SENSES AND SENSITIVITY:

NEURONAL ALLIANCES FOR SIGHT AND SOUND

DECEMBER 8 AND 9, 1997

Broadcasting and Webcasting live from the Howard Hughes Medical Institute
Headquarters and Conference Center, Chevy Chase, Maryland USA

Four exciting lectures by

A. James Hudspeth, Ph.D., M.D.
Howard Hughes Medical Institute and The Rockefeller University

Jeremy H. Nathans, M.D., Ph.D.
Howard Hughes Medical Institute and
The Johns Hopkins University School of Medicine

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Kay Chernush, p. 10
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HOWARD HUGHES MEDICAL INSTITUTE PROGRAMS

The Howard Hughes Medical Institute (HHMI) was founded in 1953 by aviator-industrialist Howard R. Hughes. Its charter, in part, reads: *The primary purpose and objective of the Howard Hughes Medical Institute shall be the promotion of human knowledge within the field of the basic sciences (principally the field of medical research and medical education) and the effective application thereof for the benefit of mankind.*

BIOMEDICAL RESEARCH PROGRAM

The Howard Hughes Medical Institute is a nonprofit medical research organization dedicated to basic biomedical research and education. Its principal objectives are the advancement of fundamental knowledge in biomedical science and the application of new scientific knowledge to the alleviation of disease and the promotion of health.

Through its program of direct conduct of medical research, HHMI employs more than 330 independent investigators, based at 72 medical schools, universities, and research institutes located throughout the United States. The Institute conducts research in five broad areas: cell biology, genetics, immunology, neuroscience, and structural biology.

To assist in these research efforts, the Institute is involved in the training of graduate and postgraduate students in its investigators' laboratories, gives substantial support to the international human genome mapping program, provides research training to medical students through the Research Scholars Program (conducted jointly with the National Institutes of Health), and organizes scientific conferences, workshops, and program reviews.

GRANTS AND SPECIAL PROGRAMS

To complement its research program, the Institute sponsors a grants program that is dedicated to strengthening education in the biological and related sciences. Administered by the Office of Grants and Special Programs, Institute grants are designed to enhance science education at the graduate, undergraduate, and precollege levels; to increase public understanding and appreciation of science; and to support fundamental biomedical research abroad as well as research resources in U.S. medical schools. The grants reach a wide range of institutions involved in formal and informal science education, including colleges and universities, medical schools, research institutes, elementary and secondary schools, and museums.

The Institute also regularly gathers and analyzes data to evaluate its various grant initiatives and identify national trends relevant to science education and research. In addition, the Institute convenes meetings of educators, scientists, and policy experts to discuss these trends and issues relevant to public and private sector programs.

Providing Support to Students of Science

Since 1988, the Institute's grants program has provided approximately $115 million in fellowship support to 1,600 students and physician scientists who show promise of becoming tomorrow's leading biomedical researchers.

The undergraduate program has awarded $335 million to strengthen life sciences education at 220 public and private colleges and universities. These awards are intended to enrich educational opportunities for science majors and to enhance the general scientific literacy of students who major in nonscience subjects.

In addition to precollege activities in the undergraduate program, the Institute has awarded $29 million to 74 science museums, aquaria, botanical gardens, and zoos, and 42 biomedical research institutions to support innovative educational programs and to interest youngsters in science.

The Institute's local science education initiatives provide opportunities in the Washington, D.C., area for precollege students at all levels to gain experience in the science classroom and laboratory. The Holiday Lectures on Science series for high school students, held each December at Institute headquarters in Chevy Chase, Maryland, is telecast via satellite throughout North America to more than 8,000 senior high schools.

Another component of the Institute's grants program is the research resources competition. A research resources competition was held in 1995, and a total of $80 million was awarded to 30 U.S. medical schools. Annual payments of $550,000 to $1 million per institution will be made over four years for junior faculty, startup, core facilities, pilot projects, emergency funds, and other activities that will help the schools sustain their commitment to research. The research resources program also provides support to research organizations serving the biomedical community as unique resource laboratories and teaching facilities.

In addition, through a grants initiative launched in 1991, the Institute supports the research of outstanding biomedical scientists abroad. In February 1997, 47 leading researchers in Argentina, Brazil, Canada, Chile, Mexico, and Venezuela were named as International Research Scholars in the most recent initiative of the program. Altogether, more than $53 million in five-year grants has been awarded to 190 research scholars.

The Institute's home page on the World Wide Web, http://www.hhmi.org/, provides direct links to the grants program pages. For additional information on the HHMI Web site, refer to the section on the Howard Hughes Medical Institute Web site in this guide, page 37.

INTRODUCTION:
Howard Hughes Medical Institute Holiday Lectures on Science

In 1993, the Howard Hughes Medical Institute established the Holiday Lectures on Science, a series of lectures for high school students. The lectures build on traditions established in 1827 in London by the British scientist Michael Faraday and on science lecture series offered annually by colleges and universities around the world.

The Holiday Lectures on Science are held for two days in the Conference Center at the Institute headquarters in Chevy Chase, Maryland. The lectures are developed with the advice and assistance of the HHMI Holiday Lectures Teacher Resource Group, which is composed of high school educators from the Washington, D.C., area, and the HHMI Holiday Lectures Museum Resource Group, consisting of curators from Washington, D.C., area museums. The speakers are scientists known to be effective in communicating scientific concepts to the general public and to precollege students. Approximately 190 students from 80 high schools in the Washington, D.C., area attend the lectures each year. Department chairs and principals in each area high school nominate participants on the basis of their demonstrated interest in science.

The lectures are part of the Institute's grants program, which complements the Institute's research activities. Through its grants, the Institute is a major contributor to the enhancement of science education for students from their earliest years through graduate or medical school and beyond. Since 1988, the Institute has granted approximately $617 million, including $547 million to be expended through fiscal year 1997 and the rest committed to four- and five-year annual awards. The awards have reached a wide range of institutions, including colleges, universities, medical schools, research institutes, science museums, and elementary and secondary schools, covering an extensive array of educational activities.

This Year's Lecture Series

This year, A. James Hudspeth, Ph.D., M.D., HHMI Investigator at The Rockefeller University, and Jeremy H. Nathans, M.D., Ph.D., HHMI Investigator at The Johns Hopkins University School of Medicine, will present *Senses and Sensitivity: Neuronal Alliances for Sight and Sound*. Their lectures will discuss how two highly specialized organs—the eye and the ear—enable humans and other organisms to see and hear.

PREVIOUS LECTURES

The inaugural lectures in 1993, entitled "Da Vinci and Darwin in the Molecules of Life," were given by Stephen Burley, M.D., D. Phil., and John Kuriyan, Ph.D., both HHMI Investigators at The Rockefeller University. These lectures discussed the three-dimensional structure of biologically important molecules and their role in health and disease. In 1994, Shirley M. Tilghman, Ph.D., HHMI Investigator at Princeton University, and Robert L. Nussbaum, M.D., of the National Human Genome Research Institute at the National Institutes of Health, spoke on "Genes, Gender, and Genetic Disorders" and presented the latest findings on sex determination in mammals and other animals.

In 1995, Thomas R. Cech, Ph.D., HHMI Investigator at the University of Colorado at Boulder, presented "The Double Life of RNA," in which he described the discovery of a catalytic function for RNA that may help fight viruses, cancer, and genetic disease. And in 1996, John W. Kappler, Ph.D., and Philippa Marrack, Ph.D., HHMI Investigators at the National Jewish Center for Immunology and Respiratory Medicine, discussed how the immune system functions and, on rare occasions, malfunctions.

Dr. Hudspeth will begin by discussing how simple organisms—such as bacteria—have the capacity to detect and react to a stimulus. By unraveling the events that make sensory transduction in bacteria possible, researchers have gained insights into how the more specialized sense organs of higher organisms function. Dr. Nathans will then discuss how the visual process involves the detection of light by photoreceptors in the retina.

On the following day, Dr. Hudspeth will explain the basis for the ear's remarkable ability to detect sound through the hair cell, the sensory receptor found in the inner ear. Dr. Nathans will complete the lecture series by clarifying what is known about the brain's ability to process and integrate various elements of the visual system, such as color, motion, and depth.

The Institute is strongly committed to enhancing science education. This year's series is supported by materials based on the lectures and provided by the Institute to 12,000 teachers around the country. Using advanced satellite and computer technologies, the Institute will once again broadcast the lectures to more than 8,000 senior high schools.

THE HHMI Holiday Lectures Teacher Resource Group consulted with Institute staff and Washington, D.C., area students to develop a resource guide to accompany the Holiday Lectures on Science (l-r: HHMI Vice President Joseph G. Perpich, teacher Toby Horn, student Joe Train, and teacher Judy Brown).

From far left, Dennis Liu, HHMI Program Officer; Audrey Davis, former Curator of Medical Sciences, National Museum of American History; Terry Sharrer, Curator, National Museum of American History; and Anne Whitaker, Librarian, National Library of Medicine, develop the holiday lectures exhibit at a meeting of the HHMI Holiday Lectures Museum Resource Group.

THE 1997 HOLIDAY LECTURES ON SCIENCE: Meet the Presenters

A. James Hudspeth, Ph.D., M.D., Howard Hughes Medical Institute Investigator and Head of the Laboratory of Sensory Neuroscience, F.M. Kirby Professor, and Director of the F.M. Kirby Center for Sensory Neuroscience at The Rockefeller University, New York City.

Jeremy H. Nathans, M.D., Ph.D., Howard Hughes Medical Institute Investigator and Professor of Molecular Biology and Genetics, of Neuroscience, and of Ophthalmology at The Johns Hopkins University School of Medicine, Baltimore.

