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6. AUTHOR(S)
Kathleen Turano

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Johns Hopkins University School of Medicine
Wilmer Vision Research Center
720 Rutland Avenue
Baltimore, MD 21205

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13. ABSTRACT *(Maximum 200 words)*

Two psychophysical studies investigated an observer's ability to perceive self motion. In both studies, the stimuli were computer-generated images simulating an observer moving relative to a volume of randomly-positioned dots. The first study investigated an observer's ability to determine whether s/he was moving forward along a straight or curved path as forward speed was varied. The results showed that with eye movements, the deviation required to detect a departure from a straight path increased with forward speed. When eye movements were restricted, the required deviation remained constant across forward speeds. A second study investigated the effectiveness of various sizes and retinal locations of the stimulus in determining the direction of a curved path. The results showed an increasing linear relationship between optimal size and retinal eccentricity. Given optimally-scaled stimuli, the central and peripheral retinal locations yielded equivalent performance. Finally, a computational model has been developed to emulate a human observer's ability to detect a curved path of motion. Computer simulations of the model have been run on a task to discriminate between a curved and straight path of motion. The simulation results closely match psychophysical data.

14. SUBJECT TERMS
egomotion, motion perception, curvilinear motion,
self motion perception, eccentricity, eye movements

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(A) Objectives of the research effort:

The main goal of the research program is to understand the mechanism(s) underlying the human observer's visual perception of self motion. With this as a common goal, two lines of research are currently being conducted. One line of research is a psychophysical investigation of the basic aspects of self motion perception, e.g. detecting the direction in which an observer is moving, detecting a change in the direction or speed of motion. A second line of research is the development and testing of a computational model that emulates the human observer's ability to detect self motion information. The goal is to develop a biologically-feasible model that is built upon a foundation of psychophysical findings.

(B) Status of the research effort:

The report on the status of the research effort is divided into three parts. Section 1 consists of the findings of two completed psychophysical studies, section 2 discusses the status of the development of a computational model, and section 3 reports the status of the current study.

(1) Completed Psychophysical Studies:

Study #1 - Visual discrimination of a curved or straight path of self motion: Effects of forward speed and eye movements

In this study, we addressed the question of whether the retinal motion produced from an observer moving through an environment is sufficient to determine whether s/he is moving forward along a straight or curved path. The stimuli used in this study were computer-generated images simulating an observer moving relative to a volume of randomly-positioned dots. Predictions were generated from a computer simulation of a current model for the computation of self motion information

(Rieger, 1983).[1] Psychophysical results were obtained and compared to the model predictions to determine whether or not the visual system behaves in a manner similar to the model.

For both the psychophysical tests and the computer simulations, two sequences of simulated observer motion were presented to the subject (or computer): one sequence was a simulation of observer motion along a straight path and the other sequence was a simulation of observer motion along a curved path (the direction of the circular path was either right or left, randomly determined). The task was to determine which sequence was the curved path of motion. The angle of the deviation from a straight path occurring within a second of time (angular speed) served as the independent variable. Each subject was given 200 trials, 40 trials for each of 5 preselected angular speeds. A psychometric function was obtained by plotting the proportion of correct responses against angular speed (x). A Weibull function (Equ.1) was fit to the proportion-corr distribution. The parameter α specifies the threshold (angular speed where performance was at 82% correct), and the parameter β specifies the slope of the psychometric function.

$$f(x) = 1 - 0.5 \cdot \exp[-(x/\alpha)^{\beta}] \qquad \text{(Equation 1)}$$

Angular-speed thresholds were measured at forward speeds ranging from 2.0 (walking speed) to 26.4 m/s (driving speed at 60 m/hr). The means of four subjects' angular-speed thresholds and standard errors for each forward speed are shown in Figure 1 together with angular-speed thresholds calculated from the simulation results. As shown, subjects can detect a departure from a straight path of motion when the deviation is as small as 2.0 - 4.0 arcmin/s at a forward

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[1]Reiger, JH (1983) Information in optical flows induced by curved paths of observation. J. Opt. Soc Am A, 73, 339-344.
The model is based on the fact that when an observer moves along a curved path, the orientation of the translational component of the velocity field changes over time. If an observer moves along a straight path, the orientation of the translational component does not change. Thus a large difference in the velocity vectors of the translational component sampled at different time intervals indicates a curved path of motion.

