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13. ABSTRACT (Maximum 200 words):
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.
Progress has been made on the following 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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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 published in the proceedings of the 6th European Conference on Eye Movements. A second manuscript has been submitted to experimental brain research.

PERFORMANCE OF COMPLEX TASKS INVOLVING HAND-EYE COORDINATION.

Copying Task Using Macintosh Display.

In the task we have chosen, subjects copy a pattern of colored blocks on a computer screen using the mouse to move blocks around the display. Recent successful robotic models of complex tasks avoid computationally expensive internal representations by allowing frequent access to the sensory input during the problem solving process. These models use so called 'deictic primitives' in which aspects of a scene can be referred to by denoting that part of the scene with a special marker, such as the fixation point. We have little knowledge of how humans actually perform in comparable sensori-motor tasks. We have shown so far that human performance is also characterized by deictic strategies and limited memory representations. This suggests that current approaches in robotics are also useful for understanding human brain mechanisms. It also suggests a computational rationale for the limitations on human working memory. The limited nature of human working has been taken as a kind of explanatory primitive in understanding cognitive processes. However, there has been surprisingly little effort directed at understanding *why* it is limited, and how these limitations play themselves out in normal behavior. The 'active vision' approach in robotics forces a new consideration of the computational role of working memory. It seems likely at this point that there is a real advantage to be gained by such a system in terms of simplifying the underlying cortical decision making processes and minimizing the need for a central executor. A better understanding of how the system works as a whole should provide better guidance in how to approach the underlying neural organization. A manuscript on this work is in press in J. Cognitive Neuroscience. Another theoretical ms has been submitted to Behavioral & Brain Sciences.

Experiments involving Saccade-Contingent Display Updating. One important general class of experiments involves changes in the visual display during a saccade. In the grant period we have written programs to do this in the experimental set up where the head is fixed and the eye monitored by the DPI eyetracker and block movements are made using the mouse. Using these newly developed programs, we have begun experiments which investigate three major classes of questions: 1. What is the nature of the visual information retained from previous views? 2. What are the reference frames for programming the various movements in the task? 3. What is the nature of the sub-components of the task.

Performance in the blocks task provides plausible evidence that subjects use fixation as a deictic pointing device to serialize the task and allow incremental access to the immediately task-relevant information. To test this, in one experiment we changed the color of one of the uncopied blocks while the subject was making a saccade to the model area following a block placement. Our results so far indicate that the target selection involved in programming the saccade into the model does not involve the acquisition of color information at that location, and that this function occurs during the fixation in the model area. This implies that rather minimal information is retained from the immediately prior fixation, and is consistent with the suggestion that fixation is used for acquiring information just prior to its use. Thus the information retained from prior saccades is determined by what is currently relevant for the task.

Copying Task in a Natural Environment

In addition, we have investigated performance using real blocks and hand movements, with the subjects' head free to move, using an ASL head-free eye and head tracker, and a magnetic hand coil. (This equipment was bought on an NIH Resource Development Grant. Development of the laboratory was undertaken by Pelz and an undergraduate lab assistant supported by the grant. A new Mac to run this system will also be purchased using AFOSR funds, in order to improve the temporal sampling rate.) This has provided important validation of our task in more natural conditions in addition to revealing a number of new findings. Subjects in the natural task perform in the same stereotypical way as in the Mac task, characterized by frequent eye movements to the model pattern. Thus the use of short term memory is extremely limited, even to the extent that properties of a single block are acquired separately. Even when the cost of references to the environment was increased by moving the model and workspace 70 deg apart (requiring large head movements), the subject still made frequent reference to the model. Conversely, other experiments revealed that performance declined precipitously when frequent access to the model during task performance was prohibited.

Subjects differ in the frequency with which they make return saccades to the model but are remarkably similar in other aspects of performance, such as fixation duration, time for pick up and for put down. In addition, the time spent in the

model area does not change significantly in the course of the trial, indicating that very little learning of the model takes place.

