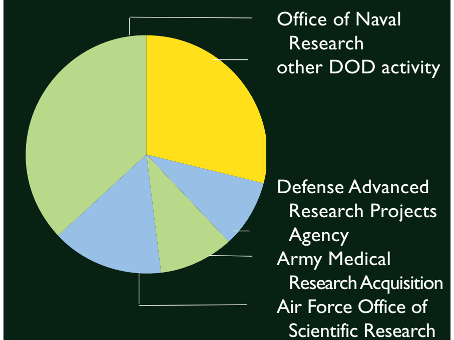
DOD

DEPARTMENT OF DEFENSE
UNIVERSITY OF CALIFORNIA

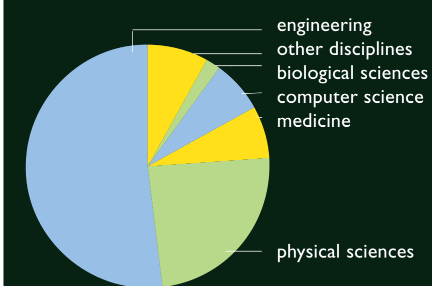
Office of Research, UC Office of the President, Autumn 2001

DOD funding facts:

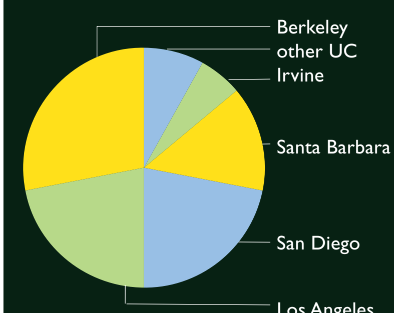
FY2000 DOD funding to UC by subagency



FY2000 DOD funding to UC by discipline



FY2000 DOD funding to UC by campus



Source: UCOP contracts and grants database

UC boosts DOD's high tech advantage

The Department of Defense awarded the University of California $144 million in FY2000 to help the United States maintain its scientific and technological edge. In fields as diverse as medicine, robotics, information systems and marine biology, UC provided fundamental research to advance our military capabilities and to improve the health of our armed forces.

The Army, Air Force and Navy each maintain specialized offices of research. In FY2000, the Office of Naval Research (ONR) awarded UC researchers $53 million, funding research in oceanography, marine mammals and other topics related to the Navy and the world's oceans. At UC Santa Cruz, ONR has helped fund a unique facility to study seals and sea lions (see pages 3 and 8).

The Air Force Office of Scientific Research provided $21 million to UC for research in aircraft and engine design, flight control and human-machine interfaces. At UC Irvine, the Air Force funded research on human vision and cognition (see page 6).

The Army Research Office funded several projects at UC, including research at UC Los Angeles to develop better protective coatings for critical metal components (see page 4).

The Army's Medical Research Acquisition Activity awarded UC $14 million for research to help meet the health needs of troops and their families who face unique health challenges when posted overseas or in locations far from hospitals.

DOD's Defense Advanced Projects Research Agency (DARPA) provided $13 million for research in emerging technologies that have potential defense applications. DARPA is helping to develop autonomous air and ground vehicles at UC Berkeley (see page 7).

Defense department awards totaling $144 million to UC were divided among several disciplines. Engineering studies received $75 million, while another $35 million supported the physical sciences. Medical and computer science research each received slightly more than $10 million, and biological sciences received $3 million. The remaining $11 million was distributed among a variety of disciplines.

In FY2000, every UC campus earned a portion of the $144 million DOD research total. The Berkeley campus received the most funding, $40 million, while UC's Los Angeles and San Diego campuses earned $31 million each. Santa Barbara earned $20 million, while Irvine earned $9 million. The remaining $13 million was divided between the campuses at Davis, San Francisco, Santa Cruz, Riverside, the Lawrence Livermore National Laboratory, and other smaller UC research sites.

