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Attention: Selective

We experience the world around us, in all its sensory detail and complexity, directly—or at least so we believe. Yet a simple test reveals that our sense of direct experience may be misleading. If you are asked to reflect, with your eyes closed, on the details of the picture on the wall, or the number of cars on the road, or the shape of a stranger's eyes, the limits in processing information become evident. At times, we may not even notice when a significant part of a visual scene has been removed or altered, seemingly in front of our eyes. Attention is the portal through which sensory information is selected for more detailed examination, classification, and registration. *Selective attention* refers to selection of certain sensory inputs for privileged perceptual processing, further analysis, and improved transfer to memory. Attention selects some regions or objects in the visual display, or some voices or environmental sound sources in the auditory display, as the focus of active processing, reducing, or eliminating the competition.

The scientific interest in selective attention and its benefits for perception date to the late 1800s, when William James observed that an object that captured attention among many simultaneously possible objects seemed perceptually vivid and important. An introspective analysis of Wilhelm Wundt at about the same time asked the reader to fixate the eye on the center of an array of letters, while placing the subjective-fixation of attention on a letter some distance away. He noted that the attended letter and its immediate surround were more clearly perceived and letters away from the focus of attention seemed unclear and outside of immediate consciousness. These authors identified attention as an important, indeed core, aspect of perception. Their introspective observations presaged the concepts of *covert attention,* the dissociation of the focus of attention

and the fixation of the eye, of *spatial attention,* a focus of attention on a region of space, and of *object attention,* the selection of focus based on objects. Yet almost a century went by between the introspective identification of these aspects of human perception and an objective, scientific understanding of the causes and consequences of selective attention in human information processing and the brain.

How does selective attention operate? Under what conditions is it important? How does attention affect the efficiency of information processing? Answering these questions about attention depends on a combination of clever selection of test conditions and an analysis of behavioral measures using formal or computational models of attention. Just as a physicist may arrange conditions to reveal a physical process, experimenters arrange test conditions to reveal mental processes. And just as mathematical theories assist in understanding many physical systems, so too are formal and computational models necessary for interpreting the behavior of human systems. Objective behavioral measures, such as the time taken to find a target, or the probability of finding a target in a very brief display presented for a fraction of a second, have replaced introspection and intuition in the study of attention.

This entry describes sensory processes and cued selective attention; selective attention in visual search; selective attention and control; selection, flanker effects, and crowding; and the significance of selective attention.

Sensory Processes and Cued Selective Attention

Sensory inputs arrive by stimulating sensory systems in the eye (or ear, or skin) that respond to specific patterns of light (or sound, or touch). Different cells in brain areas that process the sensory inputs respond to different patterns, and specific locations or objects often stimulate neurons in different locations in the brain. When you look at the visual world, sensory responses to the many stimuli across the visual field occur simultaneously, or nearly simultaneously, in parallel. They constitute a "blooming, buzzing" collection of sensory inputs or representations. Selective attention picks out the relevant from the irrelevant, the focus from the background. Many theorists have argued that attention selects one thing (or perhaps a few things) at a time for processing. So, they felt, this implied the processing of visual inputs serially—one after the next in time in a series. Selective attention may, however, function differently in distinct circumstances and is often best understood by modeling the ways in which attention operates.

Perhaps the strongest effect of selective attention occurs when a precue actively directs attention to a particular location or feature in advance. Researchers distinguish between two types of precues. Exogenous cues are flashes or other direct indicators at the location to be attended, and endogenous cues are cues that are not at the attended location. An example of an endogenous cue might be an arrow located at the center of a display asking the subject to attend to a separate, corner region. It takes between a tenth and a quarter of a second to process a precue and focus selective attention to a particular location in space.

Laboratory tests have shown that selective attention may speed a response to the stimulus but, more importantly, may improve the accuracy of identifying or classifying a briefly presented target pattern. When attention increases the accuracy of pattern identification, we can say it has improved the quality of processing. Knowing when and where to focus selective attention can be especially important when the target is obscured by noise, camouflage, or dense arrays of distracting elements. Models and tests of selective attention have shown two distinct ways in which attention may improve perception. One is to enhance responses to weak or low-contrast stimuli, rather like increasing the contrast on a television set to improve visibility. The other is to filter out other irrelevant items in noisy or cluttered displays and so improve the focus on the target. In both cases, the quality of processing is noticeably improved by directing the mind's eye of covert selective attention.