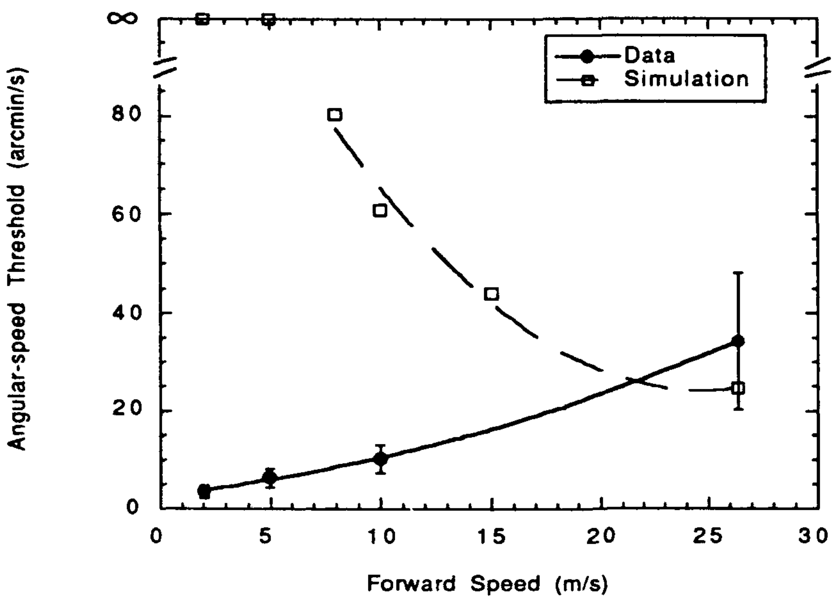

Figure 1

speed of 2.0 m/s. At faster forward speeds, subjects require a larger deviation to detect a departure from a straight path. At a forward speed of 26.4 m/s, subjects require a deviation an order of magnitude greater than required for the 2.0-forward speed to attain the same level of performance.

The simulation results show an opposite trend. Thresholds are infinite at forward speeds of 2.0 and 5.0 m/s and decrease with increasing forward speed.

What could explain the difference in performance between the model and the human observer at slow forward speeds? One difference between the model and the human visual system is the type of available information. In the model, the only information available to the decision maker is the stimulus motion. In the visual system, however, the information on the retina derives not only from stimulus motion but also from eye movements. It could be that the addition of eye movements plays a role in a subject's ability to discriminate between a straight and curved path of motion. Since the model did not take into consideration information generated from eye movements, the difference between the model and human performance may be due to this variable.

To test the hypothesis that information generated from eye movements is a critical variable, we ran a control experiment in which we measured thresholds under conditions in which the image was stabilized on the retina. In this way, we were able to restrict the motion on the retina to only stimulus motion. The image was stabilized on the retina by means of an SRI Dual-Purkinje-Eyetracker and stimulus deflector system. An unstabilized fixation point was centered on the display and was visible at all times during the experiment in order to minimize slow eye drifts.

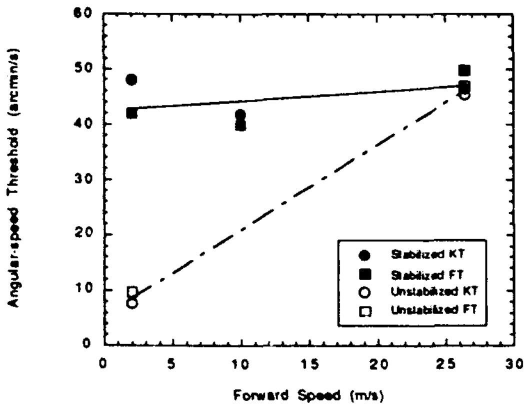

Figure 2

In Figure 2, angular-speed thresholds for the stabilized-viewing condition are shown together with the angular-speed thresholds for unstabilized viewing through the same eye-tracking system. As shown, when retinal motion generated from eye movements is eliminated, a subject can discriminate between a straight and curved path only when the deviation between the two reaches a certain value, approximately 45 arcmin/s, regardless of the forward speed. Whereas when eye movements are permitted, forward speed affects performance; thresholds are lower at slow forward speeds.

