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13. ABSTRACT *(Maximum 200 words)*

One study investigated, under two viewing conditions, an observer's ability to determine whether s/he was moving forward along a straight or curved path using simulations of optic flow patterns. In one condition, the retinal image vas stabilized against the effects of eye movements, in the other condition, eye movements were unrestricted. Stabilizing the retinal image decreased performance at slow speeds. A second study further explored the role of eye movements in the perception of motion. Speed-difference thresholds were measured under conditions of stabilized and free-viewing conditions. Despite the fact that eye movements can alter the direction and speed of the retinal-image motion relative to the stimulus motion, observers were able to judge speed differences in the free-viewing condition as well as in the stabilized-viewing condition, with the exception of the slowest speed. At the slowest speed, observers were able to detect smaller speed differences in the free-viewing condition. A third study determined the optimal stimulus for motion detection by searching the spatiotemporal stimulus whose direction was identified with least contrast energy. The best stimulus was determined to be at 3 cycles/deg,1.67 deg/s with bandwidths of 7.06 Hz and 1 - 0.5 octaves.

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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. Following are objectives of the research effort:

(1) to determine the role of eye movements in the perception of motion of:
  (a) three-dimensional (3D) motion (optic-flow patterns)
  (b) two-dimensional (2D) motion (fronto-parallel motion)

(2) to determine the optimal stimulus for the detection of motion

(3) to determine the retinal position used to make judgments about self motion

(B) Status of the research effort:
The report on the status of the research effort is divided into two parts. Section 1 consists of the findings of three completed studies and section 2 reports the status of the current study.

(1) Completed Studies:

Study #1 - Discrimination of a Curved from Straight Path of Self Motion: Stabilized versus Free Viewing

For successful locomotion, an observer must be able to detect changes in the direction of forward motion. Our studies[1], as well as those of Riemersma[2], have shown that the magnitude of angular-speed change required to discriminate between a straight and curved path of motion increases with the speed of forward motion. It could be that the addition of eye movements plays a role in an observer's ability to discriminate between a straight and curved path of motion. This study examined the role of eye movements in the perception of 3D motion.

Stimuli were computer-generated images simulating an observer moving forward along a straight or circular path relative to a volume of randomly-positioned dots. The observers had to judge whether they were moving forward along a straight path or a curved path. The angular speed of the deviation from a straight path served as the independent variable, and angular-speed thresholds were measured across a range of forward speeds.

We measured eye movements in the free-viewing condition and found no significant difference in the magnitude or direction for the straight vs. curved motion conditions (at any angular and forward speeds). The average eye-movement speed for the fastest forward-speed (26.4 m/s) conditions were significantly higher than for the slowest forward-speed (2.0 m/s) conditions. For

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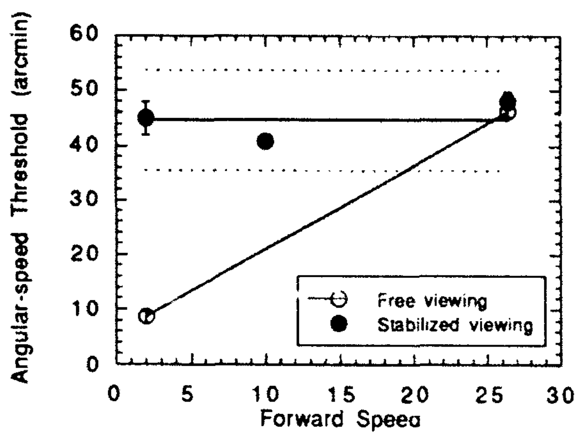
[1] Turano K, Wang X. Perception of changes in heading direction from image flow. Optical Society of America Technical Digest 1989; **18**: MA4.

