Science, Vol 282, Issue 5386, 57-58 , 2 October 1998
[DOI: 10.1126/science.282.5386.57]

Previous Article • Table of Contents • **Next** Article

Also see the archival list of *Science*'s Compass: Enhanced Perspectives

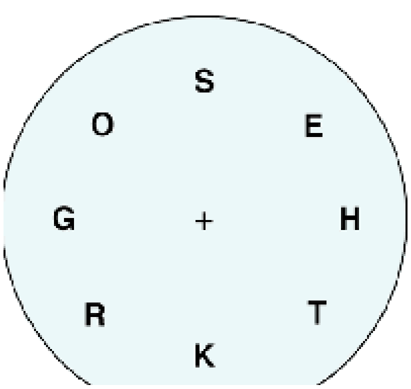
NEUROSCIENCE:

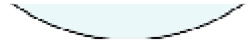
Enhanced: Separating the Wheat from the Chaff

Nancy Kanwisher [HN1] and Paul Downing*

Seeing the world around you is like drinking from a firehose. The flood of information that enters the eyes could easily overwhelm the capacity of the visual system. To solve this problem, a mechanism--attention--allows selective processing of the information relevant to current goals. As the eminent physiological psychologist Helmholtz [HN2], [HN3], [HN4] noted over a hundred years ago, even without moving our eyes we can focus our attention on different objects at will, resulting in very different perceptual experiences of the same visual input (1). Visual attention has been the focus of several decades of elegant behavioral research, but the neural basis of this process has come under intensive investigation only recently [HN5], [HN6], [HN7]. A report by Kastner et al. on page 108 (2), in which the authors used functional magnetic resonance imaging (MRI) of the brain in awake human subjects performing visual tasks, provides new clues about how our brains deal with the onslaught of sensory input.

Try a version of Helmholtz's experiment for yourself. Fix your eyes on the cross at the center of the figure (below), and without moving your eyes read the letters around the circle one letter at a time, starting at the top. Attention enhances your awareness of the selected letter, relegating the rest to the margins of consciousness.





Attention is distinct from gaze. Maintain fixation on the central cross, and read one letter at a time, progressing around the circle without moving your eyes.

Why might we have such a system in the first place? Why not just move our eyes to place objects of interest on the fovea, the high-resolution central region of the retina? Several reasons have been suggested. First, as social primates, [HN8], we are acutely aware of where others are looking (3). The ability to move attention while holding our eyes fixed allows us to keep our interests and intentions private (4). Second, having an attentional system that is independent of eye movements allows us to attend to objects whose images would not fit neatly within the fovea, as well as to track several independently moving objects at once (5, 6). Basketball players, for example, can mentally track several other players on the court--not just the one they could follow if they had to rely on eye movements alone.

How does selective attention work? According to one recent hypothesis (7, 8), the neural representations of different objects in the image suppress each other, and attention acts by biasing this competition: The visual attributes of the relevant object are strengthened while those of irrelevant objects are weakened. In the new study, Kastner and colleagues tested this idea in humans by using functional MRI [HN9], [HN10], [HN11], [HN12] to measure the summed neural responses from each of four areas of the brain that participate in processing visual signals (V1, V2, V4, and TEO), while the subjects' attention was engaged with a difficult task at the center of gaze.

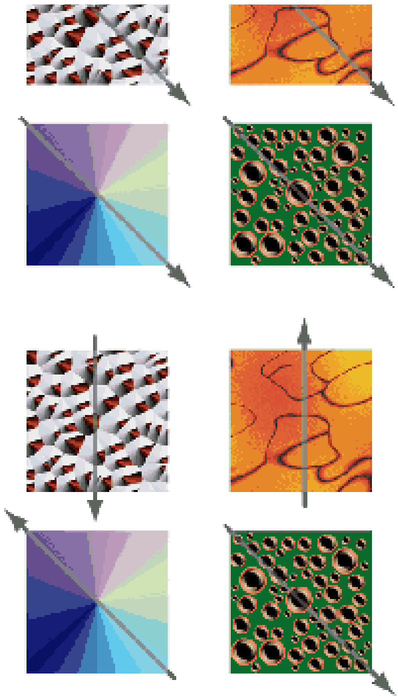
In their first experiment, the overall neural response from each of these brain areas was lower when four objects were presented simultaneously above and to the right of the central display in the peripheral parts of the subjects visual field than when the same four objects were presented sequentially in the same locations, even though the total amount of retinal stimulation (integrated over time) was identical in the two cases. The fact that there was a bigger difference between responses to simultaneous and successive presentations in V4 and TEO (higher cortical areas) than in V1 and V2 (which are earlier stages in the visual processing pathway) suggests that fewer and fewer objects can be represented as information proceeds along the visual pathway. Kastner and colleagues interpret these results as reflecting an increasing suppressive effect from competitive interactions among the neural representations of different objects.