Travelling Similar Paths

Although they have never collaborated in a laboratory setting, James Hudspeth's and Jeremy Nathans' careers share a number of common threads. Each turned a lifelong interest in science into an outstanding career. Both are M.D./Ph.D. researchers devoted to understanding how the brain gets information from the environment. And early in their scientific careers, each chose to focus on a single sense.

Dr. Hudspeth, Head of the Laboratory of Sensory Neuroscience at The Rockefeller University, works to decipher the secrets of the inner ear, where sound waves become neural signals sent to the brain. Dr. Nathans, Professor of Molecular Biology and Genetics, of Neuroscience, and of Ophthalmology at The Johns Hopkins University, has devoted his work to mapping the molecular mechanism of light-sensitive cells in the eye. In their first collaborative effort, they will deliver the 1997 HHMI Holiday Lectures on Science on December 8 and 9, at 10:00 a.m.

Dr. A. James Hudspeth and HHMI Investigator Dr. David P. Corey discuss the hair cell's conversion of vibrations into nerve signals.

A. JAMES HUDSPETH

"By the time I was five, I was interested in science, especially in learning about living things," Dr. James Hudspeth recalls. It is an interest that endures to this day as the central focus of his career.

As children growing up in the rural outskirts of Houston, Texas, Dr. Hudspeth and his younger brother avidly collected just about anything: rocks, fossils, shells, bird nests, and bones. They collected living things, too—their home became a virtual zoo. "We had more than 200 pets," Dr. Hudspeth boasts. "Dogs, cats, raccoons, opossums, snakes—you name it."

Dr. Hudspeth officially launched his research career at the age of 14, when he went to work part time in the laboratory of Peter Kellawey, a physiologist at Baylor Medical College and a family friend. He continued to work with Kellawey until he graduated from Harvard, where he received his B.S. in biochemistry. Dr. Hudspeth entered graduate school at Harvard Medical School in 1967, where he worked with Torsten Wiesel and David Hubel, Nobel laureates for their pioneering vision research, until 1974, by which time he had earned both his M.D. and his Ph.D. degrees.

Finding a Direction

When his graduate mentors assigned him to deliver a series of lectures to medical students on hearing and related topics, Dr. Hudspeth was "shocked to find that even though hearing has some really remarkable properties, very little was known about it—the critical experiments just hadn't been done." He decided that he could help bridge that gap and, as a postdoctoral fellow at the Karolinska Hospital in Stockholm, began to study the mechanisms of hearing.

Upon his return to the States, he narrowed his work even further in his studies of the inner ear, which began at the California Institute of Technology. His first challenge was to find a way to study the inner ear outside of its well-protected site in the head. His answer lay in the fact that the amphibian ear is structurally similar to the mammalian ear, but easier to access.

Discovering How It Works

Vibrations pass from the outside world through a series of bony structures to the cochlea, a coiled tube that senses the various frequencies present and passes this information to the brain. The actual sensors are hair cells, tipped with bundles of fine "feelers" called stereocilia, with taller stereocilia occupying one side and shorter stereocilia occupying the other.

Hair cells populate the length of cochlea down the basilar membrane. High frequencies penetrate only a short way into the cochlea and vibrate the basilar membrane toward the outside end; lower tones vibrate the basilar membrane further in. Pitch perception is thus encoded in the position along the basilar membrane of the hair cells that are the most strongly stimulated.

Developing New Techniques and Findings

Dr. Hudspeth developed methods to remove living hair cells from frogs and record the electrical changes that occur when their stereocilia are tickled with a vibrating probe. The new technique enabled Dr. Hudspeth and his research team to confirm that the stereocilia are in fact the hair cell's sensory organelles.

They also found that displacing the stereocilia, even by the diameter of an atom, causes a change in voltage in the hair cell. This change is the result of ions passing through membrane pores—called ion channels—that open in response to displacement. They found that this response was incredibly fast—the channels open only a few microseconds after the stereocilia move to one side.

Still, the molecular mechanism that opened the ion channels remained unclear to researchers. The speed and sensitivity of the response, according to Dr. Hudspeth, indicated that there must be a mechanical link between the ciliary movement and the channel opening. He called this link a "gating spring," but what such a spring might look like and how it might work remained a mystery. "There had to be a physical process going on," Dr. Hudspeth remembers thinking.

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The linking filament is tied to a "trap door" on the cilium's ion channel protein and pulls it open when displacement causes filament tension to increase. This theory is consistent with the evidence and represents a new mechanism by which an ion channel's opening and closing can be regulated.

Unraveling the Mystery

While Dr. Hudspeth and his team were struggling with their research dilemma, another researcher—electron microscopist James Pickles in the United Kingdom—was making headway in his work. In 1984, he observed exquisitely thin filaments linking the taller stereocilia to the tips of their shorter neighbors. The geometry was such that deflection of the bundle toward the taller member would *tighten* the filament, while deflection in the opposite direction would *relieve* the tension.

Subsequently, Dr. Hudspeth and others were able to demonstrate that the "tip links" were intimately involved in hair cell action, in part by observing that disruption of the links resulted in a loss of sensitivity to displacement.

Dr. Hudspeth presumed that the linking filament is tied to a "trap door" on the cilium's ion channel protein and pulls it open when displacement causes filament tension to increase. Although this theory is not yet completely proven, it is consistent with the evidence and represents a new mechanism by which an ion channel's opening and closing can be regulated.

Moving On

After several years at the University of California at San Francisco and at the University of Texas Southwestern Medical School, where he founded a neuroscience program and chaired the department of cell biology, Dr. Hudspeth moved to The Rockefeller University in 1995.

He is currently engaged in several projects designed to further illuminate hair-cell function. One of these projects entails a search for genes that encode the various proteins involved in the hair cell's responsiveness. Another involves an exploration of the mechanism by which hair cells adjust their sensitivity in response to their exposure to constant noise.

In the course of this study, Dr. Hudspeth has concluded that the hair-cell ion channels spontaneously close after the cilia are deflected for as little as 0.1 second. It seems that at the point at which the tip link attaches to the longer stereocilium, a motor protein slides downward, readjusting the tension. This readjustment likely relies on a motor protein called myosin—the same protein responsible for muscle movement.

The Amplification Mechanism: A Goal for Future Research

Today, Dr. Hudspeth is focusing his efforts on identifying a poorly understood amplification mechanism that appears to be at work in the cochlea. "The ear is about 100 times more sensitive than we can explain," he says. "If you put a microphone in it, you can detect noises that the ear itself generates." These sounds may be related to the amplification mechanism. Myosin molecules might be involved in this system as well.

The sound you hear is Dr. Hudspeth—single-mindedly working toward an answer.

JEREMY H. NATHANS

Dr. Jeremy Nathans continues his work at The Johns Hopkins University School of Medicine.

Jeremy Nathans admits to being a late bloomer. The son of a Nobel Prize–winning scientist (for his work in molecular genetics), Dr. Nathans did not see science as his future until his senior year of high school. Until then, he says, "I was more interested in basketball."

That year, as a student at Baltimore's Polytechnic High School, Dr. Nathans discovered that math and science were no longer mere "fun." "They suddenly got very, very interesting," he says. "I started doing some reading in math and chemistry on my own, and I realized I didn't have to rely on what was being taught in the classroom." That discovery launched a distinguished and innovative career.

Finding a Niche

His first love was physics, but as an undergraduate at the Massachusetts Institute of Technology, he became increasingly fascinated by the life sciences and began what he describes as a "slow detour" toward biology. He graduated in 1979, with a degree in chemistry and biology.

It was as a graduate student at Stanford that Dr. Nathans first became attracted to the study of the eye and the mechanism of vision. "I heard a couple of lectures on vision as part of the medical curriculum," Dr. Nathans remembers. He was so fascinated that he "ran—literally ran—straight to the library" to learn more.

He soon discovered a particular fascination for the problems of color vision, the mechanisms of which remained obscure. It was a chance to tread new ground: the most important molecular players in this sensory function remained undiscovered.

Pinpointing Light-Absorbing Proteins

The retina contains two kinds of sensory cells: rods for black and white perception, and cones for color. The cones come in three varieties, which respond to either red, green, or blue light. "It occurred to me," Dr. Nathans recalls, "that the recombinant DNA techniques then being developed could answer many questions about color vision, in particular the identity of the proteins that absorb different wavelengths of light. I couldn't resist it."

Dr. Nathans' research strategy was based on the thesis that the light-absorbing protein found in rods—rhodopsin—would be similar to color vision pigments. To test his theory, he designed a DNA probe—based on the partial nucleic acid sequence already known for rhodopsin—that would bind to the rhodopsin gene.

"After a certain amount of sweat, we were able to identify the genes that encode each of the three pigments that absorb different colors. We got lucky," Dr. Nathans says.

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Analyzing Mutant Pigment

Dr. Nathans demonstrated that most people with aberrant color vision—commonly referred to as "color blindness"—have variant forms of one or another of the cone cell pigments.

In the years that have followed, Dr. Nathans has continued to focus his work on the retina, using an approach that combines neurobiology, physics, genetics, and clinical medicine. In his laboratory, he used the color pigment gene sequences to determine the sequence homology of both normal and aberrant forms of their corresponding proteins so that he could determine their biophysical properties—such as how their structure affects their interaction with light. He also found that many people have variations in their color pigment sequences that have small effects on their ability to distinguish colors.

Identifying the Causes of More Severe Visual Disorders

The logical extension of Dr. Nathans' interest in the mechanism of color vision was his developing interest in the genetic disorders that often cause color blindness. Although approximately 10 percent of men experience some kind of red-green color vision anomaly, complete color blindness is far less common. A mere 1 in 100,000 have the comprehensive color blindness that occurs when serious mutations occur in two out of three color vision pigments.

