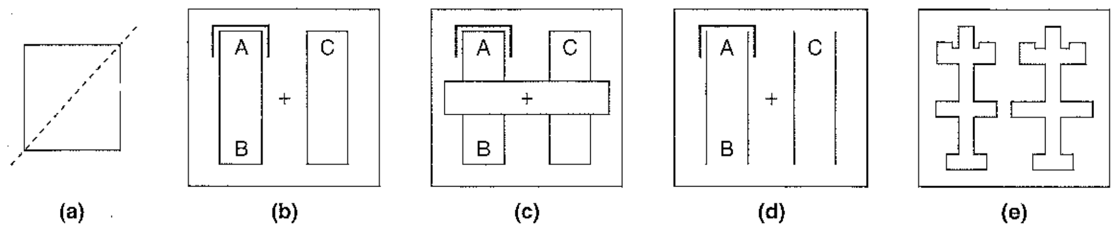

Figure 1 Examples of Object-Based Attention Displays

The single object advantage was also demonstrated in a further seminal study by Robert Egly and colleagues in 1994. In this study, subjects were presented with a display of two horizontally or vertically oriented rectangles. A cue appeared at one of the four ends indicating the most likely location in which the target would appear (see Figure 1b). Participants were required to detect the presence of the subsequently presented target (small white square). Unsurprisingly, detection times for the target in the cued location (valid trials; in Figure 1b with the cue in the upper left, this is the A position) were faster than for targets in the uncued locations (positions B or C). Most relevant for the current purpose is that reaction times were faster for targets that appeared at the uncued end of the cued rectangle (invalid; within object; position B) than for targets that appeared in the uncued rectangle (invalid; between object; position C), notwithstanding the fact that the spatial distance between the cue and both uncued locations was equivalent. The advantage for the uncued, within object location (position B) over the uncued, between object location (position C) is taken as evidence that all locations within an attended object are enhanced, the benchmark indicator of object-based attention, independent of spatial distance from the cue.

Several other behavioral paradigms have also successfully uncovered object-based attention. One such paradigm requires participants to compare two targets both of which lie on the same or on different objects—better performance is observed in the former than in the latter case. A further example is a variant of the Eriksen "flanker" task in which participants judge the identity of a target in the presence of flanking distractors that lie on the same or different objects: greater interference is observed when the flankers were in the same object, a consequence of enhancement of information within a single object. Taken together, such studies provide robust evidence that humans can select one object and, subsequently, all its information is preferentially facilitated.

Underlying Mechanisms

Having established the existence of object-based attention, much recent research has become increasingly concerned with the type(s) of visual representation and underlying mechanisms that constrain attentional processes. Indeed, growing consensus is that object-based attention may not be influenced only by object representations per se but also by the perceptual organization processes that the visual system uses to derive structure from the input. Consistent with this, many studies have uncovered object-based attention in displays in which the input can be organized into structured elements that adhere to the gestalt principles of grouping: thus, a single-object advantage can be observed for two spatially disparate parts of a single object that are occluded by a central bar (Figure 1c), for parts of an object that are discontinuous but benefit from shared symmetry, and for parts of an object that are separated but share common motion or color. Similarly, a cueing advantage has been reported for distant stimuli situated within arrays of evenly spaced parallel lines even when these lines do not form closed, coherent objects (see Figure 1d), as revealed by Alex Marino and Brian Scholl. Subparts of these holistically structured but disparate elements, which are perceptually organized, can also be selected, presumably by the same object-based attention process, but perhaps operating at a smaller scale, at the level of parts of an object. For example, this part-based attention was demonstrated in a study by Shaun Vecera and colleagues that borrowed the procedure from Duncan in which participants reported two attributes that appeared on the same part or on different parts of a single multipart object (see Figure 1e). Subjects reported two attributes in the display (e.g., gap side and arm length), and these could be from the same part or from two different parts of the same object. The report was more accurate when the attributes belonged to the same part than to different parts of the same object. Moreover, this part-based effect was not influenced by the spatial distance between the parts, ruling out a simple spatial attention interpretation of the results.

Several hypotheses have been put forward to account for the single-object attention advantage. One hypothesis maintains that object-based attention arises from the spread of attention (object-guided spatial selection)—when spatial attention is directed to one part of an object, there is a facilitation of early sensory processing that spreads to encompass other regions within the object's boundaries, hence the enhancement of all features and parts of the single object. This can be contrasted with the hypothesis that locations within the attended object are given higher priority for target search. If a target is not found at the cued location, other locations within the object's boundaries are searched before locations on uncued objects are searched. This attentional prioritization mechanism, which invokes a more top-down strategy, is proposed to control the order of locations to be searched, and on this account, the enhancement is not by virtue of early sensory processing. Ongoing investigations compare and contrast these views (as well as others) and much remains to be done to adjudicate between the alternative competing hypotheses.

Neural Basis of Object-Based Attention

Several recent investigations have begun to explore the neural mechanisms that underlie object-based attention and a series of functional magnetic resonance imaging (fMRI) and event-related potential (ERP) studies have been undertaken. One study, done by Notger Müller and Andreas Kleinschmidt using the Egly and colleagues paradigm described earlier, showed that the same object advantage is observable even in the early visual cortex (V1–V2). In an ERP study using a paradigm similar to that of Egly and colleagues in which a peripheral cue directed attention to the probable target location, an enhanced N1 component was documented at 130 to 150 milliseconds (ms) in response to targets in the cued or valid case, reflecting spatial attention, as shown by Antigona Martinez and colleagues. In addition, there was increased amplitude of the posterior, sensory-evoked N1 component over the interval 150 to 190 ms in response to uncued stimuli included within the common object, presumably reflecting the object-based selection. This site also serves as the source of these two signals, but one is earlier than the other, indicating that some of the same mechanisms likely support spatial and object-based forms of attention but that they may operate over different time scales.