In their second experiment, Kastner et al. found that the reduction in the neural response to simultaneous compared with successive stimuli was much less severe when attention was directed to one of the four peripheral stimuli. On the basis of this result, they argue that attention protects the representation of the target item from the interfering (suppressive) effects of nearby stimuli.

These experiments are elegant and important. Kastner and colleagues not only demonstrate the reduction of response for simultaneously presented objects, and the attenuation of that effect by attention, but also quantify these effects separately within each of the cortical areas that make up the early stages of the visual pathway. This work raises the standards of brain-imaging research well above the routine inventories of brain activations that are the standard fare of the field.

The interpretation of these studies, however, is not completely straightforward. First, although Kastner et al. interpret the reduced response to simultaneous compared with sequential stimuli as evidence for suppressive or competitive interactions, they do not provide direct evidence for active inhibition. They simply show that when a number of stimuli are presented at once, the visual system produces something less than the sum of its responses to the items when presented alone. Further work will be needed to determine whether these subadditive effects are actually due to inhibitory interactions, saturation of neural or functional MRI responses, or some combination thereof.

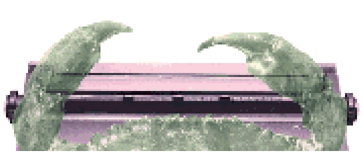
 



Unification by motion. A variation on Kastner et al.'s study might compare a situation in which four visual patterns are grouped via common motion (upper panel of figure) with one in which the same patterns are perceived as four independently moving objects (lower panel of figure).

A second concern is that in Kastner et al.'s first experiment the peripheral stimuli may have captured attention away from the primary central task more powerfully when those stimuli were presented successively (four flashes per second) than simultaneously (one flash per second). In a clever control experiment, the authors used a stimulus configuration that allowed them to measure the response in V4 to a single peripheral item, and showed that this response was lower when the item was presented simultaneously with other peripheral stimuli than when it was presented alone. This experiment controlled for stimulus presentation rate, hence reducing concerns about attentional capture. This control configuration was not used, however, in the second experiment, so the attentional effects reported reflect the responses to both attended and unattended items, somewhat complicating the interpretation of the data.

Like the results of previous imaging studies on attention (9–12), Kastner et al.'s findings are consistent with most of the current theories of visual attention (7, 8, 13, 14). An important challenge for the future will be to design imaging studies that will discriminate among these theories. For example, the object-based view of attention that inspired the biased-competition model in the first place (7) holds that attention selects whole objects (including all of their visual attributes), rather than selecting spatial locations or feature dimensions for attention. Several key predictions of this theory can be tested with functional MRI. First, does attention to one feature of an object necessarily enhance the representation of other features of the same object (see the figure above)? Second, can the representation of one object be selectively enhanced even when it appears in the same spatial location as either a single distractor object overlaid on top of it or a series of objects appearing one at a time in the same place (15)? Finally, would the suppressive interactions in Kastner et al.'s experiments be reduced or eliminated if the four objects were connected, for example, by shared motion, to make one large object, as in the figure below?



Does color follow shape? Object-based models of attention suggest that attention to one aspect of an object (for example, the shape of the typewriter) necessarily enhances other features of that object (its color).

CRAB: TOM MCHUGH/PHOTO RESEARCHERS, INC. TYPEWRITER:KAREN LEEDS/THE STOCK MARKET

We are not passive recipients of the information that washes over our sensory receptors, but active participants in our own process of perception. Understanding the cognitive and neural mechanisms of selective attention--the control of the floodgates of sensory information--is one of the most important missions of cognitive neuroscience.