"Color perception works by the brain comparing the strengths of the red, green, and blue outputs," explains Dr. Nathans. "So if you lack two out of the three, you are left with shades of gray." This discovery may eventually help color-blind men who in their thirties often experience a progressive loss of sensitivity in the center of the retina, where most of the cone cells are found. Thanks to Dr. Nathans and his colleagues, our understanding of how the mutations lead to this degeneration has increased, although so far no one has identified a way to halt it.

Dr. Nathans has also identified a connection between retinitis pigmentosa—a degeneration of the peripheral retina—and mutations in the rhodopsin gene. "Most of the mutant pigments are unstable—they unfold spontaneously," he explains. "The unfolded protein is a mess for the cell to deal with, so over time that increases the chance that cells will die. Rods and cones don't regenerate, so if you lose them, that's it."

The Retina as Mini-Brain

Today, Dr. Nathans' retina research is driven by an even more ambitious curiosity. "I'm really interested in how the human brain is built and how it works. That is a mighty tall order, but it is also the biggest challenge for modern biology. The only way to approach such a huge problem is to pick it apart into small enough pieces that you can design an experiment and get yourself an answer."

Learning more about the retina may help him find the answer to his questions. "The retina is not just a sensor, like a camera; it is a mini-brain that processes an image in a number of ways. By studying how the retina develops during embryogenesis, you can study how the brain is built—how embryonic cells make the right connections and are programmed to become the mature cells they ultimately become."

Best of all, says Dr. Nathans, "You can get a sense of how the genetic blueprint for making cells evolved. And you can study genetic differences in individuals and between species, and how these differences affect function."

Dr. Nathans continues to help us see how intricate—and how miraculous—our eyes can be.

CURRICULAR MATERIALS

LECTURE 1—SENSORY TRANSDUCTION: GETTING THE MESSAGE

TEACHER RESOURCES

Hole, J.W. Jr. *Human Anatomy and Physiology*, 6th ed. Wm. C. Brown, 1993. This textbook is designed for students pursuing careers in allied health fields who have minimal backgrounds in the physical and biological sciences. Supplementary materials include a computerized study guide and testing service, transparencies, laboratory manual, visual testbank, extended lecture outline software, and audiovisual materials.

[1]Difficulty Level: 3-4

[2]Content Level: 3-4

National Association of Biology Teachers and Society for Neuroscience. *Neuroscience Laboratory and Classroom Activities*, 1996. This laboratory manual provides neuroscience laboratory and classroom activities on the senses; neural processing activities; and stress and the nervous system.

Difficulty Level: 3

Content Level: 3-4

[1] Refers to the estimated subject knowledge needed by a high school student to understand the information contained in a publication or other media reference. Rank is based on a scale of 1 to 5 (highest).

[2] Refers to how directly relevant the information in a publication or other media reference is to extending the information being presented by the lecturers. Rank is based on a scale of 1 to 5 (highest).

Key Concepts

- The initial step in the response to any stimulus is sensory transduction, the translation of the stimulus into an intracellular signal. In higher organisms, this signal is generally an electrical response.
- In bacteria, sensory transduction is carried out through steps involving proteins and ending in the movement of the cell toward or away from the stimulus.
- Receptor molecules, which are often found on cell surfaces, are proteins that detect a sensory signal and initiate an electrical response.
- In addition to photoreceptors to detect light, hair cells to detect sound, taste receptor cells to detect food sensations, and olfactory receptor cells to detect odors, higher organisms have receptor cells that can detect chemicals (chemoreceptors), damaging stimuli (nociceptors), temperature (thermoreceptors), body position (proprioceptors), and physical distortion (mechanoreceptors).
- Certain receptors diminish their response when a stimulus is continuous. This is known as adaptation.
- Nerve cells encode information in the form of electrical impulses, termed action potentials. These responses can be distinguished by their duration and frequency. This process is analogous to Morse code sent down the telegraph wire, where information is encoded in the pattern of electric impulses.
- Impulses result from the movement of ions, particularly sodium and potassium, across the cell membrane, altering the charge on the membrane. Sodium ions moving into a cell create a positive charge within, whereas potassium ions moving out create a negative charge within.
- Both sodium and potassium ions move through specialized ion channels that open when the charge on the membrane inside the cell is more positive and close when it is negative.
- The region of contact between one nerve cell and another is termed the synapse. Communication across the synapse usually occurs when one cell releases chemical substances. These substances can act on the other cell in two ways. They either cause an ionic movement by opening specialized ion channels, or they instigate a biochemical change that modifies existing activity.

Selected Publications

Axel, R. "The molecular logic of smell." *Scientific American* 273(4):154–159, 1995. Genes responsible for the synthesis of special odor receptors in the nose form the basis of our sense of smell. Less well understood is how the signals from the receptors are analyzed and integrated with other brain functions.

Difficulty Level: 3 Content Level: 3

Bragg, R. "A Sixth Sense and Sensibility." *The New York Times* 22 Oct. 1996:A18. Judge Tony Cothren, although blind, is able to use his other senses and a "sixth sense" to make judicial decisions.

Difficulty Level: 1-2 Content Level: 3

Garciá-Añoveros, J. and D.P. Corey. "The molecules of mechanosensation." *Annual Review of Neuroscience* 20:567–594, 1997. Mechanosensation is the transduction of mechanical forces into electrochemical signals, allowing organisms to sense touch. Research on the mechanosensation systems of flies and worms should help us better understand how humans sense physical stimuli such as touch, acceleration, and body movements.

Difficulty Level: 5 Content Level: 5

Stock, J.B., A.M. Stock, and J.M. Mottonen. "Signal transduction in bacteria." *Nature* 344:395–400, 1990. Genetic and biochemical approaches show that sensory receptors in bacteria couple a stimulus to a response through the transfer of energy-rich bonds involving phosphoryl groups.

Difficulty Level: 5 Content Level: 5

Selected Web Sites for Teachers and Students

Another Day, Another Neuron. Part of *Access Excellence: On Becoming a Neuroscientist.* On this Web site, experts discuss the educational background needed for becoming a neuroscientist, types of places that offer employment, different career paths that a neuroscientist can take, and what a typical day is like for a neuroscientist.

[3]Difficulty Level: 2 [4]Content Level: 3

http://www.gene.com/ae/LC/SS/chudler/chudler_seminar.html

A. James Hudspeth. This home page is connected to the Web site for The Rockefeller University. It provides a brief overview of Dr. Hudspeth's research, a list of his publications, and links to other sites at The Rockefeller University.

Difficulty Level: 2 Content Level: 5

http://www.rockefeller.edu/sep/hudspeth.html

Biomedical Research. This site provides visualizations of neural processes prepared by the Center for Biomedical Imaging Technology.

Difficulty Level: 4-5 Content Level: 4-5

http://panda.uchc.edu/htbit/indiv/research.html

[3] Refers to the estimated computer aptitude and/or subject knowledge needed by a high school student to understand the information contained in a Web site. Rank is based on a scale of 1 to 5 (highest).

[4] Refers to how directly relevant the information in a Web site is to extending the information being presented by the lecturers. Rank is based on a scale of 1 to 5 (highest).

Introduction to Neuroscience. A useful resource for teachers, this course was developed by the Center for Talented Youth in Baltimore, Maryland, and it outlines both laboratory and didactic material.

Difficulty Level: 3-4 Content Level: 4
http://www.slc.edu/pages/m/mbelmont/CTY/cty_neuroscience.html

Neurons and Their Growth Cones. Growth cones are leading edges of the elongating portion of a nerve cell that help connect the cell to its proper target. This site provides movies of early neuronal formation and other events of interest in the neurosciences. Requires a PC.MOV translator (*Indeo Video* extension).

Difficulty Level: 4 Content Level: 4
http://gramercy.ios.com/~pab9/index.html

The Neuroscience Connection. This Web site contains a rich collection of related neuroscience links including library resources for writing a project or term paper, as well as links to search engines, newsgroups, and software.

Difficulty Level: 3-4 Content Level: 3-5
http://www.udel.edu/skeen/BBcspace1.html#2

Physiology and Endocrinology Neuroscience Links. In addition to presenting extensive links to neuroscience search engines, journals, and sites with information on neurological diseases, neuroanatomy, and neuroimaging, this Web site also contains primers on the nervous system, sight, hearing, and brain functions ranging from learning and memory to sleep.

Difficulty Level: 3-4 Content Level: 5
http://www.mcg.edu/som/PhyEndo/NEUROLNK.HTM

Science Learning Network. The Network is a community of educators in schools and museums across the Internet. The Network offers opportunities to share resources and ideas, collaborate, connect with other teachers, and exchange project concepts.

Difficulty Level: 3 Content Level: 3
http://www.sln.org/

Virtual Neuron. Material on this Web site illustrates how images are obtained from neurons by using microscopy and how movie sequences can be constructed from these data.

Difficulty Level: 3-4 Content Level: 3-4
http://lenti.med.umn.edu/NEURON_BRAIN/NEURON.html

LECTURE 2—THE SCIENCE OF SIGHT: GETTING THE PICTURE

Key Concepts

- Vision begins with the detection of light by photoreceptors located in the retina at the back of the eye.
- The photoreceptors include rods that are specialized for low light levels and cones that are responsible for color vision.
- The photoreceptors convert, or transduce, light energy into changes in membrane potential, thereby helping to initiate nerve impulses.
- Color is perceived by the activation of different proportions of cones capable of detecting blue, green, or red.
- The brain assigns colors based on a comparison of the readout of the three cone types, according to the Young-Helmholtz Trichromacy Theory.
- Color blindness results when one or more sets of cones responsible for detecting a particular color are absent or dysfunctional.
- Accommodation is the process by which light is focused on the retina by changing the shape of the eye's lens.
- Adaptation is the process by which the eye adjusts to the available light level by dilation or closure of the pupil and various changes in the retina.
- Amplification is the process by which the visual system produces a significantly enhanced response to an initial visual stimulus through a series of chemical reactions.
- Nerve cells bundled together into optic nerves extend from the retina to several different brain structures, each of which analyzes separate parts of the field that we see.