The proportion of angular speed to forward speed is an estimate of curvature (curvature=1/radius). In order to determine whether subjects require a minimum amount curvature to discriminate between a straight and curved path we replotted the data obtained under the free-viewing condition (from Fig. 1) as a function of curvature in Figure 3. Proportion correct is plotted against curvature, and the different symbols represent data at different forward speeds. The functions across the different forward speeds coincide reasonably well (with the exception of subject KT at a forward speed of 2.0 m/s). Thus, it appears that under free-viewing conditions, with eye movements permitted, subjects discriminate between a straight and curved path at a

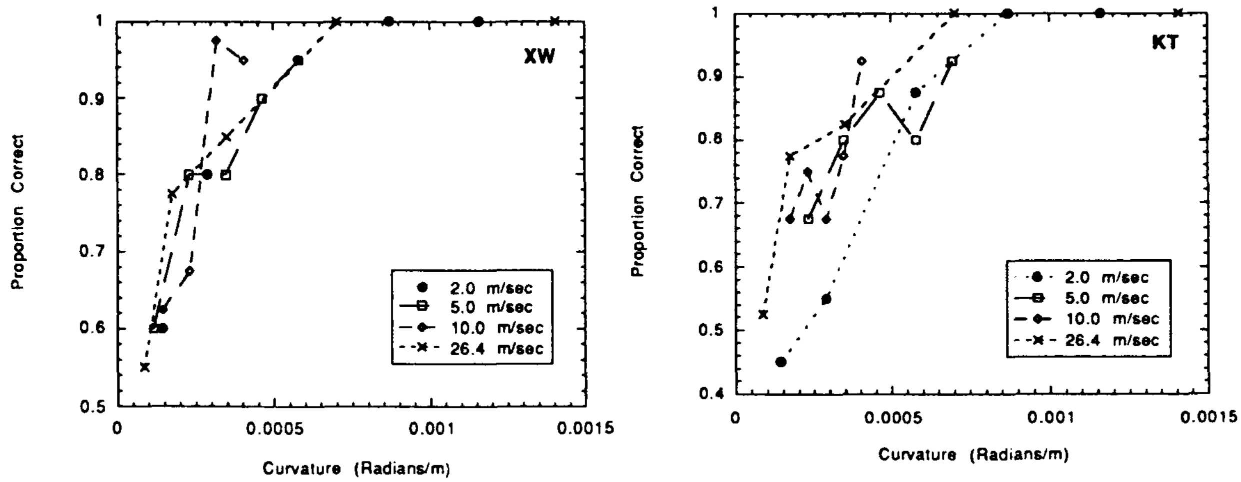

Figure 3

constant curvature. But, without eye movements permitted, subjects discriminate between the two at a constant angular speed.

Study #2 - Size and eccentricity effects on direction discrimination of a curved path of self motion

This study investigated the effectiveness of various sizes and retinal locations of the stimulus motion relative to an observer's retina in determining the direction of a curved path of motion. We addressed two questions:

(1) What is the minimum window size of stimulus motion required for a subject to accurately discriminate a rightward from a leftward curved path?

(2) Are some retinal locations more sensitive to the stimulus motion than others for the discrimination of a rightward and leftward curved path? Several studies that have investigated the effectiveness of retinal locations for other aspects of self motion perception (e.g. vection and postural control) suggest that the periphery plays a dominant role. Therefore, a likely outcome in the present experiment is that the peripheral retina would prove to be more sensitive than the central

retina for the discrimination of a rightward and leftward curved path.

Computer-generated images simulating an observer moving along a curved path relative to a volume of randomly-positioned dots served as stimuli. A sequence of the images was presented to the subject, and the subject's task was to indicate the direction (left vs. right) of the curved path. The angle of the deviation from a straight path occurring within a second of time (angular speed) served as the independent variable. Each subject was given 200 trials, 40 trials for each of 5 preselected angular speeds. A psychometric function was obtained by plotting the proportion of correct responses against angular speed, and a Weibull function (Equ.1) was fit to the proportion-correct distribution.

In order to answer the first question, what is the minimum window size required to accurately discriminate a rightward from a leftward curved path, we measured angular-speed thresholds across a range of window widths and retinal locations. Figure 4 shows the thresholds of two subjects across a range of window widths and 1 retinal location.

