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The goal of this project is to examine the consequences of observer motion for visual function. The research has focussed on two issues: One issue is how a grossly time-varying retinal input (because of eye, head, and body motion) results in the perception of a continuous and directionally stable visual world. A second issue concerns how the information in successive views is related, and the nature of the visual information retained from previous views. Understanding these processes is important for a wide variety of visuo-motor tasks.

In the past year progress has been made on the following six projects.

1) The role of the visual scene and eye position signals in visual stability.
2) The role of attention in integrating across saccades.
3) Reference frames for spatial memory.
4) Hand-eye coordination during complex tasks.
5) Detectability of changes during saccades.
6) Short term visual memory of complex scenes.

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Annual Technical Report: AFOSR No 91-0332. Reference Frames in Vision

15 Jan 91 - 14 Jan 92

The goal of this project is to examine the consequences of observer motion for visual function. The research has focussed on two issues: One issue is how a grossly time-varying retinal input (because of eye, head, and body motion) results in the perception of a continuous and directionally stable visual world. A second issue concerns how the information in successive views is related, and the nature of the visual information retained from previous views. Understanding these processes is important for a wide variety of visuo-motor tasks.

SUMMARY OF RESEARCH

In the past year progress has been made on the following six projects.

1) The role of the visual scene and eye position signals in visual stability.
In collaboration with Jeff Pelz, I have developed a novel technique, using the perceived movement of afterimages of complex scenes, to demonstrate that the stability of the visual scene depends on the nature of the visual context. In the dark, the position of a single object is computed using eye position information. In the light, however, the experiment shows that stationarity is attributed to the visual scene, despite eye position information to the contrary. This technique is relatively easy to use and has a lot of potential for exploring the properties of the visual scene which determine its relative weight in the choice of a stable reference frame. (This technique was described in the original proposal Experiment 3B.) This work was reported at ARVO in 1991 and we are currently preparing a manuscript.

2) The role of attention in integrating across saccades.
This work is in collaboration with Joel Lachter, a graduate student partially funded by the project. It is a modified version of Experiment 6 in the proposal. In an earlier experiment we demonstrated that the perception of form can be achieved whether or not the eye is stationary, and that very precise spatial relationships can be computed across different eye positions. We have now demonstrated that this ability requires attention. This suggests that only a sparse representation of the visual scene is maintained across saccades. (This is consistent with current computational 'active vision' approaches.) The work has been reported at ARVO 1991, and a manuscript is in progress.

3) Reference frames for spatial memory.
Spatial memory plays a crucial but relatively unexplored role in much of our motoric interaction with the world. Previous work (described in Experiment 10 in the proposal) has demonstrated the use of both body centered and object centered reference frames in encoding the positions of objects. In this experiment Keith Karn, Per Moeller and I explored whether object centered reference frames have the advantage of being more robust across a series of

changes in eye position. Surprisingly, both forms of encoding appeared to be equally robust. This has implications for the source and precision of the eye position information. We estimate that information about eye position in a head centered reference frame is available to the visual system with a standard deviation of less than 1.4 degrees. This work was reported at ARVO 1991 and a manuscript has been accepted for publication in the proceedings of the 6th European Conference on Eye Movements.

4) Hand-eye coordination during complex tasks

Many of the questions under investigation in this grant can be asked most naturally in the context of ongoing 'normal' behavior. In collaboration with Dana Ballard, Steve Whitehead, and Feng Li, I am exploring performance of a complex visuo-motor task with the goal of building a computational model which accurately reflects human performance. The subject's task is to copy a pattern of colored blocks on a computer screen using the mouse to move blocks around the display. Performance appears to conform to a relatively stereotyped sequence of actions. Computations for each block tend to be kept separate. Although some trials reveal the use of visual memory from previous trials, the modal response pattern points to the use of minimal memory in performing the task. Information is apparently acquired only just before it is needed. Such a strategy is compatible with recent computational models of robot performance which use deictic representations to selectively index the parts of the scene that are currently relevant to the task. This has proved vastly more efficient than conventional models which exhaustively represent the properties and locations of all the objects in the scene. The task also reveals other more detailed aspects of hand-eye coordination, not covered in prior experimental protocols. We observe here that Ss chose to make nearly simultaneous movements to disparate hand and eye targets. Such movements cannot be programmed by a single central motor command, as has been suggested from observations in simpler paradigms. We are currently exploring the reference frame used to guide the eye movements when putting down the blocks, and the nature of the memory representations used in performing the task. The work will be reported at ARVO this year, and a manuscript with preliminary observations is in progress.