With the end of the Cold War and the advent of the war on terrorism, the defense needs of the country have shifted. National security threats now include bio-terrorism and cyber attacks.

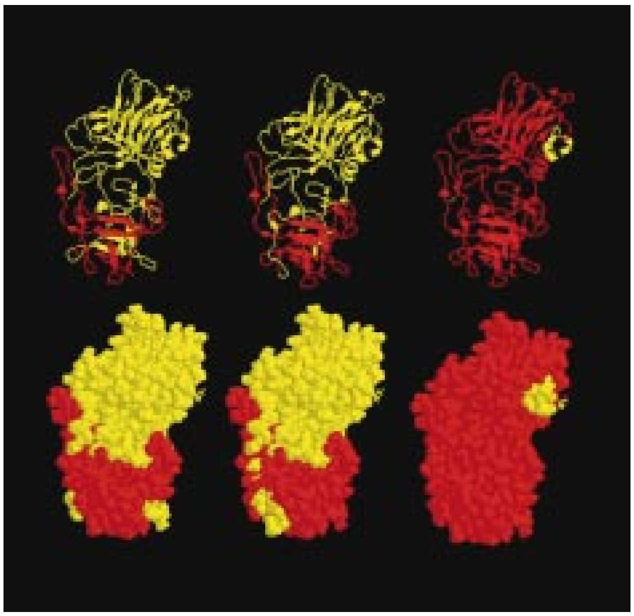
DOD has played an historic and fundamental role in funding scientific research in the U.S. As the nation's defense needs shift in the face of new threats, UC will continue to perform the research that helps support our national security.

FIGHTING Botulism

Clostridium botulinum is a common and usually harmless soil bacteria. In the right conditions, however, the microbe secretes a deadly neurotoxin that – if inhaled or eaten – prevents muscle tissue from contracting. The result can be paralysis of the diaphragm, suffocation and death. With Department of Defense funding, UC San Francisco's James D. Marks is developing a safe, cost-effective antitoxin to combat botulism. His techniques also can be used to produce antibodies to fight anthrax and other deadly diseases.

Botulism occurs rarely in the U.S., but it can result from improperly preserved foods and infected wounds. Infants are particularly susceptible.

Botulism also is a potent bioterrorism threat. The Japanese cult Aum Shinrikyo staged three botulism attacks in the 1990s, but the attacks failed due to the cult's lack of technical sophistication. After the Persian Gulf War, United Nations inspectors reported that Iraq had produced 5,000 gallons of crude botulinum toxin.



Molecular models of the botulinum toxin showing in yellow the epitopes, or binding sites, for three different antibodies.

Botulism is just one of many diseases that the defense department helps fight. Due to the threat of illnesses faced by GIs in foreign settings, DOD historically has helped nurture medical research on diseases like malaria and yellow fever. These maladies now are so rare in the developed world that pharmaceutical firms have little incentive to pursue treatments.

Although a vaccine is available for botulism, a national vaccine program is considered impractical given the rarity of the disease. Antitoxin is an alternative treatment that has the advantage of being effective even after the onset of symptoms. Botulism antitoxin can be derived from the antibodies of vaccinated humans, but the supply is limited.

UCSF's Marks is seeking an antitoxin based on his research with monoclonal antibodies, or bioengineered copies of single human antibodies. Marks is an M.D. who also has trained as a bench scientist. He completed his residency in internal medicine and anesthesiology at UCSF, and then earned a Ph.D. in molecular and cell biology under Greg Winter of England's Cambridge Center for Protein Engineering. Winter is considered the father of antibody engineering.

The human immune system relies on antibodies that can identify millions of potential invaders. When an antibody binds to a specific antigen of the invader, the cells that produce the antibody begin to replicate rapidly. If the antibody response is fast enough, the invader is overwhelmed. If not, death can result, especially in the case of an extremely toxic antigen like botulinum.

