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6. AUTHOR(S)

DR EILEEN KOWLER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

Department of Psychology
Busch Campus
Rutgers University
New Brunswick, NJ 08986

8. PERFORMING ORGANIZATION REPORT NUMBER

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9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)

DR JOHN F. TANGNEY
AFOSR/NL
Building 410
Bolling AFB DC 20332-6448

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The research carried out during the period of the grant continued several lines of investigation on the way in which sensory and high-level influences contribute to the control of smooth and saccadic eye movements and on the perceptual implications of eye movements. We: (1) provided the first clear evidence that symbolic cues determine the direction of anticipatory smooth eye movements, showing that adaptive models, based on algorithms that modify pursuit according to prior performance cannot work; (2) showed that saccades to spatially-extended targets are best understood by a serial model, with a selection stage followed by a spatial pooling mechanism; (3) showed that slow control is a velocity, not a position, corrective and (4) showed that saccades (not shifts of attention) are required for accurate exception of poorly-segregating textures. These results are all consistent with the view that sensory and cognitive influences combine at a relatively high level of processing to provide a single, coherent input to the oculomotor system. Kowler also edited a book, published by Elsevier, containing major reviews and theoretical treatments of eye movements, vision and cognition.

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Eileen Kowler
Department of Psychology
Busch campus
Rutgers University
New Brunswick, NJ 08903
908-932-2086
kowler@zodiac.rutgers.edu

March 9, 1992

Dr. John Tangney
AFOSR/NL
Bolling AFB, DC 20332

Dear John:

Enclosed is a copy of the final technical report for AFOSR 88-0171. It covers the period January 1, 1988 to September 30, 1991. Let me know if you need any other information.

Sincerely,



Eileen Kowler

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Eileen Kowler (PI)
Department of Psychology
Rutgers University
New Brunswick, NJ 08903
tel: 908-932-2086
email: kowler@zodiac.rutgers.edu

Abstract. The research carried out during the period of the grant continued several lines of investigation on the way in which sensory and high-level influences contribute to the control of smooth and saccadic eye movements and on the perceptual implications of eye movements. We: (1) provided the first clear evidence that symbolic cues determine the direction of anticipatory smooth eye movements, showing that adaptive models, based on algorithms that modify pursuit according to prior performance cannot work; (2) showed that saccades to spatially-extended targets are best understood by a serial model, with a selection stage followed by a spatial pooling mechanism; (3) showed that slow control is a velocity, not a position, corrective and (4) showed that saccades (not shifts of attention) are required for accurate perception of poorly-segregating textures. These results are all consistent with the view that sensory and cognitive influences combine at a relatively high level of processing to provide a single, coherent input to the oculomotor system. Kowler also edited a book, published by Elsevier, containing major reviews and theoretical treatments of eye movements, vision and cognition.

Detailed Progress Report

1. He and Kowler (1989) demonstrated effects of location probability on saccades. This paper challenges previous ideas that tendencies to make saccades to the center of a stimulus configuration, containing a target as well as irrelevant background stimuli, represent automatic sensorimotor averaging responses. We found that the so-called "centering" or "averaging" saccades occur only when subjects are uncertain about where the target is located. Centering responses, therefore, represent visual search strategies rather than oculomotor reflexes. We reject models of saccadic control featuring parallel subsystems (one voluntary, another reflexive) in favor of a serial model in which a selection stage is followed by automatic computation of the saccadic command to bring the line of sight into the selected (attended) spatial region. The serial model (unlike the parallel models) guarantees that the line of sight will be directed to regions of interest rather than being drawn to large or intense (but nevertheless unimportant) areas in the visual field.

2. He and Kowler (1991), following up the experiments described above, studied the ability of subjects to direct saccades to designated locations within eccentric forms. Surprisingly, this situation has not been studied before, with



investigators preferring unnatural targets, such as points or crosshairs, where the desired endpoint of the saccade is clearly marked. We found that subjects can direct saccades accurately and precisely to locations within forms. Saccades directed to the "whole form" tend to land near the center. The results, which show that the line of sight lands in the center of the selected target region, are consistent with the 2-stage serial model described above.

3. Kowler (1989) showed that anticipatory smooth eye movements are genuine responses to cognitive expectations about the direction of future target motion rather than automatic tendencies to repeat previous pursuit responses. This was done using a novel method of having subjects track motion along cued paths. I found that symbolic cues about the path determine anticipatory smooth movements, overriding effects of past history. Explaining this result will require new pursuit models. Existing models of predictive tracking are based on the assumption that prediction is simply an extrapolation of past performance. The sensitivity of pursuit to symbolic cues implies that a central representation of motion, combining immediate and expected future target motion impending target motion, is the significant input to pursuit.