TEACHER RESOURCES

Society for Neuroscience. *Brain Facts: A Primer on the Brain and Nervous System*, 1990. This 32-page booklet presents an introduction to the brain and nervous system and associated disorders. In addition to discussing how the nervous system functions, the booklet contains chapters on the senses, disease advances, current disease challenges, new diagnostic methods, and potential therapies.

Difficulty Level: 3
Content Level: 3-4

Selected Publications

Masland, R.H. "Unscrambling color vision." *Science* 271:616–617, 1996. The author, a Howard Hughes Medical Institute Investigator, discusses how the perception of color is detected by cone photoreceptors in the retina and interpreted by various nerve sites in the brain.

Difficulty Level: 3-4 Content Level: 4-5

Nathans, J. "The genes for color vision." *Scientific American* 260(2): 42–49, 1989. By isolating and analyzing the genes for the four proteins in the eye responsible for detecting light, scientists have a means for understanding the molecular basis of color blindness in humans.

Difficulty Level: 3 Content Level: 5

Pennsylvania Biotechnology Association. *Your World/Our World* 6(1), 1996. In this issue, the editors use easy-to-read text and color graphics to focus, in part, on describing neuronal receptors and their role in transmitting signals to the brain.
Difficulty Level: 2 Content Level: 3

Roush, W. "A 'master control' gene for fly eyes shares its power." *Science* 275:618–619, 1997. Specific genes are responsible for the development of eyes. Some genes have the capability of giving rise to eyes in out-of-the-way places such as a developing leg or antenna.
Difficulty Level: 3-4 Content Level: 4-5

Schnapf, J.L. and D.A. Baylor. "How photoreceptor cells respond to light." *Scientific American* 256(4):40–47, 1987. This article examines how rods and cones, the photoreceptors found in the retina of the eye, respond in the visual process and generate electrical signals that are then transmitted to the brain.
Difficulty Level: 3 Content Level: 3

Society for Neuroscience. *Brain Concepts: Looking and Seeing*,1991. This four-page brochure discusses types of eye movements and why they are crucial.
Difficulty Level: 2 Content Level: 4

Stryer, L. "The molecules of visual excitation." *Scientific American* 257(1):42–50, 1987. When a rod cell, one type of photoreceptor in the retina, absorbs light, a series of chemical reactions is unleashed that generates an electrical signal. Molecular biologists have helped to unravel the molecular pathway involved.
Difficulty Level: 3 Content Level: 5

Wade, N. "Alteration of Genes in Brain Cells Shows How Mice Remember Maps." *The New York Times* 31 Dec. 1996:C3. A mouse in new surroundings quickly forms a mental picture of its environment. By altering a single gene in the brain, scientists have interfered with this process and gained insights into how memory works.
Difficulty Level: 1-2 Content Level: 3-4

Wald, G. "The molecular basis of visual excitation." *Nature* 219:800–807, 1968. A history of the research of one of the three Nobel laureates who discovered the role of vitamin A and the protein rhodopsin in the chemical pathway that results in vision.
Difficulty Level: 4 Content Level: 5

Selected Web Sites for Teachers and Students

Anatomy of the Visual System

The Eye. This site presents anatomical information about the structures of the eye, together with microscopic photos of human eye structures, a tutorial, and a glossary.
Difficulty Level: 3-5 Content Level: 4-5
http://retina.anatomy.upenn.edu/~lance/eye/eye.html

Eye Simulation Page. On this Web site, eye motion and the effects of inhibiting one or more of the nerves and one or more of the muscles that control eye movement are demonstrated. Macromedia Shockwave plug-in is required.

Difficulty Level: 3-4 Content Level: 3-4
http://moby.ucdavis.edu/rick/eyesim.htm

How We See: The First Steps of Human Vision. Part of *Access Excellence: Activities Exchange*. This report briefly summarizes the history of our understanding of vision and emphasizes the chemical basis of the visual pigments.

Difficulty Level: 3 Content Level: 4
http://www.gene.com/AE/AE/AEC/CC/vision_background.html

Jeremy Nathans. A brief description of Dr. Nathans' work appears on the HHMI Web site, together with links to an overview of genetics, other HHMI investigators in genetics, and *Research in Progress*, an annual publication of HHMI that describes the research progress of the HHMI investigators.

Difficulty Level: 2 Content Level: 5
http://www.hhmi.org/science/genetics/nathansj.htm

Webvision Home Page. Extensive information on the retina, microscopic anatomy of the retina, retinal circuits, and neuroactive substances in the retina is provided. Requires Apple's QuickTime for either Macintosh or Windows.

Difficulty Level: 3-4 Content Level: 5
http://insight.med.utah.edu/Webvision/index.html

Eye Diseases and Treatment

Eye Care Information Services. Information on various surgical techniques for treating glaucoma—a condition that results in excess pressure in the eye and that can damage the retina—is provided.

Difficulty Level: 3 Content Level: 3
http://www.eyeinfo.com/surgproblems.html

National Eye Institute. Information is provided regarding research currently being conducted in the Institute's laboratories and clinics, together with announcements of new research and treatment advances.

Difficulty Level: 2 Content Level: 3-4
http://www.nei.nih.gov/

Visual Games and Illusions

B-Eye. This site allows visitors to view images as perceived through a bee's eyes.

Difficulty Level: 1 Content Level: 1-2
http://cvs.anu.edu.au/andy/

IllusionWorks. This site offers a potpourri of interactive optical illusions. Java software and a Macromedia Shockwave plug-in may be required to view some of the scientific demonstrations.

Difficulty Level: 4 Content Level: 2-3
http://www.illusionworks.com/

The Joy of Visual Perception. A number of experiments are provided to demonstrate different elements of visual perception, such as movement, afterimages, distance perception, and color vision.

Difficulty Level: 3 Content Level: 3-4
http://www.yorku.ca/research/vision/eye/toc.htm

Learning Studio On-Line Exhibits. Through this site, students can view a variety of exhibits and illusions that illustrate visual perception, color vision, and other aspects of vision. Some sites may require Macromedia Shockwave plug-in, QuickTime VR, or a Macintosh computer.

Difficulty Level: 4 Content Level: 2-3
http://www.exploratorium.edu/learning_studio/lsxhibit.html

Neuroscience for Kids. This Web site contains graded experiments to test vision for students from kindergarten through twelfth grade. Related sites that describe the eye, retina, and visual system, as well as other senses are available.

Difficulty Level: 2 Content Level: 3-4
http://weber.u.washington.edu/~chudler/chvision.html

LECTURE 3—THE SCIENCE OF SOUND: HOW HEARING HAPPENS

Key Concepts

- The receptors of sound—hair cells—are located in the organ of Corti. Each such cell has a mechanically sensitive organelle, the hair bundle, which consists of "feelers," the stereocilia. By bending in response to sound waves, the hair bundle converts sound into a neural signal.
- A protein in the cell membrane, called an ion channel, is linked by an elastic filament from the tip of one stereocilium to a similar ion channel in the tip of an adjoining stereocilium. Because of unusual ionic distributions of the inner ear, potassium ions move into the cell when a channel opens.
- Movement of the hair bundle in one direction increases the tension of the elastic filament, which opens the ion channel. Potassium ions then flow through the channel into the cell, thus making the electrical potential across the cell's membrane more positive—a process called depolarization. This is the first step in a series of changes within the cell that lead to the development of an electrical response.
- Movement of the hair bundle in the opposite direction relieves the tension, allowing the channel to close completely, thereby stopping the inward movement of potassium ions. This in turn causes the membrane potential to become more negative—a process called hyperpolarization.
- The electrical signal from the hair cell is conveyed by the release of neurotransmitter to the neurons that make up the auditory pathway to the brain.
- Outer hair cells respond to sound with both receptor potentials and changes in length. Alterations in size are caused by motor proteins in the membranes of the cells. The resulting variation in hair-cell length can help amplify the initial sound stimulus to the ear.

TEACHER RESOURCES

Marieb, E.N. *The A&P Coloring Workbook*, 3rd ed. Benjamin/Cummins, 1991. This workbook contains exercises designed to help students review for a test or laboratory quiz on the human body. The exercises include labeling and coloring anatomical and physiological drawings, matching structures and processes with descriptive terms, filling in blanks with correct terms, providing brief definitions, answering true and false questions, eliminating terms that don't belong, and visualizing the human body in miniature.

Difficulty Level: 3
Content Level: 4

Shipp, T.C. and R.E. Parrott. *The Senses*. Christopher Lee Publications. This kit includes a collection of study and activity sheets that emphasize how the hearing system works and contains information on other senses such as sight, smell, taste, and feeling. The kit includes vocabulary quizzes, puzzles, and a unit exam on the five senses.

Difficulty Level: 3
Content Level: 4

Selected Publications

Blakeslee, S. "Workings of Split Brain Challenge Notions of How Language Evolved." *The New York Times* 26 Nov. 1996:C3. A patient whose brain hemispheres were separated lost the ability to respond in either the spoken or written word to a visual stimulus to one eye. The results suggest that in some people, the capacities for written and spoken language may be located in different halves of the brain.