Taking a cue from this natural process, Marks starts with B lymphocytes, the white blood cells that produce antibodies. The lymphocyte genes that express antibodies are copied millions of times by using polymerase chain reaction, one of the staple techniques of molecular biology. The antibody genes then are cloned into bacteriophages, viruses that infect bacteria. These phages are used as vectors to insert the genetic material into *E. coli* bacteria. The *E. coli*, once infected, reproduce the genetic material of the phage, thereby becoming miniature antibody production factories.

Antibodies render antigens impotent by chemically binding to them, preventing the invader from locking onto human cells. Only a very few of the antibodies produced by Marks will bind and disable the botulinum toxin. Producing a sufficient quantity of the right antibodies requires several rounds of purification.

In the first round, these antibodies are tested against the botulinum toxin. The nonbinding antibodies are washed away, and the genetically-modified phages with antibodies that bind and disable the toxin are inserted into fresh *E. coli*, where they reproduce again. After several rounds of this process, antibodies that exist in frequencies as low as one in a billion can be produced in concentrated quantities.

Once antibodies effective against botulinum are identified, they must be produced in quantities sufficient for use as medications. Fortunately, these antibodies can be mass-produced using existing commercial methods.

By winnowing the rich endowment of antibodies that millions of years of evolution have programmed in the human immune system, Marks has identified extremely potent candidates for botulinum antitoxin.

Says Marks, "The wonderful thing about our methods is that they can be used to identify antibodies against many threats to human health, including viruses, bacteria, toxins and cancer." With DOD support, Marks is laying the foundation for a new approach to finding antibody-based medications.

Pinnipeds and Noise Pollution

UC Santa Cruz marine biologist Ronald Schusterman examines a resident harbor seal at the Long Marine Mammal Laboratory.

The pinnipeds – seals, sea lions, and walruses – survived the onslaught of hunters in the 19th century and ocean pollution in the 20th century, only to be confronted with a new threat in the 21st century. As shipping has expanded, and as sonar and underwater seismic explorations have grown louder, the rising level of noise in the oceans may be hurting seal and sea lion populations.

At UC Santa Cruz's Long Marine Mammal Laboratory, researchers are conducting fundamental research about pinniped cognition and hearing. Under the guidance of marine biologist Ronald Schusterman, postdoctoral researcher David Kastak and graduate students Brandon Southall and Colleen Reichmuth Kastak are producing a series of path-breaking studies of pinnipeds.

Their research is supported by the U.S. Navy's Office of Naval Research (ONR). The Navy has grown concerned about the environmental impact of a new generation of powerful low-frequency sonars. In earlier decades, the Navy was concerned with the sounds marine mammals made, and how to distinguish these sounds from those of submarines and ships. Now the emphasis has changed from how the ocean's creatures affect sonar to how sonar affects the ocean's creatures.

The Schusterman group has trained four pinnipeds – two sea lions, one harbor seal and one elephant seal – to take hearing tests. Training consists of developing new animal responses by using behavioral conditioning techniques that reinforce desired behaviors with fish rewards. Says Schusterman, "Teaching the animals various behaviors to test their hearing both in air and underwater allows us to better understand the nature and mechanics of their auditory systems."

The UC Santa Cruz Long Marine Laboratory is the only facility in the UC system with resident marine mammals. Burnyce, the resident female northern elephant seal, is the only trained member of her species in the world.

ONR funding has allowed the pinniped researchers to build a soundproofed chamber specifically designed to test the aerial hearing of the resident seals and sea lions. In the test chamber, the animals position themselves at a chin rest and await a tone produced by a speaker. If they hear a sound, they touch a paddle with their snout. Their correct responses are rewarded by fish dispensed from a tube.

The results of the experiments at the Schusterman lab are used to predict how noise of a given intensity, duration or character will affect the hearing of free-ranging pinnipeds. The information is useful not only to the Navy but also to the federal regulatory agencies charged with designing policies to protect pinnipeds and other marine mammals.