[2] Riemersma JBJ. Visual control during straight road driving. Acta Psychol. 1981; **48**: 215-225.

the 2.0-m/s forward-speed condition, the average eye-movement speed (0.29°/s) was significantly higher than the average stimulus speed (0.07°/s, calculated from velocity vectors within the central 10°). However, for the 26.4-m/s forward-speed condition, the average eye-movement speed (0.39°/s) was significantly lower than the average stimulus speed (1.1°/s, calculated from velocity vectors within the central 10°).



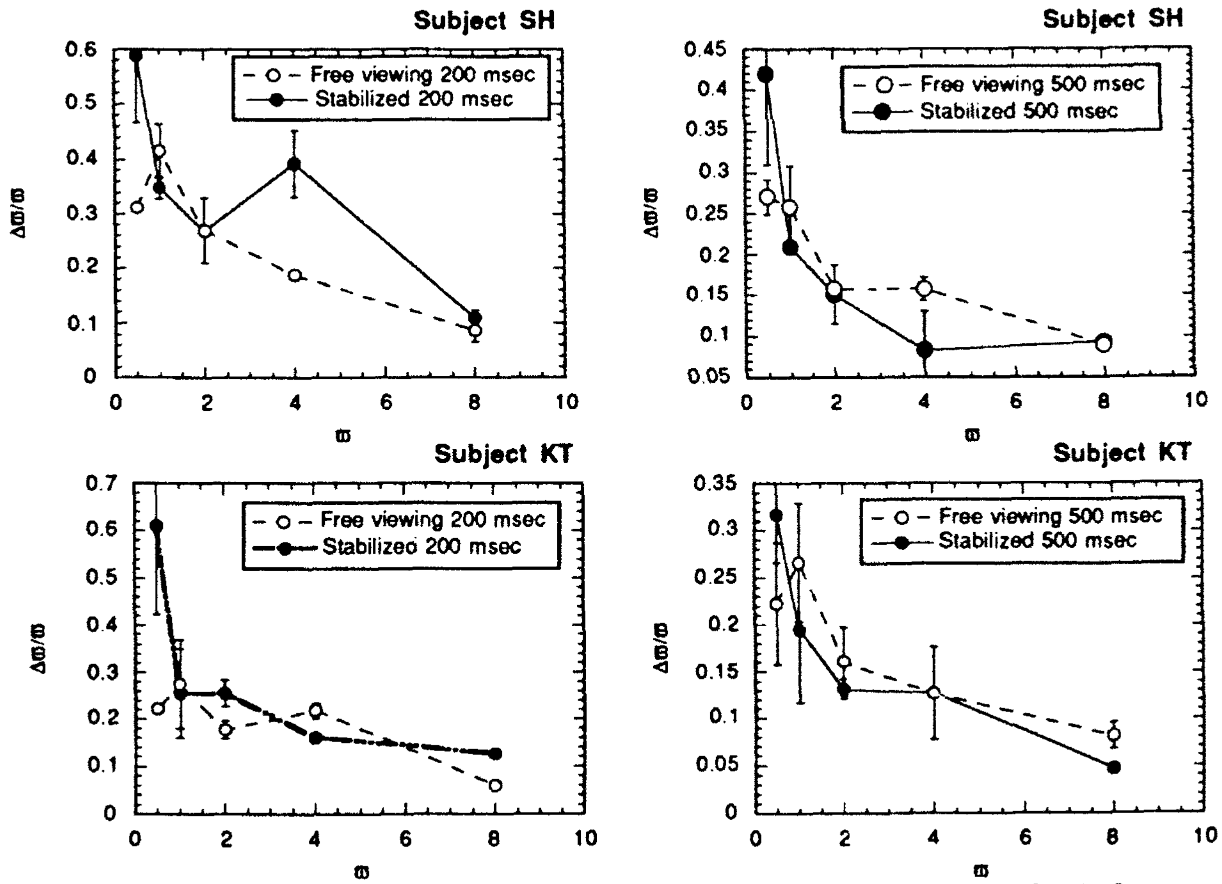
We measured, in two conditions, angular-speed thresholds for the discrimination between a straight and a curved path of motion: In one condition, the retinal image was stabilized against the effects of eye movements by means of an SRI Dual Purkinje Image eyetracker with a stimulus deflector. In the other condition, eye movements were unrestricted.The results show that when eye movements are restricted, an observer can discriminate a curved from straight path only when the angular-speed deviation between the two reaches approximately 45 arcmin/s, regardless of forward speed (Figure 1). When eye movements are permitted, forward speed affects performance; thresholds are significantly lower for the slow forward speeds.