Difficulty Level: 1-2 Content Level: 3-4

Fitch, R.H., S. Miller, and P. Tallal. "Neurobiology of speech perception." *Annual Review of Neuroscience* 20:331–353, 1997. How the human brain can perceive and discriminate complex and rapidly changing components of human speech is not yet well understood. One important question is the extent to which speech perception involves the processing of sounds versus analyzing language by the brain.

Difficulty Level: 5 Content Level: 5

Hudspeth, A. J. "The hair cells of the inner ear." *Scientific American* 248(1):54-64, 1983. The physical organization of hair cells and their placement along the basilar membrane help explain the structure and function of hair cells in the process of hearing.

Difficulty Level: 3 Content Level: 5

Hudspeth, A.J. "How the ear's works work." *Nature* 341:397–404, 1989. Hair cells of exquisite sensitivity are central to the detection of sound. As hair cells respond to a stimulus, microscopic channels open and close to produce electrical signals.

Difficulty Level: 4 Content Level: 5

Knudsen, E.I. and M.S. Brainard. "Creating a unified representation of visual and auditory space in the brain." *Annual Review of Neuroscience* 18:19–43, 1995. Although much progress has been made in understanding individual sensory systems, much less is known about how the brain integrates information from different systems as it processes complex stimuli.

Difficulty Level: 5 Content Level: 5

Pickles, J.O. *An Introduction to the Physiology of Hearing*, 2nd ed. Academic Press, 1988. Discusses the structures that make up the outer and middle ear and the processes by which mechanical vibrations from incoming sound are decoded in the inner ear and understood in the brain.

Difficulty Level: 3 Content Level: 3

Pines, M., ed. *Seeing, Hearing, and Smelling the World*, Howard Hughes Medical Institute, 1995. This HHMI report focuses on how the senses work and on current research to extend the frontiers of our understanding of the neurosciences that underlie the senses.

Difficulty Level: 2 Content Level: 4-5

Selected Web Sites for Teachers and Students

Anatomy of the Auditory System

Cochlear Mechanics. A wealth of information on the cochlea is provided, including its structure and how it functions. An MPEG player, such as Keyview by FTP Software, is required.

Difficulty Level: 4 Content Level: 3-5
http://www.boystown.org/

Research on the Auditory System

The Johns Hopkins University Center for Hearing and Balance. This Web site contains easy-to-read descriptions (with illustrations) of research being conducted in the Center's laboratories. Some emphasis on balance function in normal subjects and in patients with hearing and balance disorders is provided.

Difficulty Level: 2-3 Content Level: 4-5
http://www.bme.jhu.edu/labs/chb/

National Institute on Deafness and Other Communication Disorders. Information is provided on current research being conducted in the Institute's laboratories and clinics, together with announcements of new research and treatment advances.

Difficulty Level: 2 Content Level: 3-4
http://www.nih.gov/nidcd/

Hearing Disorders and Treatment

Cochlear Implant. This site describes a device that can be surgically implanted and that is designed to bypass the nonfunctioning hair cells in patients who get little or no benefit from hearing aids.

Difficulty Level: 2 Content Level: 3-4
http://www.netdoor.com/com/entinfo/implaao.html

Hearing and Balance. This Web site at the University of Wisconsin contains a well-illustrated course book on the auditory systems and links to other sites.

Difficulty Level: 3-4 Content Level: 4-5
http://www.neurophys.wisc.edu/h&b/

Newton's Apple: Hearing. A segment from Newton's Apple emphasizes how loud noise can damage hearing. This site also contains experiments for listening when you can't rely on your eyes to see.

Difficulty Level: 2 Content Level: 3-4
http://ericir.syr.edu/Projects/Newton/13/lessons/hear.html

Auditory Games and Tests

Neuroscience for Kids. This site offers six graded experiments to test hearing for students from kindergarten through twelfth grade. It also contains links to other sites that explore healthy hearing, auditory perception, and the anatomy of the ear.

Difficulty Level: 1 Content Level: 3-4
http://weber.u.washington.edu/~chudler/chhearing.html

LECTURE 4—NEURAL PROCESSING: MAKING SENSE OF SENSORY INFORMATION

Key Concepts

- The retina contains approximately 125 million receptors and associated nerve cells, the structure and function of which are not uniformly distributed. Cones, for example, are found primarily in the central portion of the retina, whereas rods are found primarily in the periphery.
- The receptive field refers to each portion of the retina that when stimulated induces a change in the membrane potential of the nerve cell to which it is attached. The receptive field consists of a central circular area that provides direct photoreceptor input and an encircling area called the receptive field surround.
- Lateral inhibition occurs when the response of nerve cells to light reaching the center of the receptive field is the opposite to that of light in the surround. This organization of receptors and nerve cells suggests that we see light in terms of local spatial variations rather than as absolute magnitudes of light falling on the retina. Lateral inhibition occurs in most other sensory systems as well.
- In many types of retinas, the color sensitivity of the center of the receptive field is different from that of the receptive field surround. Such an organization of cells creates what is called color opponency.
- Other retinal receptors and their nerve cells are direction-sensitive and, when probed with spurts of light moving across the retina, produce a burst of impulses at the onset and cessation of illumination. This type of receptive field provides temporal processing of visual information.
- The visual cortex—the part of the brain that deciphers visual signals—is organized into slab-like columns. In one direction, there are alternating columns that receive input from only the left or the right eye. In a direction perpendicular to those columns, one can find another set of columns that shows a preference for how a light source is oriented to the retina. The auditory cortex is organized somewhat similarly by preference for a particular sound frequency.
- Cortical cells that respond preferentially to color stimuli are found in blob-like regions at the top of the visual columns.

TEACHER RESOURCES

NIMH Brain Imaging Compilation Reel. National Institute of Mental Health, National Institutes of Health, 1993. Shot on betacamSP, this video is a compilation of magnetic resonance imaging (MRI) movies and animation. An additional videotape in the same format is available showing positron emission tomography (PET) and MRI image analysis.

Difficulty Level: 3-4
Content Level: 3

Windows into the Brain. National Institute of Mental Health, National Institutes of Health, 1993. An audio-visual documentary, this 10-minute video is on 3/4-inch (U-Matic) formatted tape and presents a history of brain imaging.

Difficulty Level: 3-4
Content Level: 3

Selected Publications

Barinaga, M. "Visual system provides clues to how the brain perceives." *Science* 275:1583–1585, 1997. Visual awareness involves more than just what our retinas register. Just how the brain selects and alters visual signals is a momentous issue in neuroscience being addressed through study of the visual systems of man and monkeys.

Difficulty Level: 2-3 Content Level: 4-5

Blakeslee, S. "Researchers Track Down a Gene That May Govern Spatial Abilities." *The New York Times* 23 July 1996:C3. Scientists have identified a gene that is somehow responsible for higher mental processes, particularly the ability to break a problem into pieces and then reassemble it.

Difficulty Level: 1-2 Content Level: 3-4

Carr, C. and M. Konishi. "Axonal Delay Lines for Time Measurement in the Owl's Brainstem." *Proceedings of the National Academy of Sciences USA* 85:8311–8315, 1988. Determining the source of sound is based on anatomical and physiological evidence of unequal delays to a stimulus being transmitted from each ear to the sound-detection portion of the brain.

Difficulty Level: 5 Content Level: 5

Hilgetag, C.C., M.A. O'Neill, and M.P. Young. "Indeterminate organization of the visual system." *Science* 271:776–777, 1996. One approach to examining how the visual system is organized is through the use of a computer algorithm that organizes anatomical data into hierarchical relationships.

Difficulty Level: 3 Content Level: 4-5

Hubel, D.H. *Eye, Brain, and Vision*. Scientific American Library, 1988. This book focuses on how the eye registers a visual image and transmits nerve cell impulses to the brain, which then separately processes and integrates the information into a coherent picture.

Difficulty Level: 3 Content Level: 5

Hubel, D.H. and T.N. Wiesel. "Brain mechanisms of vision." *Scientific American* 241(3):150–162, 1979. The authors describe how a stimulus to the visual field of each eye is represented in the visual cortex, the portion of the brain responsible for processing visual information.

Difficulty Level: 3 Content Level: 5

Livingstone, M.S. "Art, illusion, and the visual system." *Scientific American* 258(1):78–85, 1988. How the components of a visual image, such as color, form, movement, and depth, are processed independently by three separate pathways in the brain is detailed in this article.

Difficulty Level: 3 Content Level: 3

Livingstone, M.S. and D.H. Hubel. "Segregation of form, color, movement, and depth: anatomy, physiology, and perception." *Science* 240:740–749, 1988. This article summarizes the anatomical, physiological, and psychological evidence for how primates independently analyze different aspects of the same visual image, such as color, movement, and depth.

Difficulty Level: 4 Content Level: 4

Raichle, M.E. "Visualizing the mind." *Scientific American* 270(4):58–64, 1994. The brain, encased within the skull, is equivalent to a so-called "black box," into which it is almost impossible to peer. The development of new methodologies—including one called positron emission tomography (PET)—has helped investigators surmount this formidable research obstacle.

Difficulty Level: 3-4 Content Level: 4-5

Shaywitz, S.E. "Dyslexia." *Scientific American* 275(5):98–104, 1996. Dyslexia is a disorder characterized by difficulty or an inability to read. Until recently, scientists thought dyslexia involved a defect in the visual system. Current studies suggest that the language-processing region of the brain rather than the visual system may be responsible.

Difficulty Level: 2-3 Content Level: 4

Selected Web Sites for Teachers and Students

Brain Awareness Week. This page provides a national quiz on brain structure and function, a calendar of activities, and links to Internet brain science resources.