Eye-head Coordination. As well as examining performance at the overall level of strategies used, we have also analyzed performance at the level of the individual actions. The coordination of the eyes and head have been examined in some detail since it is one in which we can address the question of what kind of spatial representation guides a change of gaze involving both eye and head. A major issue here is whether the eye and head are programmed with respect to a shared spatial map. Current models of changes in gaze postulate that both eye and head movements are driven by the desired gaze shift in body-centered or exocentric (spatial) coordinates and that the VOR is suppressed until the spatial goal is achieved. Little is known, however, about the coordination of the eyes and head in natural situations where the head is unrestrained and sequences of goal directed movements are involved. Our experiments show startling dissociations of eye and head movements, with the eye and head simultaneously moving towards spatially separate goals. We are exploring these patterns and attempt to determine whether these diverging movements are programmed independently and sequentially, and whether the linkage between the movements is at the highest level of an attentional mechanism which flexibly defines separate or shared spatial goals. Thus the synchrony of eye and head may in general be determined by a combination of attentional demands and the goal structure of the task. Alternatively, the saccades may be programmed as a structured sequence of movements together with the head movement to a common spatial goal.

Development of a Driving Simulator.

One of the primary limitations of the block copying task is that the visual environment is stationary. A convenient way to make the visuo-motor interactions time-dependent is to investigate a driving paradigm. We are currently developing a driving simulator using a Silicon Graphics Reality Engine to generate scenes displayed on the North Carolina virtual reality LCD displays, with the capability of tracking the eyes and head during a simulated driving task. The display is linked to the head movements to simulate driving through a landscape. Currently, eye movements can be recorded, but not used to update the display. At the moment, simulated motion through the display is linked only to accelerator, brake, and steering wheel of the go-cart frame. One of the primary goals of the simulator is to examine the nature of the visual processing in unattended regions of the visual field, and the mechanisms which govern attentional modulation. Experiments are currently underway to examine task sharing between following and obstacle avoidance. (This work has been partially funded by an NIH Resource Development Grant as well as the current grant.)

Other Studies.

Keith Karn has begun an investigation comparing the effect of external reference frames on perception and reaching. Perception and action have often been thought to involve different neural channels. Karn is examining the hypothesis that the differences are more simply accounted for in terms of the reference frame used for the task in question. These experiments will form the basis for his dissertation, which he plans to complete by the end of the year.

Joel Lachter has continued experiments on how much visual information gets processed outside the focus of attention. He is using a novel technique introduced by Rock to look at this question. He has received his Ph D on the basis of this work and is currently a post doctoral fellow at Princeton. His experiments suggest that visual processing outside the focus of attention is minimal. Lachter and I have also worked on a manuscript on the role of attention in integrating information across saccades. This is under revision for *Perception & Psychophysics*.

A. PUBLICATIONS

Ballard, D., Hayhoe, M., & Whitehead, S. (1992) Hand-Eye coordination during sequential tasks. *Phil Trans Roy Soc Lond B.*, 331-339.

Van Rensbergen, J. & d'Ydewalle, G. (Eds.), *Studies in Visual Attention*. North Holland. pp. 71-82. 1993.

Karn, K., Moeller, P., and Hayhoe, M. Precision of the eye position signal.

Hayhoe, M, Ballard, D, Whitehead, S. Memory Use During Hand-Eye Coordination. *Proceedings of the Cognitive Science Society*. pp534-538, 1993

Karn, K., Moeller, P., Lachter, J., & Hayhoe, M. (1993) Task dependent spatial memory across saccades. *Brain & Behavioral Sciences* Commentary.

Pelz, J. and Hayhoe, M. Influence of the visual scene in visual direction constancy *Vision Res* (in press) .

Ballard, D., Hayhoe, M. & Pelz J Working memory limitations in sensory-motor tasks. Houk (ed) *Basal Ganglia*. (1994)

Ballard, D., Hayhoe, M. & Pelz J Memory representations in natural tasks *Cognitive Neuroscience* (in press)

Hayhoe, M., Ballard, D., & Pelz J Visual representations in natural tasks (1994) *Proceedings IEEE*.