The UCSC researchers have discovered that sea lions don't have highly sensitive low-frequency hearing, which may save them from some of the ill effects of noise pollution. In contrast, seals are more sensitive to lower frequency sound, and as a result are more vulnerable to the ill effects of noise pollution.

Both seals and sea lions do exhibit a phenomenon known as temporary threshold shift. Just as human hearing takes a few hours to recover after prolonged exposure to

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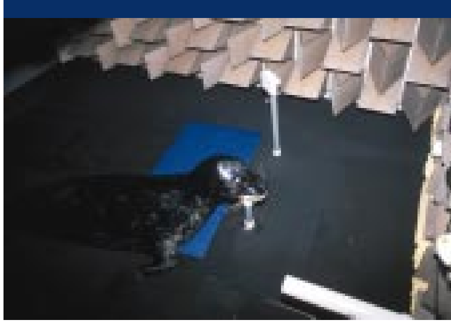
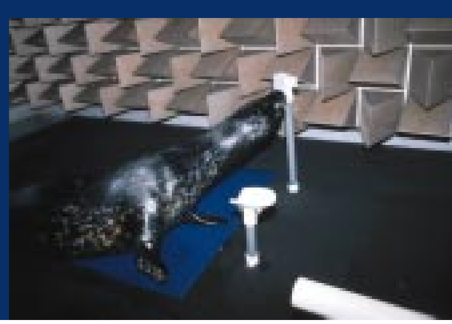
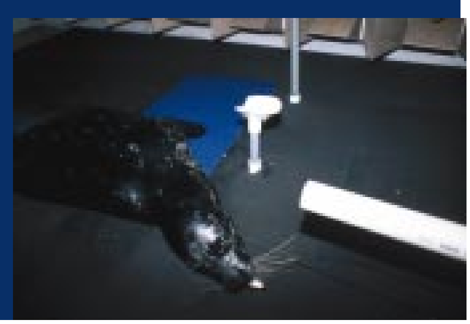






In a soundproof chamber, a harbor seal positions his head on a chin rest *(left)*. A tone is played on a loudspeaker. If the seal hears the tone, he touches a paddle with his nose *(center)*. If he is correct, he receives a fish reward from the tube on the lower right of the photograph *(right)*.

Protecting Metals

Inside a modern jet engine, temperatures are hot enough to melt alloy turbine blades. Maximum fuel efficiency requires combustion above 1370º Celsius, while the nickel alloys used to make the turbine blades have melting points in the range of 1230º to 1315º Celsius. The engines survive only because of the insulating ceramic coating on the blades.

At UC Los Angeles, chemist Emily A. Carter is working to improve the ceramic coatings that make modern jet engines possible. A film less than one millimeter thick reduces the temperature of the underlying alloy several hundred degrees Celsius. Unfortunately, this ceramic coating is fragile and subject to chipping.

Carter is working to prevent "spalling," the chipping of the protective ceramic layer that results from the constant heating and cooling of the engine. Spalling leads to downtime and to expensive engine repairs. To avoid this problem, jet engines are run at lower than optimal temperatures, leading to reduced fuel economy.

Although ceramic coatings have been used in jet engines for years, the exact nature of the interface at the atomic level between metal and ceramic is poorly understood. Carter is attempting to gain an atomic-level understanding of how these coatings fail.

In addition to her role as a chemistry professor, Carter is the UCLA director of modeling and simulation for the California Nanosystems Institute (see box on opposite page). She is a leader in "first principles" computer simulations of chemical interactions at the atomic scale.

These first principles computer modeling techniques include quantum mechanical effects by tracking the complex energy states of electrons involved in chemical reactions between atoms. These complicated simulations often require massively parallel supercomputers.

Carter, along with former postdoctoral fellow Asbjorn Christensen and graduate student Emily Jarvis, is using these techniques to model the interactions between the elements in the nickel alloy of the turbine blades, the crystal structure of the insulating ceramic coating and the bond coat that joins them. The ceramic coating is usually yttria-stabilized zirconia, an oxide of the 39th and 40th elements of the periodic table.