Difficulty Level: 2-4 Content Level: 2-4
http://www.dana.org/brainweek/

The Digital Anatomist Program. This Web site provides two- and three-dimensional views of the brains of cadavers, using magnetic resonance imaging (MRI) and computer reconstructions. The atlas also is available on CD-ROM. In addition, a laboratory guide is under construction.

Difficulty Level: 3-4 Content Level: 5
http://www1.biostr.washington.edu/

Human Anatomy On-line. This Web page provides interactive and didactic material covering human anatomy. The program contains illustrations, animations, and descriptive links. This system uses Java applets. Programs are also available on CD-ROM.

Difficulty Level: 3-4 Content Level: 3-5
http://www.innerbody.com/

The Whole Brain Atlas. An atlas of brain structure and function, this Web site is illustrated with images of normal brains and brains affected by such disorders as stroke and by Alzheimer's disease, multiple sclerosis, AIDS dementia, and Creutzfeld-Jakob disease.

Difficulty Level: 3-4 Content Level: 5
http://www.med.harvard.edu/AANLIB/home.html

EXPLORING NEUROBIOLOGY: Selected Web Sites to Visit

NEUROANATOMY

The Digital Anatomist Program. This Web site provides two- and three-dimensional views of the brains of cadavers, using magnetic resonance imaging (MRI) and computer reconstructions. The atlas also is available on CD-ROM. In addition, a laboratory guide is under construction.

[1]Difficulty Level: 3-4 [2]Content Level: 5
http://www1.biostr.washington.edu/

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Difficulty Level: 3-4 Content Level: 3-5
http://www.innerbody.com/

Virtual Neuron. Material on this Web site illustrates how images are obtained from neurons using microscopy and how movie sequences can be constructed from these data.

Difficulty Level: 3-4 Content Level: 3-4
http://lenti.med.umn.edu/NEURON_BRAIN/NEURON.html

The Whole Brain Atlas. An atlas of brain structure and function, this Web site is illustrated with images of normal brains and brains affected by such disorders as stroke and by Alzheimer's disease, multiple sclerosis, AIDS dementia, and Creutzfeld-Jakob disease.

Difficulty Level: 3-4 Content Level: 5
http://www.med.harvard.edu/AANLIB/home.html

NEUROSCIENCE

Another Day, Another Neuron. Part of *Access Excellence: On Becoming a Neuroscientist*. On this Web site, experts discuss the educational background needed for becoming a neuroscientist, types of places that offer employment, different career paths that a neuroscientist can take, and what a typical day is like for a neuroscientist.

Difficulty Level: 2 Content Level: 3
http://www.gene.com/ae/LC/SS/chudler/chudler_seminar.html

Biomedical Research. This site provides visualizations of neural processes prepared by the Center for Biomedical Imaging Technology.

Difficulty Level: 4-5 Content Level: 4-5
http://panda.uchc.edu/htbit/indiv/research.html

[1] Refers to the estimated computer aptitude and/or subject knowledge needed by a high school student to understand the information contained in a Web site. Rank is based on a scale of 1 to 5 (highest).

[2] Refers to how directly relevant the information in a Web site is to extending the information being presented by the lecturers. Rank is based on a scale of 1 to 5 (highest).

Brain Awareness Week. This page provides a national quiz on brain structure and function, a calendar of activities, and links to Internet brain science resources.

Difficulty Level: 2-4 Content Level: 2-4
http://www.dana.org/brainweek/

Introduction to Neuroscience. A useful resource for teachers, this course was developed by the Center for Talented Youth in Baltimore, Maryland, and it outlines both laboratory and didactic material.

Difficulty Level: 3-4 Content Level: 4
http://www.slc.edu/pages/m/mbelmont/CTY/cty_neuroscience.html

Neurons and Their Growth Cones. Growth cones are leading edges of the elongating portion of a nerve cell that help connect the cell to its proper target. This site provides movies of early neuronal formation and other events of interest in the neurosciences. Requires a PC.MOV translator (*Indeo Video* extension).

Difficulty Level: 4 Content Level: 4
http://gramercy.ios.com/~pab9/index.html

The Neuroscience Connection. This Web site contains a rich collection of related neuroscience links, including library resources for writing a project or term paper, as well as links to search engines, newsgroups, and software.

Difficulty Level: 3-4 Content Level: 3-5
http://www.udel.edu/skeen/BBCspace1.html#2

Physiology and Endocrinology Neuroscience Links. In addition to presenting extensive links to neuroscience search engines, journals, and sites with information on neurological diseases, neuroanatomy, and neuroimaging, this Web site also contains primers on the nervous system, sight, hearing, and brain functions ranging from learning and memory to sleep.

Difficulty Level: 3-4 Content Level: 5
http://www.mcg.edu/som/PhyEndo/NEUROLNK.HTM

Science Learning Network. The Network is a community of educators in schools and museums across the Internet. The Network offers opportunities to share resources and ideas, collaborate, connect with other teachers, and exchange project concepts.

Difficulty Level: 3 Content Level: 3
http://www.sln.org/

VISION

Anatomy of the Visual System

The Eye. This site presents anatomical information about the physical structures of the eye, together with microscopic photos of human eye structures, a tutorial, and a glossary.

Difficulty Level: 3-5 Content Level: 4-5
http://retina.anatomy.upenn.edu/~lance/eye/eye.html

Eye Simulation Page. On this Web site, eye motion and the effects of inhibiting one or more of the nerves and one or more of the muscles that control eye movements are demonstrated. Macromedia Shockwave plug-in is required.

Difficulty Level: 3-4 Content Level: 3-4
http://moby.ucdavis.edu/rick/eyesim.htm

How We See: The First Steps of Human Vision. Part of *Access Excellence: Activities Exchange*. This report briefly summarizes the history of our understanding of vision and emphasizes the chemical basis of the visual pigments.

Difficulty Level: 3 Content Level: 4
http://www.gene.com/AE/AE/AEC/CC/vision_background.html

Jeremy Nathans. A brief description of Dr. Nathans' work appears on the HHMI Web site, together with links to an overview of genetics, other HHMI investigators in genetics, and *Research in Progress*, an annual publication of HHMI that describes the research progress of the HHMI investigators.

Difficulty Level: 2 Content Level: 5
http://www.hhmi.org/science/genetics/nathansj.htm

Webvision Home Page. Extensive information on the retina, microscopic anatomy of the retina, retinal circuits, and neuroactive substances in the retina is provided. Apple's QuickTime for either Macintosh or Windows is required.

Difficulty Level: 3-4 Content Level: 5
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Eye Diseases and Treatment

Eye Care Information Services. Information on various surgical techniques for treating glaucoma—a condition that results in excess pressure in the eye and that can damage the retina—is provided.

Difficulty Level: 3 Content Level: 3
http://www.eyeinfo.com/surgproblems.html

National Eye Institute. Information is provided regarding research currently being conducted in the Institute's laboratories and clinics, together with announcements of new research and treatment advances.

Difficulty Level: 2 Content Level: 3-4
http://www.nei.nih.gov/

Visual Games and Illusions

B-Eye. This site allows visitors to view images as perceived through a bee's eyes.

Difficulty Level: 1 Content Level: 1-2
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IllusionWorks. This site offers a potpourri of interactive optical illusions. Java software and a Macromedia Shockwave plug-in may be required to view some of the scientific demonstrations.

Difficulty Level: 4 Content Level: 2-3
http://www.illusionworks.com/

The Joy of Visual Perception. A number of experiments are provided to demonstrate different elements of visual perception, such as movement, afterimages, distance perception, and color vision.

Difficulty Level: 3 Content Level: 3-4
http://www.yorku.ca/research/vision/eye/toc.htm

Learning Studio On-Line Exhibits. Through this site, students can view a variety of exhibits and illusions that illustrate visual perception, color vision, and other aspects of vision. Some sites may require a Macromedia Shockwave plug-in, QuickTime VR, or a Macintosh computer.

Difficulty Level: 4 Content Level: 2-3
http://www.exploratorium.edu/learning_studio/lsxhibit.html

Neuroscience for Kids. This Web site contains graded experiments to test vision for students from kindergarten through twelfth grade and offers related sites that describe the eye, retina, and visual system, as well as other senses.

Difficulty Level: 2 Content Level: 3-4
http://weber.u.washington.edu/~chudler/chvision.html

HEARING

Anatomy of the Auditory System

Cochlear Mechanics. A wealth of information on the cochlea is provided, including its structure and how it functions. An MPEG player, such as Keyview by FTP Software, is required.

Difficulty Level: 4 Content Level: 3-5
http://www.boystown.org/

Research on the Auditory System

A. James Hudspeth. This home page is connected to the Web site for The Rockefeller University. It provides a brief overview of Dr. Hudspeth's research, a list of his publications, and links to other sites at The Rockefeller University.

Difficulty Level: 2 Content Level: 5
http://www.rockefeller.edu/sep/hudspeth.html

The Johns Hopkins University Center for Hearing and Balance. This Web site contains easy-to-read descriptions with illustrations of research being conducted in the Center's laboratories. Some emphasis on balance function in normal subjects and in patients with hearing and balance disorders is provided.

Difficulty Level: 2-3 Content Level: 4-5
http://www.bme.jhu.edu/labs/chb/

National Institute on Deafness and Other Communication Disorders. Information is provided on current research being conducted in the Institute's laboratories and clinics, together with announcements of new research and treatment advances.

Difficulty Level: 2 Content Level: 3-4
http://www.nih.gov/nidcd/

Hearing Disorders and Treatment

Cochlear Implant. This site describes a device that can be surgically implanted and that is designed to bypass the nonfunctioning hair cells in patients who get little or no benefit from hearing aids.