5) Detectability of changes during saccades.

In a more formal investigation of the nature of the visual information retained from previous views, I have begun work on a project designed to measure the detectability of changes in shape, color, and position of objects in a multiobject display when the changes occur during a saccadic eye movement. We are investigating the nature of the visual information preserved from the immediately preceding fixation.

6) Short term visual memory of complex scenes.

Jeff Pelz has developed a technique for viewing a normal scene (reflective surfaces) through a variable sized aperture which moves with the eyes. He and Greg Zelinsky (Brown University) are currently working on a project which examines the nature of the information retained from a short view of a scene. This new version of the aperture viewing technique has a range of interesting applications for testing the richness of the representation of previously and currently viewed scenes.

RELEVANT PUBLICATIONS

1. Hayhoe, M, Lachter, J., Feldman, J. (1991) Integration of form across saccadic eye movements. *Perception, 20* 393-402.

2. Hayhoe, M.M., Lachter, J. & Moeller, P. (1992) Spatial memory and integration across saccadic eye movements. In K. Rayner (Ed.), *Eye Movements & Visual Cognition*. Springer-Verlag. (in press)

3. Karn, K., Moeller, P., and Hayhoe, M. Precision of the eye position signal. (1992) To appear in Van Rensbergen, J. & d'Ydewalle, G. (Eds.), *Studies in Visual Attention*. North Holland.

4. Ballard, D., Hayhoe, M., & Whitehead, S. (1992) Hand-Eye coordination during sequential tasks. To appear in *Proc Roy Soc B*.

MANUSCRIPTS IN PREPARATION

1. Moeller, P., Hayhoe, M., Ballard, D., Albano, J. Saccades to remembered visual targets and the perception of spatial position. (in preparation).

2. Lachter, J., Hayhoe, M. & Feldman, J. Capacity limits in the integration of information across saccades. (in preparation)

3. Pelz, J. & Hayhoe, M. Influence of the visual scene in space constancy. (in preparation)

PRESENTATIONS AT SCIENTIFIC MEETINGS

1991, K. Karn, P. Moeller, and M. Hayhoe, "Eye Movements to Remembered Targets; Disruption by Intervening Saccades." Paper presented at meeting of the Association for Research in Vision and Ophthalmology, Sarasota, Florida.

1991, J. B. Pelz and M. M. Hayhoe, "Influence of the Visual Scene and Eye Position Signals in Space Constancy." Paper presented at meeting of the Association for Research in Vision and Ophthalmology, Sarasota, Florida.

1991, J. Lachter, M. Hayhoe, and J. Feldman, "Capacity Limitations in the Integration of Information Across Saccades." Paper presented at meeting of the Association for Research in Vision and Ophthalmology, Sarasota, Florida.

PERSONNEL

In the past year six graduate students have participated in this project. They are supported by a combination of funds from this grant, an NIH training grant, and University funds. The students are Joel Lachter, Per Moeller, Keith Karn, Jeff Pelz, Brady Duga, and Feng Li. In the

coming year Lachter, Moeller, Karn, and Pelz will continue to work on the project. In addition to this, a graduate student from Brown University, Greg Zelinsky, visited for two months under our Summer Fellowship program. Steve Whitehead joined the project in November as a post doctoral fellow after completing a degree in Computer Science at the University of Rochester with Dana Ballard.

EQUIPMENT

A MacIIfX, Super Mac large screen monitor, 24 bit color board, and cartridge drive have been purchased. This is being used in conjunction with one of the DPI trackers for experiments where a large display is important.