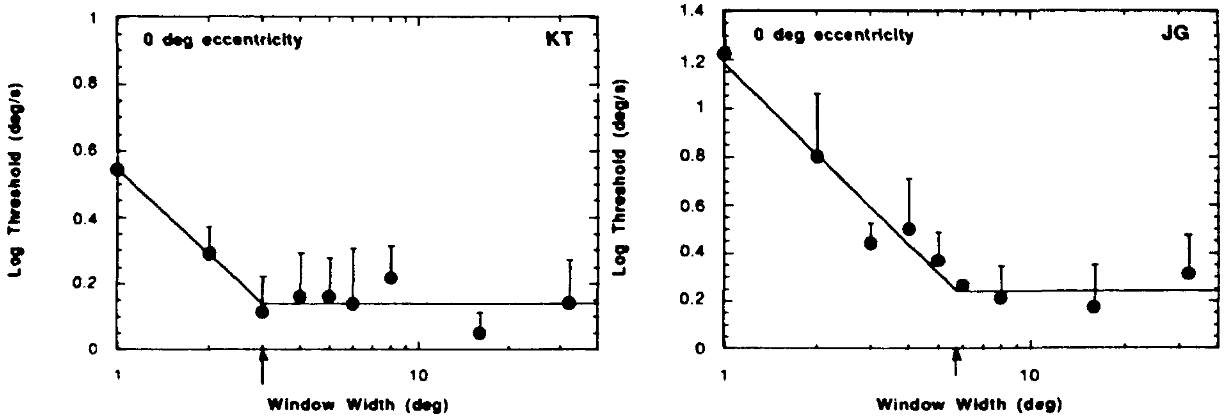

Figure 4

Thresholds were obtained at 0, 5, 10 and 20 deg, where eccentricity is defined as the distance between the fixation point and the center of the window.

The results showed that subjects required a larger deviation from a straight path in order to determine the direction (left vs right) of the deviation with small window sizes than with larger window sizes. At some point, increasing the size of the window size had no effect on the thresholds.

The data (log angular threshold as a function of log window width) were fit with two linear functions, one with a negative slope and the other a 0 slope. The breakpoints of the 2 functions indicate the minimum window width. The minimum window width is plotted in Figure 5

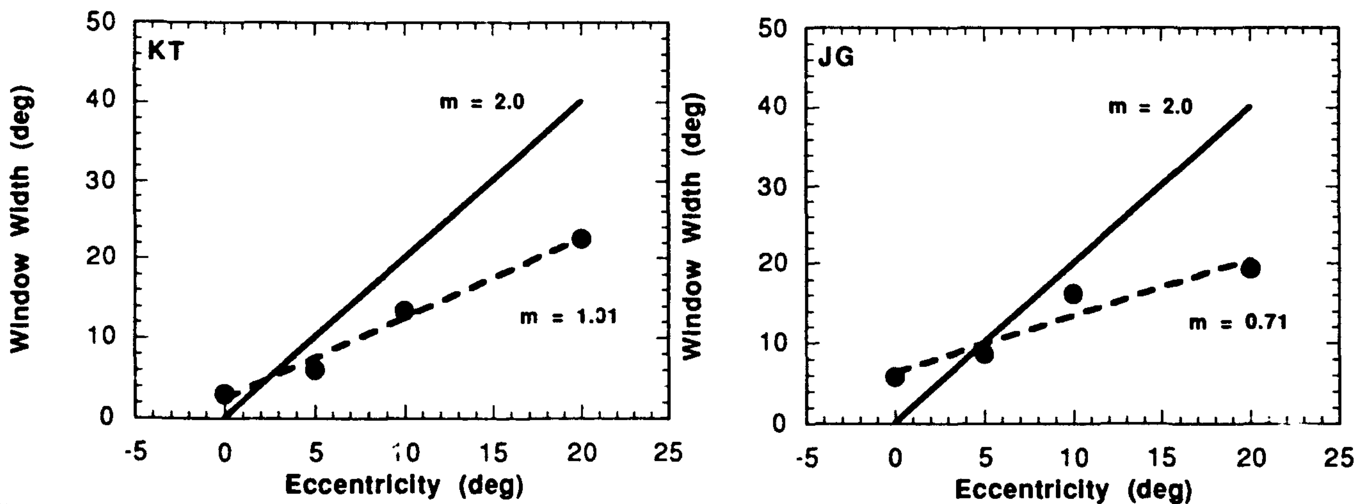

Figure 5

as a function of eccentricity for two observers. The data are represented by solid circles and the dashed line indicates the best linear fit to the data. The r^2 values for the fits are .99 and .95 for KT and JG, respectively. The slopes for the two functions are 1.01 and 0.71. These slopes are remarkably similar to those found by McKee and Nakayama over the same eccentricities for 2D differential motion thresholds. If optimal performance was not dependent upon the size of the window per se but rather by the nearest edge of the window to the fixation point then the functions relating window size to eccentricity should have a slope of 2.0. Instead, the data indicate that this hypothesis cannot account for the data.