Difficulty Level: 2 Content Level: 3-4
http://www.netdoor.com/com/entinfo/implaao.html

Hearing and Balance. This Web site at the University of Wisconsin contains a well-illustrated course book on the auditory systems and links to other sites.

Difficulty Level: 3-4 Content Level: 4-5
http://www.neurophys.wisc.edu/h&b/

Newton's Apple: Hearing. A segment from Newton's Apple emphasizes how loud noise can damage hearing. This site also contains experiments for listening when you can't rely on your eyes to see.

Difficulty Level: 2 Content Level: 3-4
http://ericir.syr.edu/Projects/Newton/13/lessons/hear.html

Auditory Games and Tests

Neuroscience for Kids. This site offers six graded experiments to test hearing for students from kindergarten through twelfth grade. It also contains links to other sites that explore healthy hearing, auditory perception, and the anatomy of the ear.

Difficulty Level: 1 Content Level: 3-4
http://weber.u.washington.edu/~chudler/chhearing.html

ON-LINE PUBLICATIONS

Annual Review of Neuroscience. This site provides the opportunity to obtain abstracts of chapters and to order publications.

Difficulty Level: 5 Content Level: 3-5
http://www.annurev.org/

Business Week. Visitors have the opportunity to search selected articles from the current issue as well as recent features from the past year or so.

Difficulty Level: 2 Content Level: 3
http://www.businessweek.com/

Cell. Links are provided to journals covering neuroscience and the genome. Visitors can join BioMedNet, a club for biologists.

Difficulty Level: 3-5 Content Level: 3-4
http://www.cell.com/

Discover Magazine. Viewers can access current articles, review Discover programs for television, access an archival library, and tour other science sites.

Difficulty Level: 2 Content Level: 3-4
http://www.enews.com/magazines/discover/

The Economist. Visitors to the home page can review this week's articles. Search capability is provided, but selected topics may be difficult to find.

Difficulty Level: 2 Content Level: 2
http://www.economist.com/

Journal of Biological Chemistry. This site offers a browse-and-search capability for articles published in this science journal.

Difficulty Level: 4-5 Content Level: 3
http://highwire.stanford.jbc/

Journal of Neurochemistry. This site provides abstracts of publications and links to other neurochemical societies and neuroscience resources.

Difficulty Level: 5 Content Level: 3-5
http://www.jneurochem.com/

Nature. This Web site provides information on science articles and science news appearing in *Nature*, an international weekly journal of science. The home page contains an update on science topics, as well as links to coverage of genetics, medicine, structural biology, and biotechnology.

Difficulty Level: 3-5 Content Level: 3-5
http://www.nature.com/

The New York Times. Free registration allows access to articles from the current day's edition, as well as limited search functions.

Difficulty Level: 1-2 Content Level: 3
http://www.nytimes.com/

The Nobel Foundation. This site includes announcements of this year's Nobel prize winners and the opportunity to search for information about previous Nobel laureates.

Difficulty Level: 3-4 Content Level: 3
http://www.Nobel/

Retina: The Journal of Retinal and Vitreous Diseases. This page provides the opportunity to search journal archives and links to retina-related resources and retina-related societies.

Difficulty Level: 3-5 Content Level: 3-5
http://www.retinajournal.com/textversion.html

Science On-Line. This site provides browse and search capabilities and contents of most recent issues of *Science* magazine.

Difficulty Level: 3-5 Content Level: 3-5
http://science-mag.aaas.org/

Scientific American. This page contains links to quick article summaries, selected articles, news and analysis, interviews, and other features.

Difficulty Level: 2-3 Content Level: 3-5
http://www.sciam.com/

Technology Review. This Web site allows access to selected recent articles.

Difficulty Level: 2-3 Content Level: 3
http://web.mit.edu/techreview/www/

U.S. News & World Report. This site offers current news articles as well as search capability for topics from previous issues.

Difficulty Level: 2 Content Level: 3
http://www.usnews.com/

THE HOWARD HUGHES MEDICAL INSTITUTE WEB SITE

The HHMI Web site, http://www.hhmi.org/, has been on line since January, 1996, providing access to information on the varied activities of the largest private philanthropy in the United States. Two major areas of the HHMI Web site include Biomedical Research and Grants for Science Education. The Biomedical Research area, http://www.hhmi.org/science/, profiles Institute investigators and their cutting-edge work in five broad fields of biomedical research: cell biology, genetics, immunology, neuroscience, and structural biology. The Grants for Science Education area, http://www.hhmi.org/grants/, provides information on the largest private science education initiative in U.S. history.

GRANTS FOR SCIENCE EDUCATION WEB SITE DESIGN

The Grants for Science Education area of the HHMI Web site is designed for easy navigation, fast page loading, and interactive activities. Intuitive navigation tools appear on each page to help users combat "Web disorientation." These tools provide continuity and act as a guide or map, facilitating exploration. When users jump between hyperlinks, the navigation system provides users with information on (1) their current location, (2) how they can return to previous pages, and (3) what link options are available from the current page.

Navigation Tools

General Navigation (Electronic Breadcrumbs). Returning to a site visited several hyperlinks or mouse clicks ago often requires a lot of effort. To make this easier, the age-old technique of leaving breadcrumbs along a trail to keep track of where one has been is used in cyberspace. Electronic breadcrumbs track the pages users have visited on our site. At any given time, they may return to a previous site with a single mouse click on that breadcrumb.

Grants Program Navigation. The six major grants program areas are listed along the top of each page. Clicking on one of these immediately transports users to their destination. Those who aren't sure where they want to be can use the on-line search capabilities for finding sites of interest.

Topical Navigation. Concept-based menus of available topics are provided along the left side of the screen. These menus change to reflect topics available from a specific page.

The HHMI Grants for Science Education Web site is located at http://www.hhmi.org/grants/.

Rapid Page Loading

Because slow download times can be frustrating, rapid page loading is especially useful for those dialing in through modems and phone lines. The new design of the Grants for Science Education area of the HHMI Web site addresses this problem by including an overview that helps users understand the design of the site. The overview contains minimal text and small graphics to facilitate rapid loading. As users become more interested in a particular area and wish to delve into deeper layers, pages may contain more graphics. This design helps ensure that users do not experience long download times for pages they may not be interested in viewing.

Interactivity

A key advantage of the Web is its potential as an interactive medium. The HHMI Web site, including the Grants for Science Education area, is now optimized for interactive activities through a variety of plug-ins, Java applets, and Web-based messaging.

OTHER FEATURES OF THE HHMI WEB SITE

Other features of the HHMI Web site include interactive maps that allow users to locate HHMI laboratories and grant recipients in the United States and International Research Scholars around the world, http://www.hhmi.org/whereis/start.htm. News releases, http://www.hhmi.org/whatsnew/, and Institute publications such as the acclaimed *Beyond Bio 101: The Transformation of Undergraduate Biology Education*, http://www.hhmi.org/beyondbio101/, are also available on line.

A powerful search engine, www.hhmi.org/search, provides keywords that allow for the rapid location of particular topics or investigators of interest. Searches can be performed on the entire HHMI Web site or restricted to one of the HHMI publications—*Research in Progress, Grants for Science Education, or Laboratory Chemical Safety Summaries.*

HOLIDAY LECTURES ON SCIENCE ON LINE

In 1993, the Howard Hughes Medical Institute established a series of lectures for high school students, called the Holiday Lectures on Science. The lectures are held for two days in the Conference Center at the Institute headquarters in Chevy Chase, Maryland. The speakers are scientists known to be effective in communicating scientific concepts to the general public and to precollege students.

The HHMI Holiday Lectures on Science Web site, http://www.hhmi.org/lectures/, is currently being updated to reflect the 1997 lectures, *Senses and Sensitivity: Neuronal Alliances for Sight and Sound*. The lectures will be presented by A. James Hudspeth, Ph.D., M.D., HHMI Investigator, Head of the Laboratory of Sensory Neuroscience, F.M. Kirby Professor, and Director of the F.M. Kirby Center for Sensory Neuroscience at The Rockefeller University, and Jeremy H. Nathans, M.D., Ph.D., HHMI Investigator and Professor of Molecular Biology and Genetics, of Neuroscience, and of Ophthalmology at The Johns Hopkins University School of Medicine.

The 1997 lectures will be available for viewing via live and time-zone delayed satellite/cable broadcast and cable rebroadcast. In addition to the satellite and cable broadcasts, the 1997 lectures will be Webcast live. The Webcast version also will be available as downloadable videostreams following the lectures. Visit the HHMI Holiday Lectures on Science Web site for information on receiving the lectures via cable, satellite, or the Web.

Interactivity has become a key element of the Holiday Lectures on Science Web site, which has been redesigned to provide a number of activities related to learning about neurophysiology. From investigating the leech's nervous system in the virtual laboratory to studying virtual exhibits about the senses (ones that you know about and others you might not think of), the activities are designed by neuroscientists to provoke questions. Another section of the site allows visitors to pose their own questions to a select group of young scientists sponsored through the Institute's fellowship programs.

High- and low-bandwidth paths are available. Users who view the high-bandwidth path will be able to select interactive multimedia resources, such as the virtual laboratory, through Macromedia's Shockwave plug-in for Netscape Navigator and Microsoft Internet Explorer.