Selective Attention in Visual Search

Precueing of a spatial region focuses selective attention in advance. Researchers have also been fascinated with understanding the role of selective attention in searching visual displays in which the target location is unknown and may appear anywhere. The act of finding visual targets in complex visual scenes is a capacity that represents a common real world activity. Efficient visual search for

environmental dangers likely had evolutionary significance. The processes—by which the natural targets of a lost child, the ripe fruit, or the proverbial tiger in the foliage are found—can also be tested in the laboratory. Visual search displays in scientific studies are designed to vary from simple to complex and generally consider sets of spatially separated objects.

For visual search, the primary theoretical question has been whether deployment of attention is serial, moving the focus of attention to one location or object after another, or can be done in parallel. In the laboratory, this involves looking for a single red target among distractors. Some cases, such as looking for the red target among all green items, can be direct and simple regardless of the number of items in the display. In these cases, the likelihood of finding the target in a brief display, or the time to find it in a longer display, is almost independent of the number of items. Searches where the target is immediately obvious regardless of the number of irrelevant distractors have been called *pre-attentive* (i.e., identified without attention) by some. In such cases, all the locations could be scanned in parallel, or at the same time, for the presence of the target feature, redness.

In more difficult searches, the target is not unique. An example is looking for a red horizontal line among distractor items that vary in color (red and green) and in orientation (horizontal and vertical). But this time, there are many red items and many vertical items, so the trick is to find the conjunction of the two properties together. One major question has been whether such difficult attentive searches require serial processing. If searching for a target among more distractor items takes longer or is less accurate, does this imply a serial process of attending to a sequence of items in turn? Not necessarily. If the job is to state whether a target was present in a display, even simultaneous parallel searches could show more errors or longer search times with, say, 10 distractors than with 2. Distractor items may be mistaken for a target or a target may be missed. Increasing the number of distractors leads inevitably to more missed targets or more false alarms. If there are too many false alarms, it makes sense to tighten the criterion for deciding that something is a target—thus increasing the likelihood of missing it. Furthermore, even parallel searches that begin simultaneously finish at different times. If no target is present, finishing the last of all of 10 items will be slower than finishing the evaluation of 2, even if all items are processed in parallel. So, parallel searches can show somewhat lower accuracy and longer search times with more distractors, but serial search models of attention predict more dramatic slowing as displays become larger. Other ideas about search include a combination of parallel and serial processes. Search may be serial, but may be guided by pre-attentive parallel evaluations that point to the more likely or salient items first, or eliminate some classes of distractors. For example, now the red horizontal target is hidden among a small number of red vertical items and a large number of green horizontal items. Often, people can use the comparative salience of the fewer red items to guide their analysis. These models have made it possible to more accurately understand how attention operates in different conditions.

The evidence indicates that parallel processing is more pervasive, and the role of covert attention selection more restricted, than was originally believed. The ability to accurately find a target in brief displays is quite often consistent with parallel processing of multiple objects, with added distractors causing exactly the predicted increases in errors. Parallel processing seems to account for the results of many tests, including many difficult visual search conditions that on the surface seemed to be limited by serial selective attention. However, serial processes may have a role to play in some difficult situations—those where targets cannot be seen well in the periphery, or where direct scrutiny is required to tell targets and distractors apart. Often, such difficult visual searches engage explicit movements of the eye to new positions in the field in addition to any deployment of covert selective attention. Such movements of the eye and associated episodes of attention are intrinsically serial. However, moving the eye is quite different from moving the internal focus of covert attention.

Selective Attention and Control

Selective attention is influenced both by goal-directed top-down control and by bottom-up processing of the visual or auditory inputs. Goal-directed control of attention occurs when a particular spatial region or feature is cued as more likely to include a target or when we know the goal of a search, or its

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.

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

Further Readings

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