PAPERS SUBMITTED AND IN PREPARATION

Ballard, D., Hayhoe, M. & Pook, P. Deictic codes for the embodiment of cognition. submitted to *Behavioral & Brain Sciences*.

Lachter, J & Hayhoe, M. Memory limits in integration across saccades. under revision for *Perception & Psychophysics*

Karn, K., Moeller, P., & Hayhoe, M. Precision of the eye position signal. (submitted to *Experimental Brain Research*).

Moeller P., Hayhoe M., Ballard D., & Albano J., Guidance of Saccades to Remembered Targets and the Perception of Spatial Position. (in preparation)

B. ADDITIONAL RESEARCHERS WORKING WITH PRINCIPAL INVESTIGATOR.

Faculty: Mary Hayhoe, Dana Ballard, Department of Computer Science

Postdocs: Steve Whitehead, Greg Zelinsky

Graduate Students: Brady Duga Feng Li Per Moeller Jeff Pelz, Keith Karn, Joel Lachter David Bensinger

Undergraduate Assistants: Andrew Forsberg. Allen Ingling

C. PROFESSIONAL HONORS

Fellow, Optical Society of America, June 1993

REPORT OF INVENTIONS AND SUBCONTRACTS

(Pursuant to "Patent Rights" Contract Clause) (See Instructions on Reverse Side.)

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1a. NAME OF CONTRACTOR / SUBCONTRACTOR University of Rochester 518 Hylan Bldg. Rochester, NY 14627	2a. NAME OF GOVERNMENT PRIME CONTRACTOR	3. TYPE OF REPORT (X one) a. INTERIM <input type="checkbox"/> b. FINAL <input checked="" type="checkbox"/>
c. CONTRACT NUMBER AFOSR-91-0332	d. AWARD DATE (YYMMDD) 91/01/15	4. REPORTING PERIOD (YYMMDD) a. FROM 91/01/15 b. TO 94/07/30

SECTION I - SUBJECT INVENTIONS

5. "SUBJECT INVENTIONS" REQUIRED TO BE REPORTED BY CONTRACTOR / SUBCONTRACTOR (If "None," so state)		d. ELECTION TO FILE PATENT APPLICATIONS		e. CONFIRMATORY INSTRUMENT OR ASSIGNMENT FORWARDED TO CONTRACTING OFFICER	
a. NAME(S) OF INVENTOR(S) (Last, First, MI)	b. TITLE OF INVENTION(S)	(1) United States		(1) Yes	
		(a) Yes	(b) No	(a) Yes	(b) No
none	none				

SECTION II - SUBCONTRACTS (Containing a "Patent Rights" clause)

6. SUBCONTRACTS AWARDED BY CONTRACTOR / SUBCONTRACTOR (If "None," so state)		d. DFAR "PATENT RIGHTS"		f. SUBCONTRACT DATES (YYMMDD)	
a. NAME OF SUBCONTRACTOR(S)	b. ADDRESS (Include ZIP Code)	(2) Date (YYMM)		(1) Award	
		(1) Clause Number	(2) Date (YYMM)	(1) Award	(2) Estimated Completion
none	none				

SECTION III - CERTIFICATION

7. CERTIFICATION OF REPORT BY CONTRACTOR / SUBCONTRACTOR	(Not required if Small Business or Non-Profit organization) (X appropriate box)
a. NAME OF AUTHORIZED CONTRACTOR / SUBCONTRACTOR OFFICIAL (Last, First, MI) Senator, Donna J.	c. I certify that the reporting party has procedures for prompt identification and timely disclosure of "Subject Inventions," that such procedures have been followed and that all "Subject Inventions" have been reported.
b. TITLE Assistant Research Administrator	d. SIGNATURE <i>Donna J. Senator</i>
	e. DATE SIGNED 1/9/95