4. Kowler et al. (1991) studied movements of the head and eye during reading and during visual scanning. We found that: (a) during reading subjects made idiosyncratic, coordinated patterns of head and eye movement, including unusual features such as episodes of head and eye moving in opposite directions; (b) eye rotations compensated well for head rotations and translations, leaving residual image velocities comparable to those observed on the biteboard (n.b., image velocities are large enough to move the image at least one letter space during a reading pause: How do we see in the presence of such smear?); (c) saccade rates were faster with free rather than fixed heads and faster during reading than during visual scanning; (d) subjects had difficulty programming simultaneous head and eye movements with different spatial and temporal patterns. All these results suggest the existence of a common, central programmer for head and eye movements, whose activities are tied to the ongoing visual and cognitive demands of the task, and whose precise characteristics have yet to be determined.

5. He and Kowler (1992) studied the perception of texture patterns when observers used saccadic eye movements to scan the display and when the line of sight was maintained in the display center without saccades. Saccades improved the discrimination of the size and the shape of a central randomly-shaped polygon for display durations > 1 sec. Saccades were more helpful with textures that did not readily segregate into target and background regions than with those that did. Yet performance with saccades never reached levels achieved without saccades for easily-segregating textures, showing that a useful representation

of the texture is not constructed from sequences of foveal views. Our results show that saccades, not attention shifts, are needed for accurate processing of poorly-segregating textures. The failure of saccades to be helpful when exposures were brief may be attributed to ineffective saccadic strategies and need not imply that attention shifts are able to mimic the sequential exploration normally mediated by saccades.

6. Kowler et al. (1990) distinguished between position- and velocity-corrective models of slow control. We found that slow control is equally effective for symmetric and asymmetric (i.e., a single eccentric point) targets. This result argues against a position-corrective model because position correction should be better with a symmetric targets, where a stable internal reference position can be defined. Slow control stability also declined as target eccentricity increased. Eye movements became more like eye movements observed in the dark, suggesting a successively smaller contribution of low-velocity motion detectors as eccentricity increases. This is consistent with previous psychophysical results showing that the pool of low-velocity detectors decreases with eccentricity. A ms describing these results will be submitted shortly (Epelboim and Kowler).

7. Kowler et al. (1989) demonstrated effects of expected duration on smooth pursuit, namely, smooth responses barely get off the ground unless subjects expect the target motion to continue. There was also evidence that velocity and acceleration saturation, usually taken to be characteristics of the sensory mechanisms that launch the pursuit responses, are seen only with randomized target motions, and, therefore, are not true system limitations at all. Further experiments are in progress to nail down this assertion.

8. Eye Movements and Their Role in Visual and Cognitive Processes, edited by Kowler (1990), is volume 4 of the series Reviews of Oculomotor Research. The book is unique in that it contains major reviews and critical evaluations of research on the role of eye movements in visual contrast detection, motion perception, visual localization, the perception of depth, reading, visual search and problems solving. Also covered are the perceptual and cognitive influences on smooth and saccadic eye movements.

Publications

He, P. and Kowler, E. (1989) The role of location probability in the programming of saccades. Vision Research 29, 1165-1181.

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performance of natural (and unnatural) visual tasks. In The Head-Neck Sensory Motor System. (edited by Berthoz, A., Vidal, P.P. and Graf, W.) Oxford Univ Press, NY.

Kowler, E. (ed.) (1990) Eye Movements and Their Role in Visual and Cognitive Processes (Volume 4 of Reviews of Oculomotor Research). Elsevier, Amsterdam.

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Kowler, E. (1991) The stability of gaze and its implications for vision. Chapter in Eye Movements (Edited by R. Carpenter) in the series Vision and Visual Dysfunction. Macmillan.

Steinman, R.M., Kowler, E. and Collewijn, H. (1990) New directions for oculomotor research. Vision Research, 30, 1845-1864.

He and Kowler (1992) The role of saccades in the perception of texture patterns. Accepted by Vision Research pending receipt of minor revisions.

Talks

He, P., Kowler, E. and Leyton, M. (1988) Saccadic eye movements to simple forms. ARVO.

Kowler, E. (1988) Cogito ergo moveo: The role of visual and cognitive processes in the control of eye movement. Exploratory Vision: The Active Eye. Ann Arbor, MI.

Kowler, E., Steinman, R.M., He, P. and Pizlo, Z. (1989) Smooth pursuit depends on the expected duration of target motion. ARVO.

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