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Mind sight

Eye-tracking reveals not just what you're looking at, but how hard you're thinking about it

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In a nondescript office building off Alvarado Road near San Diego State University, a woman sits at a computer monitor, scrolling through news stories on the MSN.com Web site.

There's little else in the room: a second computer, another chair, a large two-way mirror. On the other side of the mirror, Sandra Marshall, a professor of psychology at SDSU, keeps one eye on the woman – colleague Cassie Davis – and one on two monitors that track Davis' eyes via cameras beneath her own computer screen.

EDUARDO CONTRERAS / Union-Tribune
At EyeTracking Inc., a San Diego company, small cameras suspended below researcher Nathan Meixler's eyes tracked his pupils' movements.

The first monitor depicts the same Web pages Davis is looking at, with a pair of moving green dots showing where on the screen her eyes are focused. The second monitor displays dials recording pupil dilation and brain activity, the needles rising or falling with Davis' mental interest; and graphs measuring how much light is entering her eyes, the data dropping briefly to zero when she blinks.

At first glance, the scene does not appear remarkable, but Marshall and others suggest it is a glimpse of the future, one that will be seen – and analyzed – through the eyes.

Marshall, Davis and colleagues are part of a relatively new field of research that uses eye-tracking technologies to change the way we see, understand and relate to the world.

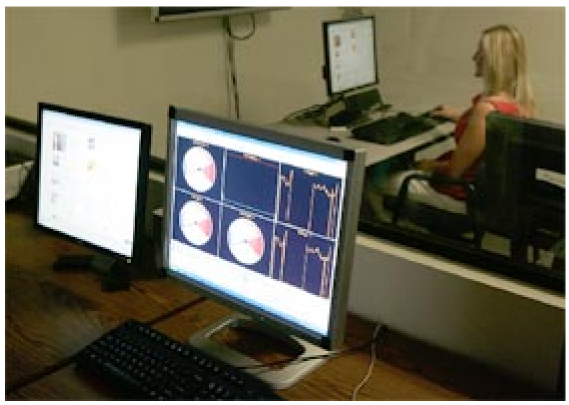
It is a science with immense potential for practical applications, from refining the ever-closer interactions between humans and computers to helping soldiers make smart decisions in battle, improving the competence of surgeons and building cars that are not just safer on the road, but intuitively easier to use.

“I think we're in for some big changes,” said Marshall.

Eyes have it

Everyone has shifty eyes. Our eyes are in almost constant motion: two to four movements per second, more than 100,000 over the course of a day. The movement is the result of how our eyes are constructed, said Jeff Pelz, an associate professor of imaging science at the Rochester Institute of Technology in New York.

Species such as hawks are extremely sharp-sighted, but they have very limited fields of view. Animals like rabbits possess much wider ranges of vision, but they see everything at considerably lower resolution.



EDUARDO CONTRERAS / Union-Tribune
New wireless technologies eliminate eye-tracking headgear altogether. As Cassie Davis perused a Web site, a monitor recorded her mental activity based on pupil dilation.

Humans have taken the evolutionary middle road: We see a small part of the world in sharp relief, and a lot more of it in increasingly fuzzy, peripheral detail.

“There is simply not enough neural real estate available in the brain to support a visual system that has high resolution over the required field of view,” Pelz explained. “Even if we left no room in the cortex for any other senses – not to mention housekeeping functions like breathing or keeping the heart beating – the human cortex could not support the optimal size/resolution sensor.”

Our most sharply focused vision occurs only within a tiny central region of the retina called the fovea, which encompasses less than 0.1 percent of our total visual field. From the fovea outward, our sight grows progressively less detailed.

To compensate, our eyes move constantly, ceaselessly redirecting the fovea at different points in our field of view to bring the larger picture into focus. These movements, called saccades, are controlled by sets of six muscles attached to the outside of each eye. They are among the fastest movements our bodies can make. Each saccade lasts just 20 to 200 milliseconds. A millisecond equals 1/1,000th of a second. The average eye blink takes 300 to 400 milliseconds.

Scientists have known this much for a while. In 1879, French ophthalmologist Louis Emile Javal discovered that readers' eyes don't glide smoothly over text (as was presumed) but instead make short jumps – called fixations – across words, sentences and pages, sometimes bouncing backward to words and locations already viewed.

Javal's revelations opened eyes and a whole new field of inquiry: Why do the eyes stop and start? Why do they stop and start where they do? The discipline of eye-tracking research was born, and it has added incrementally ever since to a body of knowledge, particularly about how people read.

By the 1990s, however, researchers like Marshall were pushing past existing boundaries. At the time, Marshall was working on a project for the Department of Defense and the U.S. Navy, which had asked her to help them better understand how officers, sitting at isolated computer consoles deep within ships, make decisions and solve problems in crisis situations.

The project, called TADMUS, for Tactical Decision-Making Under Stress, was created in response to the 1988 incident in which the American guided missile cruiser Vincennes mistakenly shot down an Iranian airliner over the Persian Gulf, killing 290 people.

"The idea was to figure out what was going on in the officers' minds so that such accidents could be avoided in the future," said Marshall.

Initially, she used basic eye-tracking hardware purchased off the shelf: two small head-mounted cameras that recorded where each eye was looking from second to second, and a third camera that showed what the eyes were looking at.

Such a system, though, can provide only limited information. Marshall wanted to know if the brain was actively involved. Were eye-tracking subjects actually thinking about and understanding what they were seeing?

To determine that, she exploited a long-standing belief among psychologists: Your pupils expand and shrink based on brain activity. "Physiological researchers have been working on this for at least 25 years," Marshall said. "It's generally accepted."