Why would stabilizing the retinal image against the effects of eye movements decrease performance? One possible explanation is that there is a mismatch between the expected and observed image motion in the stabilized-viewing condition. In the free-viewing condition, when the observer makes eye movements there is a corresponding change in the retinal-image motion, along with information about the eye movement from extra-retinal sources, such as proprioceptive feedback from the extraocular muscles or efference information. Thus there is a match between the expected retinal-image motion and the observed retinal-image motion. In the stabilized-viewing condition, the expected and observed retinal-image motion do not match. The observer may make eye movements, thus triggering extra-retinal information, but there is no corresponding change in the retinal-image motion. According to this explanation, the mismatch between the two sources of information result in elevated thresholds.

An alternative explanation is that our perception of motion is based on the output of a comparator stage whose inputs are retinal-motion information and extra-retinal information about eye movements. The inputs to the comparator are differentially weighted by the respective spatio-temporal sensitivities of the two systems. The extra-retinal information may be more heavily weighted than the retinal-motion information at the slow speeds (or low temporal frequencies).

Study #2 - Speed Discrimination: Stabilized versus Free Viewing

In order to further explore the role of eye movements in motion perception and, in particular, to determine whether speed discrimination is limited by retinal-image noise introduced by eye movements, speed-discrimination thresholds were measured under conditions of stabilized and free-viewing conditions in a basic speed-discrimination task. For 3 observers, minimum detectable speed differences have been measured for drifting sine-wave gratings (speeds from 0.5 to 8.0 deg/s; spatial frequencies of 1.5, 3.0, 6.0, and 9.0 c/deg; mean durations of 0.2 and 0.5 s). A Dual Purkinje Image eyetracker was used to measure eye movements and, with a stimulus deflector, to stabilize the image.



In normal viewing, average eye velocities range from +/- 2.0 deg/s for stimulus speeds centered around 4.0 deg/s and from +/- 1.0 deg/s for stimulus speeds centered around 0.5 deg/s.

Yet, speed-discrimination thresholds in normal viewing are equivalent to thresholds obtained in stabilized viewing, with the exception of the lowest stimulus speed, 0.5 deg/s. At 0.5 deg/s, thresholds in stabilized viewing are 2 - 3 times **higher** than in normal viewing.

Despite the large difference between retinal and stimulus velocities introduced by eye movements in normal viewing, observers are able to make accurate judgments about stimulus speed. The results can be explained by a visual motion model with a comparator stage whose inputs are retinal-motion information and extraretinal information about pursuit eye movements. The inputs to the comparator are differentially weighted by the respective spatio-temporal sensitivities of the two systems.

Study #3 - The Optimal Motion Stimulus

In order to specify the optimal stimulus for the detection of motion and thereby define the three-dimensional shape (x,y,t) of the human motion sensor, we have searched for that spatiotemporal stimulus whose direction (left vs right) is identified with least contrast energy.

The search space consisted of Gabor functions with varied height, width, duration, velocity of the Gaussian aperture, spatial frequency and speed of the sinusoidal modulation. In the frequency domain, these stimuli are translations, scalings and shearings of a pair of three-dimensional Gaussians.

For two observers, the best stimulus is at approximately 3 cycles/deg and 1.67 deg/sec (5 Hz). The optimal bandwidths are 7.06 Hz and 1-2 cycles/deg (1-0.5 octaves). Sensitivity to aperture motion is nearly flat from -5 to 5 deg/s. This flatness may be explained by the minimal effect of aperture speed on the stimulus spectrum, due to the brief duration of the optimal stimulus.