Carter's results suggest three solutions to the problem of spalling. The first is to reduce the amount of aluminum, perhaps by substituting silicon, in the bond layer between the alloy and the ceramic coating. The aluminum oxidizes in the high temperatures inside the jet engine, forming a layer that bonds poorly to the coating, allowing it to chip away. Carter has shown that an alternative – a high-temperature oxide of silicon – binds strongly to the coating and may act as a corrosion inhibitor.

UCLA professor Emily A. Carter points to the tur-bine of a jet engine. Ceramic coatings prevent these turbine blades from melting.

The second solution to spalling is to include the aluminum, but add certain reactive elements that increase the binding of the aluminum oxide that forms in high heat. Despite the fatal flaw of weak binding, the aluminum oxide prevents corrosion of the metal blades. Carter has shown that adding some metals to the bond layer can double the binding strength of aluminum oxide to the alloy of the turbine blades.

A third and even more intriguing solution is to modify the nature of the zirconia crystals in the insulating coating itself. A nanostructured pure zirconia – a laboratory-designed crystal not available in nature – could maintain its stability and structure over a wide temperature range. If properly structured, such zirconia crystals would not require the addition of yttrium-based stabilizers.

"If we could use nanotechnology to improve these coatings and allow jet engines to run at optimal temperatures," says Carter, "the savings would be significant – as much as 10 million gallons of fuel every year for a fleet of 250 airplanes."

Carter's simulation techniques also are useful in learning more about chemical reactions in situations where experiments are nearly impossible. For example, the heat and pressure inside a jet engine pale in comparison to what happens inside a tank gun barrel the moment a shell is fired. The metal of the gun barrel is subjected to extreme pressures and temperatures, as well as to caustic chemicals.

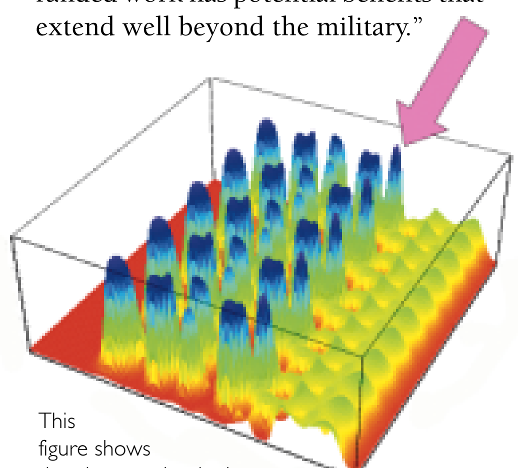
The U.S. Army has protected gun barrels with chromium coatings, much like those on the chrome bumpers of automobiles a generation ago. Unfortunately this method uses extremely toxic chemicals and can cause serious environmental problems.

Carter is helping the Army Research Office look for alternative methods to protect gun barrels. Working with postdoctoral fellow Ashok Arya and graduate student Wun Chiou, Jr., she is trying to understand what happens inside gun barrels by using simulation techniques much like those she employs in her work on jet engines.

Carter suspects corrosion is due to microscopic cracking of the gun barrel that allows excess carbon to combine with the steel. A brittle carbon-iron material called cementite can form in the cracks. Cementite and other carbon-iron compounds have low melting points compared to the steel of the gun barrel. As the steel is converted to cementite, it may be melted away in the heat of the blast. As with jet engine turbine blades, a solution might be a coating that protects the underlying metal of the gun barrel.

Carter's work is a good example of "dual-use" technology that serves both the military and civilian sectors. There are widespread applications for protective coatings – from longer-wearing pistons in internal combustion engines to smoother bearings in motors. Turbine engines are used to produce electricity in power plants, and improved coatings will lead to higher operating temperatures and greater fuel efficiency, reducing the cost of energy.