Here's the basic idea: When you look at something that captures your attention, your pupils (the black, circular centers of your eyes) reflexively dilate or enlarge. When you lose interest, they grow smaller. What makes this pupil-brain linkage particularly useful to researchers is that it's involuntary. It cannot be consciously controlled.

Marshall and colleagues developed and patented computer programming and algorithms that identify and measure pupil dilation during eye-tracking experiments, providing an instant and continuous assessment of mental effort. Marshall dubbed it the Index of Cognitive Activity, or ICA.

“Nobody had done anything with the pupil,” she said. “People had just been taking measurements. It became clear to me that sometimes those signals (from the pupils) were more agitated, and that they were different from person to person.”

Pelz said the system was a major breakthrough.

“I had been a skeptic,” said Pelz, who conducts his own eye-tracking research. “I thought people were putting too much stock in pupilometry. But Marshall's work is providing very convincing evidence that there's a strong correlation (between pupil dilation and brain activity). And any measure we can get of a person's cognitive state is valuable.”

Many applications

Valuable, indeed. In 1999, Marshall founded a company called EyeTracking Inc. to market her services. Among her first clients were Internet companies such as AOL and Yahoo!

Davis, EyeTracking's chief technical officer, said the companies were interested in parsing the usability of their online products, “such as finding out which components of a Web page attracted the viewer's attention, in what order and for how long, and which parts were ignored.”

More recently, the technology has been used by companies testing the visual appeal of new-product packaging and product placement in video games.

“They want to know whether players actually notice the products, whether the exposure creates a good response and if the placement affects actual game play, especially if it hinders play,” Davis said.

Marshall and colleagues have pursued even broader applications of eye-tracking technology. In 2003, she persuaded the Transportation Security Administration to conduct eye-tracking tests of airport baggage screeners. The goal was to determine how screeners scrutinize baggage X-rays and how they mentally assess their contents and threat potential. The experiments took place a year later, using 20 screeners at San Diego International Airport.

“We were able to see how the screeners reacted to the different kinds of bags they were screening,” Marshall said. “We were able to see which parts of the images captured their attention for the most amount of time and how their eyes scanned the most complex bags.”

The baggage-screening tests are part of a larger effort to find ways to ease mental strain and workload, not just for airport screeners but for anyone doing hard, concentrated thinking under stress.

“The military is very interested,” said Pelz. “They would like to be able to monitor human performance, to make sure soldiers don't get pushed beyond the limit. They would like soldiers to be near the limit, but not too near.”

More commercial applications, however, will likely appear sooner and more obviously. Marshall said her eye-tracking system has been licensed to two foreign automobile manufacturers interested in developing technologies that would monitor driver awareness and attention.

“Many car companies are actively working to put cameras or devices in their cars to measure the driver's state, especially fatigue and distraction,” she said.

(The concern about tired or distracted drivers is significant. The National Highway Traffic and Safety Administration estimates that drowsiness is the primary cause of 100,000 police-reported accidents each year.)

Surgical skill

Marshall is also working with doctors at the North Shore-Long Island Jewish Health System, a group of 15 hospitals in New York, in assessing the skill of surgeons. Wearing eye-tracking systems, doctors perform actual laparoscopic surgeries (minimally invasive operations) that can then be evaluated to assess their abilities.

“Just by looking at physiological measures, we can detect pretty well their competence,” she said.

Marshall's Index of Cognitive Activity records mental activity associated with each eye. The eyes, of course, reveal different brain functions. The right eye is wired to the left hemisphere of the brain, which handles analytical, logical reasoning. The left eye connects to the right half of the brain, which concerns itself more with spatial, intuitive tasks.

When surgeons operate while wearing an eye-tracking device, researchers can see how each eye is working. “In something like a surgery, where spatial skills are very important, you expect to see a really active left eye,” Marshall said.

At Mississippi State University, psychology professor Stephanie Doane works with pilots instead of doctors. “We take measurement of eye movements and integrate them into flight learning and skill acquisition,” she said.

But more than that, Doane predicts that more sophisticated eye-tracking systems could be incorporated into planes themselves, just like cars. The plane could then actively monitor the pilot's performance and anticipate needs or dangers.

“For example, a plane could tell a pilot that he wasn't paying enough attention to something important. When a pilot is flying, say, 2 feet above the ground, they tend to stop thinking about other things. A computer, though, doesn't forget and could point out other issues.”

Such as a looming mountain or tree.

The effort to develop a reliable, seamless interaction between human and machine drives much eye-tracking research. It's a notion called augmented cognition. Advocates say that by taking real-time measures of users, future computers might be able to adapt themselves on the fly, becoming more efficient and thus making the user more efficient, too.

Some fairly crude efforts have already been made. At Imperial College in London and elsewhere, scientists have built computer systems roughly controlled by the user's eyes. An infra-red eye-tracking headset tells the computer where on the monitor the user is looking, allowing the user to perform tasks by sight alone, such as moving a cursor or clicking on a function. The goal is the development of systems that could be used easily by people with physical disabilities.

One of the biggest hurdles of the moment, says Marshall, is hardware. Eye-tracking devices have gotten smaller and lighter, but the most precise and best are still relatively cumbersome.

But Marshall sees improvements coming. Her latest equipment, the computer used by Davis, employs a hidden camera below the monitor, completely unattached to the user.

Anthony Hornof, an associate professor of computer and information science at the University of Oregon, envisions future systems that would be completely transparent – “that can monitor exactly where you are looking down to the pixel level, no matter where your head is in front of the computer.”

Pelz goes further, predicting that eye-tracking will inevitably venture beyond the laboratory.

“We've learned a lot about how people move their eyes in laboratories under controlled conditions,” he said. “What we really want to know is how people use their eyes in the real world.”