Space Life Sciences Research Highlights

Eye Tracking Studies Bring Visual Perception Models into Focus

Dr. Lee Stone's research into the underexplored link between eye movements and visual perception has application for improved training and safety of astronauts, pilots, or anyone in an occupation that relies heavily on accurate visuomotor control.

For air traffic controllers, pilots, and astronauts, the ability to track a selected moving target among many other possible targets is essential. Perceptual errors during a critical flight maneuver can lead to disaster. In order to understand how such perceptual mistakes are made, scientists must first have a way to measure perception without interfering with the performance of the task.

Dr. Lee Stone, a human-factors scientist at NASA's Ames Research Center, studies the link between human visual perception and eye movements. His lab is developing and validating a new technique, oculometrics, which uses measurements of eye movements to monitor human visual perception. Using recent technological advances in eye tracking equipment and computers to study visual performance in flight-like scenarios, Dr. Stone and his colleagues have used oculometrics for unobtrusive monitoring and quantitative analysis of perceptual errors in real-world situations.

Most animals track a moving object with short, jerky eye movements called saccades. Primates, including humans, have a unique ability called smooth pursuit: a continuous eye rotation that follows a chosen object. This ability, which developed late in evolution in tandem with advanced visual processing in the brain, allows for more accurate tracking of motion in a world full of conflicting visual cues. A long-standing question in neurophysiology is how these eye movements relate to visual perception—what we see or think we see.

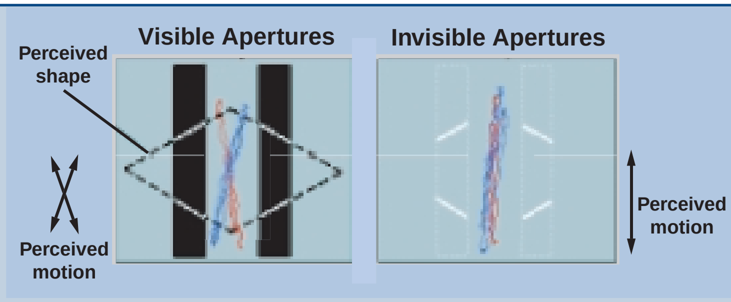
Dr. Stone's lab studies the human factors of navigation performance and visuomotor, or hand / eye, control. The long-term goal of his research, he says, is to make better display systems and better training methods that account for and overcome human weaknesses in the performance of real world tasks that require accurate eye movements and visual perceptual judgements. In particular, he and his colleagues are interested in possible changes in visuomotor performance by astronauts once they have adapted to microgravity and then return to Earth.

New Techniques Utilized

The science of applied oculometrics is relatively new, and Dr. Stone and his colleagues Dr. Brent Beutter of NASA and Dr. Miguel Eckstein of the University of California at Santa Barbara are at the forefront of validating new experimental techniques in this field. Traditional methods of meas-uring eye movements are invasive, making monitoring eye movements in real-world settings difficult. Furthermore, these methods alone do not allow scientists to examine the possibility of a link between eye movements and perception.

A unique aspect of Stone's research is the simultaneous tracking of eye movements and quantification of perception through techniques such as direction discrimination tasks. With this technique, the eye tracks an object on a computer screen. In this way, the correlation between perception and motor behavior can be examined, quantified, and modeled.

Stone has adapted infrared video technology to allow for high-quality data gathering with less cumbersome and minimally invasive equipment. He and his colleagues have shown that this technique can provide precision in many cases on a par with the traditional, invasive methods. By coupling the infrared eye movement measurements with perceptual measurements, they have shown that errors in eye movement are linked to errors in visual perception.



In this experiment, subjects were asked to visually track four lines moving diagonally back and forth on a computer screen through either visible or invisible apertures. Through visible apertures, subjects perceived a diamond moving in alternating diagonal directions and their eye movements followed. (Eye movement shown as red and blue lines overlapping the screen pattern.) Through invisible apertures (aperture indistinguishable from the background), no rational shape was perceived, and the eyes moved in a vertical pattern, following the individual lines. In both cases, the subjects' eye movements correlated to their perception of the object.

Results Support a New View of Eye Movements and Visual Perception

Until recently, the most widely accepted scientific theory stated that smooth pursuit eye movements had little or no relation to visual perception. If so, then measuring such movements would provide little insight into how the brain processes visual information. The smooth pursuit response was thought to be mostly mechanical—a feedback loop from the retina to the eye muscles, not involving any higher brain centers. Recently, Stone and other scientists have begun to quantify the relationship between perception and smooth eye movement and challenge the more established theory.

In the past few years, they have shown that human perceptual performance in discriminating the direction of an object's motion can be quantitatively predicted from smooth eye movement responses alone. Their experiments have also produced evidence that smooth pursuit and saccadic eye movements share overlapping visual pathways related to visual perception and higher-order brain centers. In addition, recent studies have shown that smooth pursuit and visual perception are similarly influenced by factors that produce erroneous responses in motor tasks.

Perception in the Real World

A better understanding of the relationship between eye movements and visual perception may be useful in practical situations where accurate visual perception is critical. What interests Stone is how the visual misperceptions that he generates in a laboratory translate into motor errors. In the case of smooth pursuit, he has observed a very close correlation between a test subject misperceiving motion direction and his/her eye movements making the same mistake.

Landing the Space Shuttle is an example of a situation in which accurate visual perception is vital. "In making their final approach," says Stone, "[Shuttle pilots] must line up a reference marker with a computer-generated marker using a joystick. Behind this is the runway and the moving outside world. They are using smooth pursuit eye movements to align that target, and they must separate the display that is used for the manual control [joystick] task from the visual information they are getting from the outside world. If we can detect the perceptual errors by looking at the eye movements, we can provide feedback in training environments to the pilots when they are indeed making errors."

In an upcoming collaboration with Dr. Barbara Sweet, another NASA investigator, Stone plans to extend his studies to include physical joystick responses, encompassing the entire scenario of perception through manual control.

Looking to the Future

The model of smooth pursuit as a mechanical function still has favor in the scientific community. However, with the advances in oculometric technology, Stone and his colleagues are now able to apply rigorous quantitative methods to measure perception from eye movement data alone, something that could not be done in the past. He believes that, based on the research done in his and other labs in the last five years, the evidence shows that perception is the major signal driving smooth pursuit eye movements, and he sees that view becoming widely accepted in the not-too-distant future.

References
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