"There are several potential commercial spin-offs from my research," says Carter, "from better turbine engines to longer-lasting protective coatings for metals in all sorts of corrosive environments. My DOD-funded work has potential benefits that extend well beyond the military."



This figure shows the electron density in a silica coating on a nickel substrate. The blue peaks indicate a dense clustering of electrons over the oxygen atoms in the silica. The smoother green area indicates a more diffused pattern of electrons in the metallic bonds of the nickel. The arrow indicated the region of bonding between the silica and nickel. Better understanding of this interface at the atomic level will lead to sturdier protective coatings.

DOD and CNSI

UC Los Angeles and UC Santa Barbara have joined forces to create the California Nanosystems Institute (CNSI), one of four new California Institutes of Science and Innovation created on UC campuses by California Gov. Gray Davis. CNSI will combine state, federal and industry money to encourage the transfer of nanotechnology research results to California's private sector.

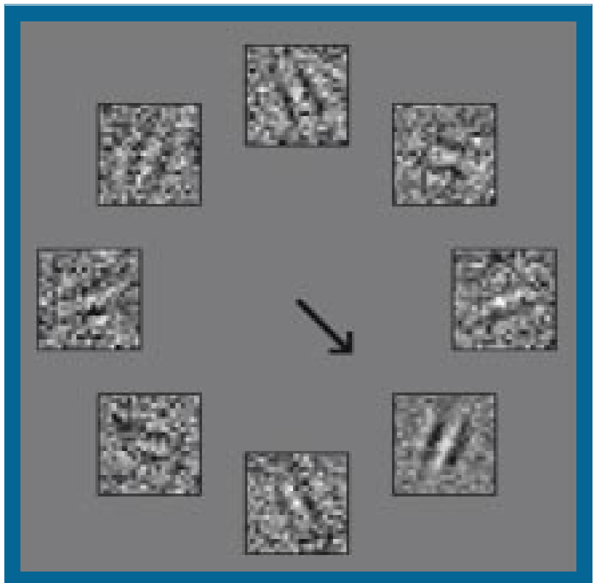
Nanotechnology is a multidisciplinary research area that spans electrical and mechanical engineering, material science, physics, chemistry, and molecular biology. Its goal is to understand and exploit the world at a scale of one-billionth of a meter, a world whose unique properties are not yet fully understood.

UCLA brings to CNSI a strong integration of medicine, the physical sciences and engineering, facilities for DNA sequencing and a new department of human genetics. UCSB adds a strong track record of interdisciplinary programs, especially in materials, optoelectronics, polymers and biomolecular materials.

The Department of Defense long has supported the development of nanotechnology. The work of professor Emily A. Carter (see story on facing page) is just one example. Several DOD-funded CNSI investigators and their research interests are listed below:

- **UCLA scientific co-director James Heath is developing nanowires and other devices for molecular electronics.**
- **UCSB scientific co-director Evelyn Hu is studying the use of new nanoscale optical devices for higher performance optical networks.**
- **UCLA professor Chih-Ming Ho is creating nanoscale electro-mechanial devices to move minute amounts of fluids for medical testing.**
- **UCSB professor John Bowers is studying fiber optic networks and high speed photonic and electronic devices.**
- **UCLA professor Kang Wang is building high power amplifiers for radar and optical sensors.**
- **UCSB professor David Awschalom is studying optical and magnetic interactions in semiconductor quantum structures and other devices for quantum information processing.**

Visual Cognition



This figure displays eight different Gabor patterns with varying degrees of noise superimposed. The arrow points to a pattern that is tilted weakly to the right (wr). Patterns can be tilted weakly or strongly, to either the left or the right. Can you tell what kind of tilt is involved with each block? How does the level of noise effect your response? Clockwise from the top, the tilts are: wl, sl, sr, wr, wl, sl, sr, wr.