The Holiday Lectures on Science Web site also provides resources and teaching materials supporting the 1997 lectures that are suitable for classroom reading and discussion. In addition, interesting and important links to general science and neuroscience Web sites are available. These range from Introduction to Neuroscience, http://www.slc.edu/pages/m/mbelmont/CTY/cty_neuroscience.html, a useful resource for teachers, to the Eye Simulation Page, http://moby.ucdavis.edu/rick/eyesim.htm, which demonstrates eye motion, to Cochlear Mechanics, http://www.boystown.org/, which offers information on the structure and function of the cochlea.

Last Year's Holiday Lectures

Those who missed the 1996 lectures, "The Immune System—Friend and Foe" by John W. Kappler, Ph.D., and Philippa Marrack, Ph.D., HHMI Investigators and members of the Department of Medicine at the National Jewish Center for Immunology and Respiratory Medicine in Denver, can order a free videotaped copy on line. In addition, a digital video clip allows users to see and hear some of the highlights of the 1996 lectures.

Other pages allow users to submit questions about immunology to the lecturers, view a teacher's guide developed especially for the lectures, and use a collection of links to academic and commercial Web sites that provide more information about cell biology and immunology.

The site also features three-dimensional photos of the lecture hall during the presentation of the 1996 Holiday Lectures on Science and of a smallpox exhibit (on loan from the Smithsonian Institution) at the HHMI Conference Center. Users can zoom in and out to view people and objects more closely, or rotate the viewing angle and see 360 degrees of the scene from their Web browser with the help of a Quick-Time plug-in.

Be sure to visit http://www.hhmi.org/lectures/ often for information and updates on the 1997 lectures, including information about on-line lecture exhibits that will be coming live to the site.

THE HOLIDAY LECTURES ON SCIENCE EXHIBIT: On Site and On Line

This year's Holiday Lectures on Science includes an exhibit exploring themes in neuroscience that emphasize seeing and hearing. The exhibit will include a variety of displays such as real brain sections and larger-than-life brain models, images produced from the latest electronic imaging technology, a history of the science of these two senses, and devices used over the years to diagnose and address problems in hearing and seeing. Also provided will be multimedia stations where students who are attending the lectures can explore the reconstructions of human neuronal tissue in real time, related to The Visible Human Project. In addition, students can see live demonstrations of communication among electric fish and award-winning inventions created by student scientists.

This is the second year that the Holiday Lectures on Science has included an exhibit, developed with the efforts and guidance of the HHMI Holiday Lectures Museum Resource Group, which is composed of curators from Washington, D.C., area museums. The exhibit will be presented in conjunction with the lectures and can be viewed by students who are attending the lectures at the HHMI Conference Center at the Institute's headquarters in Chevy Chase, Maryland.

However, students who are not attending the lectures can still participate in the exhibit experience. This is because the features of the HHMI Holiday Lectures on-site exhibit are also developed for the HHMI Web site, http://www.hhmi.org/lectures/. Descriptions of the exhibit features, both on site and on line, follow.

ON-SITE EXHIBIT: HHMI HEADQUARTERS CONFERENCE CENTER

Displays: Discovering the Science of the Senses—Seeing and Hearing

The Smithsonian Institution, with cooperation from other museums, has developed a fascinating display that highlights the history of the science of the senses of seeing and hearing. The National Museum of Health and Medicine is providing the holiday lectures exhibit with real brain sections and larger-than-life brain models, as well as other artifacts. The Museum of the American Society of Otolaryngology—Head and Neck Surgery is providing artifacts documenting the technical progress in hearing aid development from early nonelectrical devices to the latest in cochlear implants.

RELATED RESOURCES

A visit to the Smithsonian Institution Web site is especially valuable—it is designed with a multimedia tool that will read the site contents to a visitor after free special software is downloaded. The Smithsonian Institution home page address is http://www.si.edu/newstart.htm. Look for such items as the effects of light on the human brain at the Smithsonian Magazine Web site, http://www.smithsonianmag.si.edu/, and the Smithsonian Natural History Web home page's exhibit on Squid: The Inside Story, http://seawifs.gsfc.nasa.gov/OCEAN_PLANET/HTML/squid_inside_story.html. Nerve cells from squid have figured prominently in neuroscience research.

The National Museum of Health and Medicine offers an array of health and science information, interactive computer stations, and anatomical materials, as well as photographs and illustrations. Current exhibits include Civil War Medicine; Living in a World with AIDS; The Evolution of the Microscope; and Human Body/Human Being. The National Museum of Health and Medicine home page is located at http://www.afip.mil/museum/museum.html.

To learn more about hearing, visit the American Society of Otolaryngology—Head and Neck Surgery's home page, found at http://www.entnet.org/. The site features a virtual museum exhibit of early hearing aids at http://www.entnet.org/hearing.html.

Multimedia Stations: Virtual Humanity

The holiday lectures exhibit will feature several multimedia stations at which students can explore the reconstructions of human nerve tissue in real time, using data from The Visible Human Project. This project's goal is to create complete, anatomically detailed, three-dimensional representations of the male and female human bodies. The current phase of the project entails collecting transverse computerized tomography, magnetic resonance imaging (MRI), and low-temperature-sectioned images of male and female cadavers at one millimeter intervals. The digital visual data produced by the project are in the public domain, and a variety of public and private organizations have been using the data to produce products such as CD-ROMs.

The Visible Human Project can be found on the Web at http://www.hlm.nih.gov/research/visible/visible_human.html.

Demonstrations

Several Species of Electric Fish

Carl Hopkins, Ph.D., Professor of Neurobiology and Behavior at Cornell University, will be present to demonstrate an exhibit that includes several species of weakly electric fish. In contrast to electric eels and rays—which use strong electric charges for defense and to stun prey—weakly electric fish generate weak electric fields to navigate their weedy and muddy environments and to communicate with conspecifics. Exhibit tanks will display several different species of these fish, and students will be able to see and hear the electrical signals that they produce. A "social" tank will also be displayed to show how these fish use electrical signals when they interact.

This exhibit was developed with the advice and efforts of Dr. Hopkins. His home page, where you can learn more about his work and about electric fish, is located at http://www.bio.cornell.edu/neurobio/hopkins/hopkins.html.

Adrianne Noe, Director, National Museum of Health and Medicine, participates in a meeting of the HHMI Holiday Lectures Museum Resource Group to discuss the Holiday Lectures on Science exhibit.

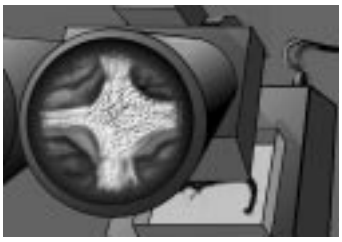
Help for the Senses—Student-Inventors

Ian Hagemann, a freshman at Princeton University, will demonstrate his invention—the portable visual field analyzer. Because this device is easy to pack and move, it can be used to identify eye diseases among people who do not have ready access to professional eye care facilities.

Michael Dauber, a freshman at the University of Michigan, will demonstrate the barcode reader he invented to help visually impaired people. The reader scans product barcodes and translates them into auditory output that users can hear and use to identify products such as goods on a grocery store shelf.

Two virtual elephant-nose fish (*Gnathonemus petersii* from Africa) inhabit the virtual electric fish aquarium.

A simulation of the electric field generated by an African electric fish (*Gymnarchus*). Notice that a cylindrical object distorts the field in its vicinity.



In the virtual neurophysiology laboratory, students make electrical recordings and anatomical observations of neurons in a leech ganglion and then identify the function of the cells. Shown is a magnified view of a ganglion of the leech central nervous system as seen through a dissecting microscope.

ON-LINE EXHIBIT: THE HHMI HOLIDAY LECTURES EXHIBIT WEB SITE

The HHMI holiday lectures on-site exhibit is also developed for our Web site, http://www.hhmi.org/lectures/, providing visitors a virtual experience that often is as rich and compelling as the real thing. Our Web exhibit will include the following features:

Electric Fish in a Virtual World

A variety of multimedia explorations are available on line that support the live exhibit of electric fish for the holiday lectures. Students will gain insight into the variety of electrical signals that these fish use for navigation and communication. Students can also experiment to determine how different behavioral patterns, such as looking for food or hiding, correlate with the production of different electrical signals.

Virtual Neurophysiology Laboratory—The Leech

This multimedia experience has been designed to guide students through the process of conducting an actual cellular neurophysiology experiment to understand the function of individual sensory neurons. Students are challenged to make electrical recordings and anatomical observations of neurons in a leech ganglion and then identify the function of the cells. The virtual laboratory includes use of a microscope, an oscilloscope, and a micromanipulator tool.

The Anatomy of the Cochlea

A beautiful animation probes the functional anatomy of the cochlea, the principal organ of hearing. Through state-of-the-art computer animation, students can see the cochlea uncoil to reveal its inner structure and workings.

Virtual Tour of the Eye

A uniquely detailed animation takes students on a brief virtual three-dimensional tour of the eye, visiting the key photoreceptors and neurons that make human vision possible.

This is just a sample of the holiday lectures on-line exhibit features that will be presented on the HHMI Web site. To get the most out of the Holiday Lectures on Science experience, visit http://www.hhmi.org/lectures/ often for previews of what's coming live to the site. Then be sure to explore the exhibits as they come on line, and don't forget to visit the related Web sites described in this guide.

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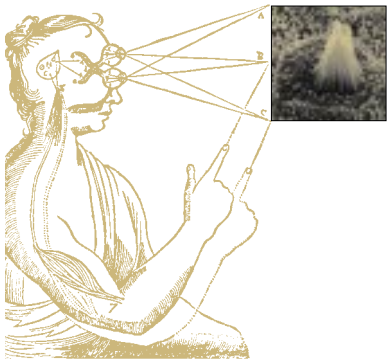

HOWARD HUGHES MEDICAL INSTITUTE

WORLD WIDE WEB SITE INDEX

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