In Figure 6, the lowest angular thresholds are plotted as a function of eccentricity. Dashed lines represent a best linear fit to a constant. The fits do not permit a rejection of a 0 slope at the 0.00 level demonstrating that the central and peripheral locations are equally sensitive for discriminating between a rightward and leftward curved path of motion.

In summary, the results of the study indicate that there is a linear relationship between window size and eccentricity for determining the direction of a curved path of motion, and the central and peripheral retinal locations are equally sensitive to the stimulus motion for the discrimination of a rightward and leftward curved path, provided the stimuli are optimally scaled.

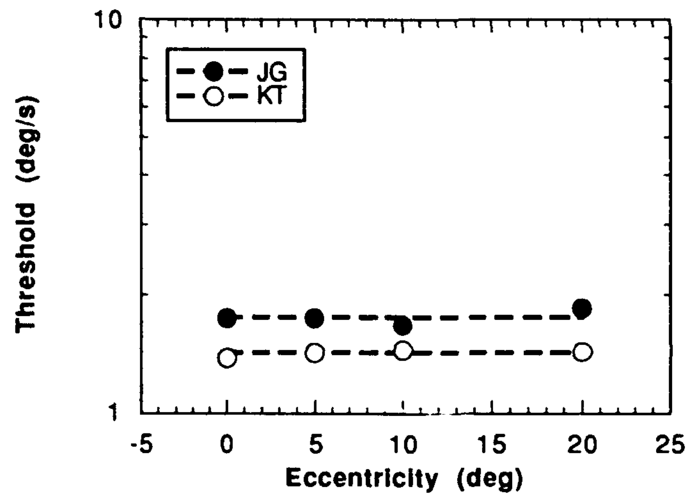

Figure 6

(2) MODEL: A neural network model for human visual perception of 3D curvilinear motion

We have developed a neural network model to emulate the ability of the human visual system to detect a curved path of motion. The network consists of three layers. The input to the network is a two-dimensional velocity field, and the output is a signal proportional to the magnitude of curved motion. The first layer of the network computes local difference vectors of the velocity field. This minimizes the rotational component of the velocity field introduced by eye movements. The second layer of the network extracts the instantaneous heading direction from the translational component of the velocity field. The last layer of the network computes the acceleration component of the velocity field, i.e. changes in heading direction over time, and outputs a signal proportional to the part of the acceleration component whose direction is perpendicular to the translational component. The magnitude of curved motion is directly proportional to the magnitude of the perpendicular-acceleration component.

We have run computer simulations of the model performing a task to discriminate between a curved and straight path of motion. The simulation results closely match psychophysical data. We are currently testing the model with other stimuli and tasks.

(3) Current Study: The effects of dynamic noise on the discrimination of straight and curved paths of self motion

There are many potential sources in the human visual system that are capable of creating noise that is uncorrelated with a visual signal. For example, there can be noise in the image formation process due to inappropriate sampling levels, less-than-optimal viewing conditions and noise within the system at early processing stages, such as the local-motion detection stage. Uncorrelated noise may interfere with the system's ability to accurately or efficiently process information. Our current study investigates how perturbations in the stimulus motion affects the ability of the human visual system to perceive self motion information. We are introducing noise to the stimulus in the form of randomly moving dots. The direction of the dots are randomly determined from a Gaussian distribution of different means and standard deviations. Other parameters that we manipulate include the speed and density of the dots. To date, the computer software for the study has been completed and we are ready to begin collecting data.

(D) Publications:

Turano, K. and Wang, X. Visual discrimination of a curved or straight path of self motion: Effects of forward speed and eye movements, to be submitted March, 1992 to Vision Research

Turano, K. Size and eccentricity effects on direction discrimination of a curved path of self motion, planned for submission to Vision Research

Wang, X. and Turano, K. A neural network model for human visual perception of 3D curvilinear motion, Proceedings of SPIE's technical program on Intelligent Information Systems (April 20-24, 1992)

(D) Professional personnel associated with the research effort:

Kathleen Turano (P.I.)

(E) Papers presented at meetings:

Turano, K. (1991) Field of view required for optimal optic-flow discrimination, presented at the Annual meeting of the Optical Society of America.