A modern aircraft with the latest radars and navigational equipment must funnel an extraordinary amount of information to a pilot whose sensory system was designed for hunting and gathering. At UC Irvine, psychologist Barbara Dosher studies human cognition with funding from the Department of Defense Air Force Research Office. Her goal is to help make aircraft cockpits and other human-machine interfaces as effective as possible.

Control systems for aircraft, automobiles and other machinery often employ blinking lights, warning tones or other signals to make the operator pay attention. Optimally designed warning indicators and other cockpit instruments can shave critical seconds from a pilot's response in an emergency,

Says Dosher, "We are exploring some of the very basic visual cognitive abilities of human beings. It's interesting work, and we're glad it will have direct benefits for cockpit designs that may ultimately be used in both military and commercial aircraft."

Dosher is trying to sort out two competing theories of what it means to "pay attention." One theory is that paying attention enhances sensory input. In the alternative theory, paying attention helps filter nonessential sensory input, or "noise," thus enhancing the ability to focus on the task. Through a clever series of visual tests, Dosher has determined that paying attention seems to be a type of noise reduction mechanism.

Dosher tested several subjects on their ability to see the orientation of Gabor patterns, or wavy patterns of light and dark. In her experiments, these patterns were displayed on a computer screen and tilted away from the vertical either to the left or right. Patterns could be tilted weakly (halfway between zero and 45 degrees from vertical) or strongly (halfway between 45 and 90 degrees from vertical).

The Gabor patterns were overlaid with "noise patterns" of varying intensity. These noise patterns consisted of a series of squares arranged in a checker board pattern, but with the light and dark squares randomly assigned.

During the experiment, a group of Gabor patterns with noise superimposed was briefly displayed after an arrow (see illustration) pointed the human subject to a specific region of the test diagram. The arrow warned the test subject to pay attention to a certain section of the chart. The test subject then had to guess the tilt of the underlying pattern.

The test was conducted with various levels of signal contrast by adjusting the intensity of the light and dark areas of the Gabor pattern. The intensity of the noise pattern also was varied by adjusting the contrast of the light and dark squares in the noise pattern.

Dosher also tried other variations of the test. In one case, she used an invalid precue – an arrow that pointed to the wrong portion of the diagram before the test patterns flashed on the screen. She also compared the results with valid and invalid precues to test results with a neutral precue – a plus sign in the middle of the diagram that didn't point to any sector of the test chart. In each case, she recorded the number of correct and incorrect answers for several different subjects, and performed rigorous statistical analysis of the results.

If paying attention is a sensory enhancement device, Dosher reasoned, then valid precues should improve the number of correct responses even in the absence of noise – a faint but noise-free pattern should benefit from extra attention. If paying attention is a noise filtering device, then the stronger the noise, the more paying attention should help the subject determine the tilt of the Gabor patterns. Dosher's results were consistent with the noise filtering hypothesis.

The downside of the attention mechanism is that humans tend to miss things they are not concentrating on. In Dosher's experiments, the invalid precue results (with the warning arrow pointing in the wrong direction) were less accurate than the tests with a neutral precue (a simple plus sign).

For designing cockpit displays, it is critical to know the amount of time a pilot needs to interpret a signal and how much noise can be tolerated. Dosher's fundamental research on human cognition eventually will help build better displays for military aircraft, improve flight simulators and enhance the training of operators using a variety of human-machine interfaces.

Robot Soldiers

Senior development engineer Ron Tal adjusts a robotic helicopter. Based on a remote-controlled agricultural helicopter, this robot has been designed to land autonomously on a pitching platform that models the deck of a ship in a severe storm.

Just as machines have replaced workers in the most dirty and dangerous jobs on the factory floor, so machines soon may replace soldiers and pilots on the battlefield. At UC Berkeley, experimental robots are being developed to autonomously perform in simulated battlefield environments.

Under the direction of electrical engineer Sastry Shankar, researchers are developing autonomous ground and air vehicles, along with computer control systems for these robotic vehicles.