These results are consistent with a motion sensor whose spectral receptive field is ellipsoidal and highly elongated parallel the temporal frequency axis. This contrasts with the oblique frequency spectrum often assumed for velocity-tuned mechanisms.

(2) Current Study

Retinal Position of Optic-Flow Patterns

In order to determine what part of the retina human observers choose to use to make judgments about their heading direction, we are currently measuring retinal positions as subjects perform a heading-discrimination task.

The displays simulate translation in a particular heading direction through a 3D cloud of spatial noise. A motion sequence consists of 16 frames. Heading-direction difference thresholds are measured at two speeds, 2.0 m/s--simulating a fast walk and 26.4 m/s--simulating a driving speed of 60 miles/hr. A two-alternative forced-choice procedure is used to determine heading-direction discrimination thresholds. On each trial, the subject views two motion sequences, separated by an interval. In one sequence (randomly chosen), the heading direction is in the reference direction (within a 2 deg radius toward the center of the screen). In the other, heading is in the test direction.The subject's task is to judge whether the heading in the second interval was to the left or right of the heading in the first interval. The independent variable is the heading angle between the reference and test directions and varies among 10 possible values (±0.2, ±0.5, ±1.0, ±2.0, and ±4.0 deg). Each heading angle is presented 10 times for a total of 100 trials per block. For each subject and condition, proportion of correct responses per magnitude of heading-direction difference is calculated. A Weibull function is fit to the proportion-correct distribution. A maximum likelihood procedure is used to fit the Weibull function with a simplex maximizing routine. Threshold is defined as the magnitude of heading-direction difference required for 82% correct.

We use the confocal scanning laser ophthalmoscope with graphics capabilities to determine the retinal location of visual stimuli directly with respect to retinal landmarks[3]. The scanning laser ophthalmoscope generates retinal images continuously with an IR laser (810 nm) and scans graphics on the retina with a modulated He-Ne laser (633 nm). A 16 x 15° image of the retina with the location of the stimuli seen directly on the retinal image is recorded continuously on videocassette tape for later analysis. The scanning laser ophthalmoscope has a resolution of about 2 min of arc for measurement of the retinal areas. The recording of the optic flow on the retinal image with videocassette tape allows an analysis of each frame of an interlaced video system.

At this time, the software has been developed and pilot testing is underway.

(D) Publications:

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

Turano, K. Visual discrimination of a curved or straight path of self motion: Stabilized versus free viewing, in preparation.

Turano, K. Size and eccentricity effects on direction discrimination of a curved path of self motion, in preparation.

Turano, K. (1992) Discrimination of a curved from straight path of self motion: Effects of eye movements. Perception, **21**, 49.

Watson, A.B. and Turano, K. (1992) What does the eye see (moving) best? Perception, **21**, 64.

(D) Professional personnel associated with the research effort:

Kathleen Turano, Principal Investigator
Andrew B. Watson, Senior scientist at NASA Ames Research Center, collaborator

(E) Papers presented at meetings:

Turano, K. (1992) Discrimination of a curved from straight path of self motion: Effects of eye movements. Perception, **21**, 49.

Watson, A.B. and Turano, K. (1992) What does the eye see (moving) best?

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[3] Webb RH, Hughes GW, Delori FC. Confocal scanning laser ophthalmoscope. Appl. Opt. 1987; **26**: 1492-1499.

Perception, 21, 64.

Papers to be presented at meetings:

Turano, K. and Heidenreich, S.M. Speed discrimination in stabilized viewing. To be presented at the Annual Meeting of The Association for Research in Vision and Ophthalmology (ARVO) on May 4, 1993 in Sarasota, FL.

Watson, A.B., Turano, K. and Eckert, M.P. The optimal motion stimulus. To be presented at the Annual Meeting of The Association for Research in Vision and Ophthalmology (ARVO) on May 4, 1993 in Sarasota, FL.