Several studies (e.g., Liu et al.; Serences et al.; Shomstein & Yantis; Yantis et al.) have also explored the neural mechanism associated with the signal to switch attention between objects (i.e., the control system that triggers the switch between objects). Using fMRI, these studies have shown that the blood-oxygenation-level-dependent (BOLD) activity in the posterior parietal cortex is enhanced following instructions to shift versus to hold spatial attention, suggesting that a signal triggers the system to shift attention from one object to another. Shifting from one spatial position to another may engage different cortical regions than does shifting from one object to another; specifically, enhanced activity for the former engages the parietal cortex bilaterally, whereas shifting or redirecting attention between objects revealed activation in the left posterior parietal cortex. Interestingly, in this same study, object-sensitive shifts of attention were accompanied by modulations within the extrastriate regions of the occipital cortex (as in the study by Martinez et al. using ERP). These neuroimaging results elucidate the neural mechanism underlying object-based attentional selection described in many behavioral studies and reveal a network in which the consequences of attentional shifts triggered in the parietal cortex are manifest in earlier, sensory regions of the visual system. This dynamic circuit between the parietal and earlier visual regions presumably enables observers to focus preferentially on objects of interest that appear in complex visual scenes.

A final ongoing question concerns the relationship between the mechanisms mediating spatial and object-based attention and the extent to which these mechanisms are shared or separate. Specifically, some researchers have suggested that similar mechanisms might be at play; for example, some studies indicate that attention is spatially spread and then constrained by the object boundaries and groupings, and that this is true over a certain spatial extent. Moreover, as stated earlier, evidence from some fMRI and ERP studies (e.g., Müller & Kleinschmidt; Shomstein & Behrmann) report that similar brain areas are activated by spatial and object-based attention and that attention-based modulation of "within" object structure is evident even in early retinotopic areas of the cortex. This provides physiological evidence that directing spatial attention to one part of an object facilitates processing of the entire object, and thus, both spatial and object-based attention contribute to the single object advantage.

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See also Attention: Spatial; Gestalt Approach; Visual Processing: Primary Visual Cortex

Further Readings

Duncan, J. (1984). Selective attention and the organization of visual information. *Journal of Experimental Psychology: General, 113*(4), 501–517.

Egly, R., Driver, J., & Rafal, R. D. (1994). Shifting visual attention between objects and locations: Evidence from normal and parietal lesion subjects. *Journal of Experimental Psychology: General, 123*(2), 161–177.

Liu, T., Slotnick, S. D., Serences, J. T., & Yantis, S. (2003). Cortical mechanisms of feature-based attentional control. *Cerebral Cortex, 13*(12), 1334–1343.

Marino, A. C., & Scholl, B. J. (2005). The role of closure in defining the "objects" of object-based attention. *Perception & Psychophysics, 67*(7), 1140–1149.

Martinez, A., Teder-Salejarvi, W., Vazquez, M., Molholm, S., Foxe, J. J., Javitt, D. C., et al. (2006). Objects are highlighted by spatial attention. *Journal of Cognitive Neuroscience, 18*(2), 298–310.

Müller, N. G., & Kleinschmidt, A. (2003). Dynamic interaction of object- and space-based attention in retinotopic visual areas. *Journal of Neuroscience, 23*(30), 9812–9816.

Serences, J. T., Schwarzbach, J., Courtney, S. M., Golay, X., & Yantis, S. (2004). Control of object-based attention in human cortex. *Cerebral Cortex, 14*(12), 1346–1357.

Shomstein, S., & Behrmann, M. (2006). Cortical systems mediating visual attention to both objects and spatial locations. *Proceedings of the National Academy of Sciences USA, 103*(30), 11387–11392.

Shomstein, S., & Yantis, S. (2004). Control of attention shifts between vision and audition in human cortex. *Journal of Neuroscience, 24*(47), 10702–10706.

Vecera, S., Behrmann, M., & Filapek, V. (2001). Attending to the parts of a single object: Part-based selection mechanisms. *Perception and Psychophysics, 63*(2), 308–321.

Yantis, S., Schwarzbach, J., Serences, J. T., Carlson, R. L., Steinmetz, M. A., Pekar, J. J., et al. (2002). Transient neural activity in human parietal cortex during spatial attention shifts. *Nature Neuroscience, 5*(10), 995–1002.

Attention: Physiological

Often, when we're interested in an object, we move our eyes toward it, allowing us to see it more clearly. However, it has long been known that even in the absence of overt movements, perception of an object in the periphery can be improved by covertly shifting attention to it. *Covert attention* refers to our ability to internally modulate sensory processing of a selected stimulus. Attention can improve perception of the attended object, even though the input to the system (the physical stimulus reaching the retina, for example) is unchanged.

When we shift attention to an object, it may appear clearer, more distinct, or more intense, whereas ignored objects may seem less distracting or even fade from awareness. These perceptual effects are caused by changes in the responses of sensory neurons. Thus, one important issue in the physiology of attention is to understand the *effects of attention on sensory processing*. A second major issue is to understand how the brain controls which particular objects are attended. This is referred to as the *neural control of attention.*

Effects of attention on sensory neurons have been observed in all the major sensory systems. Most studies have found that attention increases the gain of sensory neurons encoding the attended object or feature, effectively amplifying signals from the attended stimulus. The effects of attention on sensory neurons become progressively