The remote-controlled aircraft used today by the U.S. military still require external commands. The experimental vehicles being developed at UC Berkeley can function with very limited external controls.

Sastry's research is taking place at UC Berkeley's unmanned air and ground vehicle laboratory, under the day-to-day management of director Peter Ray. The research is funded by several Department of Defense offices, including the Office of Naval Research (ONR) and the Defense Advanced Research Projects Agency.

In ONR's vision of the future, highly maneuverable robotic aircraft will operate from a variety of ships – not just from the large aircraft carriers required for today's naval air operations. These robots will be capable of flying different types of missions, including surveillance, target recognition and air combat.

"Right now several technologies are coming together," says Sastry. "Advances in computer architectures, networking, artificial intelligence, wireless communications and micro-electric-mechanical systems are making possible a new generation of autonomous vehicles."

Sastry's research team already has demonstrated an important first step in autonomous flight. The team started with a small remote-controlled helicopter designed in Japan for crop-dusting and other agricultural uses. They added global positioning satellite (GPS) navigation, cameras, computers and wireless communication devices.

The helicopter now takes-off autonomously, navigates to a pre-determined position by GPS, and – using its on-board camera – scans the ground for a two-meter square target symbol. When the helicopter acquires an image of the ground target, it lands on the target without any outside direction or control.

In addition to research on basic control of single vehicles, Sastry is cooperating with researchers at Stanford and Cornell universities through a multidisciplinary university research initiative (MURI) sponsored by the Army Research Office. The goal is to develop intelligent computer systems to allow autonomous vehicles to coordinate activities and work in teams.

At UC Berkeley, Sastry and colleagues have equipped several experimental ground robots with GPS navigation and then linked the robots with a wireless network. The researchers now are perfecting an intelligent computer control system that allows the robots to perform complex jobs with limited human intervention.

The ultimate goal is to develop robots that can perform the most hazardous battlefield tasks, reducing the risks for soldiers. With defense department assistance, UC is making the battlefield safer for U.S. military personnel.

Three ground robots wait in front of the robot helicopter. The white platters are GPS antenna. The vehicles are also equipped with optical cameras or laser rangefinders. Each vehicle functions autonomously and as part of a wireless network that connects all the vehicles together.

Ocean Noise continued from page 3

loud music at a rock concert, so pinniped hearing is diminished temporarily by hearing loud sounds.

Schusterman and his colleagues also have tackled a long-running debate about whether pinnipeds echolocate. Like terrestrial bats, *cetaceans* – whales and dolphins – send out sound waves and interpret the returning sonar signatures to help navigate and to find prey. Some marine biologists have suggested pinnipeds also echolocate.

The Schusterman group has debunked the notion of pinniped echolocation. They determined that instead of developing a sonar system of underwater orientation, pinniped visual, tactile and acoustic sensory systems were combined for underwater perception and navigation. While the cetaceans have evolved to live solely in the water, pinnipeds have ears that must function both in the water and on land – seals and sea lions give birth on land, and some species mate on land as well. According to Schusterman, "These complex hearing requirements prevented pinnipeds from evolving the same sort of hearing mechanisms used by toothed cetaceans such as dolphins and killer whales."

Doctoral student Colleen Reichmuth Kastak tends Burnyce, the world's only trained female northern elephant seal.

Another question is how noise pollution will affect not just individuals, but wild pinniped populations as a whole. Even if anthropogenic (human-generated) ocean sound levels are too low to permanently or even temporarily damage hearing, they still can mask other critical sounds in the ocean. Pinnipeds use a variety of vocalizations to keep in touch with their young, and they use their sensitive hearing to listen for fish. If noise pollution is masking these sounds, pinniped populations could suffer as females lose track of their pups and hunting becomes more difficult.

"There is still much we don't know and much more work to be done," says Schusterman. "We're grateful for the support of ONR, as we begin to explore more broadly how humans are affecting the well-being of pinnipeds and other marine mammals."

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