References

1. H. Helmholtz, Handbuch der Physiologischen Optik. (1850; reprinted Dover, New York, 1962).
2. S. Kastner, P. De Weerd, R. Desimone, L. G. Ungerleider, Science **282**, 108 (1998).
3. M. von Grunau and C. Anston, Perception **24**, 1297 (1995) [Medline].
4. J. Driver et al., Vis. Cogn., in press.
5. J. Culham et al., J. Neurophys., in press.
6. Z. Pylyshyn and R. Storm, Spat. Vision **3**, 1 (1988) [Medline].
7. J. Duncan, J. Exp. Psychol. Gen. **113**, 501 (1984) [Medline].
8. R. Desimone and J. Duncan, Annu. Rev. Neurosci. **18**, 193 (1995) [Medline].
9. K. O'Craven, B. R. Rosen, K. K. Kwong, A. Treisman, R. L. Savoy, Neuron **18**, 591 (1997) [Medline].
10. M. S. Beauchamp, R. W. Cox, E. A. DeYoe, J. Neurophysiol. **78**, 516 (1997) [Medline].
11. E. Wojciulik, N. Kanwisher, J. Driver, ibid. **79**, 1574 (1998) [Medline].
12. M. Corbetta, F. M. Miezin, S. Dobmeyer, G. L. Shulman, S. E. Petersen, Science **248**, 1556 (1990) [Medline].
13. A. Treisman, Q. J. Exp. Psychol. Sect. A. Hum. Exp. Psychol. **40a**, 201 (1988) [Medline].
14. M. I. Posner and S. Dehaene, Trends Neurosci. **17**, 75 (1994) [Medline].
15. E. Wojciulik and N. Kanwisher, NeuroImage **7**, S78 (1998).

The authors are in the Department of Brain and Cognitive Science, Massachusetts Institute of Technology, Cambridge, MA 02139 [HN13], USA. E-mail: ngk@psyche.mit.edu

HyperNotes
Related Resources on the World Wide Web

General Hypernotes

Vision Science is an Internet resource for research in human and animal vision.

The World Wide Web Virtual Library Eye Movement provides a general introduction to oculomotor studies, as well as information of interest to those in ergonomics, optometry, ophthalmology, physiology, psychology and the neurosciences, and clinical medicine.

The World Wide Web Library Cognitive Science is a list of Web resources for the cognitive sciences.

Neurosciences on the Internet is a searchable and browsable index of neuroscience resources available on the Internet. It covers resources for neurobiology, neurology, neurosurgery, psychiatry, psychology, cognitive science, and information on human neurological diseases.

The Human Brain Project is a broad-based long-term research initiative funded by the National Institutes of Health which supports research and development of advanced technologies for communication among neuroscientists and behavioral scientists.

Consciousness and the Brain: Annotated Bibliography by Ralph D. Ellis is a bibliography of consciousness, perception, and the brain.

A Brief Tour of the Brain, developed at Syracuse University, describes the structure of the brain and the anatomy of neurons.

NeuroRing is a collection of Web sites and pages that are devoted primarily to providing information related to the neurosciences. Sites in NeuroRing cover basic science research, clinical research, neurology, behavioral neurosciences, and neurocomputing.

Cognitive and Psychological Sciences on the Internet is an index to Internet resources relevant to research in cognitive science and psychology.

The Mining Company Guide to Neurosciences is a guide to Internet resources for neurology.

Numbered Hypernotes

1. Nancy Kanwisher's Web page describes her research and lists selected publications.
2. A brief biography of Hermann Ludwig Ferdinand von Helmholtz includes a portrait.
3. The Classics in the History of Psychology Web site provides a brief biography of Hermann von Helmholtz and outlines his importance in psychology.
4. Mind, Brain, and the Experimental Psychology of Consciousness outlines the work of von Helmholtz and other early contributors to psychological thought. This essay is a chapter of Mind and Body: Rene Descartes to William James by Robert Wozniak.
5. Visual Perception by Shimon Edelman outlines the characteristics of visual attention and other aspects of visual perception.
6. Central Visual Pathways, a chapter of Neuroscience for Kids, provides a brief explanation of the major pathway that visual information takes on its way from the eye to the primary visual cortex.
7. Seeing, Hearing, and Smelling the World, a report from the Howard Hughes Medical Institute, includes essays on the visual pathway and other aspects of the visual system.
8. Primate Info Net, maintained by the Wisconsin Regional Primate Research Center, provides information about the behavior, evolution, and other aspects of the biology of primates and includes links to other information resources for primatology.
9. All About Functional Magnetic Resonance Imaging (fMRI) describes fMRI, includes examples of images, and lists additional Internet resources for MRI.
10. The Oxford Centre for Functional Magnetic Resonance Imaging of the Brain (FMRIB) provides an introduction to fMRI, recent MRI images and animations, and links to other resources.
11. The Basics of MRI by Joseph P. Hornak is an introduction to the principles of magnetic resonance imaging. Chapters cover the physics and mathematics of nuclear magnetic resonance, basic imaging techniques, imaging hardware, image artifacts, and advanced imaging techniques.
12. The Neurovisualization Laboratory at the University of Virginia presents a brief description of

functional magnetic resonance imaging.

13. Department of Brain and Cognitive Sciences, Massachusetts Institute of Technology

Volume 282, Number 5386, Issue of 2 Oct 1998, pp. 57-58.