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THE SPATIAL AND TEMPORAL PARAMETERS OF VELOCITY DISCRIMINATION

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The target duration required for the precise discrimination of velocity is quite short, amounting to about 100 msec for a single moving dot or line target. While stroboscopic motion is an adequate substitute for continuous motion in velocity discrimination, optimal discrimination depends on the use of a strobe rate greater than 10 Hz. Generally human observers have difficulty detecting acceleration in moving targets. Over small distances (0.5-1 deg), timing signals from adjacent targets presented in a sequence are pooled, so that information about their relative onset time is lost. For example, given three adjacent lines, separated spatially by 0.1 deg and presented in a sequence (apparent motion) observers are unable to discriminate between a sequence in which a 10 msec interval separates the second from the reverse order (30 msec followed by 10 msec). Velocity discrimination is not affected by blur. Sinusoidal grating targets of 3 cyl/deg or lower produce excellent discrimination. Sinusoidal gratings above 3 cycles per degree in spatial frequency are not adequate stimuli for fast velocities (> 1 deg/sec).

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ABSTRACT

The research of the past year has produced the following results:

1) The target duration required for the precise discrimination of velocity is quite short, amounting to about 100 msec for a single moving dot or line target.

2) While stroboscopic motion is an adequate substitute for continuous motion in velocity discrimination, optimal discrimination depends on the use of a strobe rate greater than 10 Hz.

3) Generally human observers have difficulty detecting acceleration in moving targets. Over small distances (0.5-1 deg), timing signals from adjacent targets presented in a sequence are pooled, so that information about their relative onset time is lost. For example, given three adjacent lines, separated spatially by 0.1 deg and presented in a sequence (apparent motion), observers are unable to discriminate between a sequence in which a 10 msec interval separates the first pair and a 30 msec interval separates the second from the reverse order (30 msec followed by 10 msec).

4) Velocity discrimination is not affected by blur. Sinusoidal grating targets of 3 cyl/deg or lower produce excellent discrimination. Sinusoidal gratings above 3 cycles per degree in spatial frequency are not adequate stimuli for fast velocities (> 1 deg/sec).

5) Dr. Ken Nakayama completed a major review of biological motion processing.

2. Research Objectives

I. An experimental analysis of the spatial parameters of velocity discrimination using measurements of human velocity discrimination for spatial frequency band-limited targets.

II. An experimental analysis of the temporal parameters of velocity discrimination, including minimum duration needed for optimal performance, and the optimal strobe rate for targets in apparent motion.

III. A psychophysical study of the detection of acceleration in visually presented targets in order to estimate the limits of spatial and temporal integration of velocity information.

IV. Measurements of the precision of smooth pursuit by the oculomotor system in response to variations in velocity.

3. Status of Research

A. The Spatial and Temporal Requirements for Precise Velocity Discrimination

Last year this laboratory demonstrated that human observers could discriminate small changes in velocity for a wide variety of targets; moving points, lines and sinusoidal gratings were all adequate stimuli for velocity discrimination. For the sinusoidal grating targets, the optimal range of spatial frequencies depended on target velocity: the faster the velocity, the lower the range of spatial frequencies required for best human performance (the discrimination of a 5% change in velocity). Velocity discrimination appeared to depend on low spatial frequency components of the stimulus, because even for the slowest velocity tested (1 deg/sec), the optimal spatial frequency range was below 3 cycles/degree. Initially, the limiting factor seemed to be target temporal frequency. When performance was plotted as a function of temporal frequency, rather than spatial frequency, the discrimination curves for different velocities were superimposed.

Our next experiment examined how random variations in spatial frequency affected velocity discrimination for a particular velocity. From trial-to-trial, the target spatial frequency was changed randomly, but subjects were expected to base their judgments on velocity. Random variations in spatial frequency would, of course, introduce random variations in temporal frequency and, if observers were unable to respond to velocity but could only judge target temporal frequency, then these fluctuations should seriously degrade their velocity performance. In fact, their performance was only slightly affected by a 300% change in temporal frequency. Random variations in contrast, ranging from 6% - 82%, also had no affect on velocity discrimination.

These results indicated that human observers actually judge velocity, not temporal frequency, even for periodic stimuli. Nevertheless, the initial findings suggested some limitation based on temporal frequency. Our next set of experiments explored the influence of the temporal periodicity. If velocity discrimination depended at some level on a temporal frequency input, then the minimum duration required for best performance should depend to some extent on the target spatial frequency, because accuracy should depend on the number of periods. Our measurements showed that velocity discrimination thresholds reached their minimum value at a duration of 200 msec for all sinusoidal gratings independent of their spatial frequency. Again our results argued against a temporal frequency basis for velocity discrimination at any level. Oddly enough, the minimum duration for complex stimuli (stimuli composed of many spatial frequency components, such as lines or square-wave gratings) was only about 100 msec.

Finally, velocity discrimination was measured with band-limited stimuli containing no spatial frequency component below 3 cycles/degree. The stimuli were luminance distributions mathematically described as the difference of two Gaussians — the DOG stimuli popularized by Wilson and his collaborators. The velocity discrimination for these band-limited targets was excellent. These results indicate that velocity is processed by a non-linear system, as it is not possible to predict performance for complex stimuli from the results for simple sinusoidal inputs. The temporal frequency dependence observed with the periodic stimuli (sinusoidal gratings) may be an artifact of the periodicity. Perhaps the repetitive nature of the stimulus actually drowns the small changes in the velocity signal on which precise discrimination depends.

B. Sequential Recruitment

This laboratory has now completed a project on the microstructure of the timing signal critical to velocity discrimination. Apparent motion (stroboscopic motion) is an adequate substitute for continuous motion in velocity discrimination. Apparent motion has another virtue; the timing of the velocity can be manipulated independently of the spatial changes. In this case, the target consisted of short lines presented at a spacing of 9 min of arc every 10 msec (15 deg/sec). The velocity was altered by changing the asynchrony between target presentations.

In principle, a single pair of asynchronously-presented targets could determine velocity. Generally, the detection of differences in synchrony is too poor to account for fine velocity discrimination. Five to eight lines presented in an apparent motion sequence are needed to produce the most precise discrimination, a discrimination based on the detection of changes in asynchrony on the order of <u>0.5 msec</u>. The improvement observed with an extended sequence is not the result of probability summation. It appears to represent the summation of signals within a physiological network sensitive to one direction of motion. Orthogonal directions of motion do not sum to produce the enhanced detectability of timing signals found with sequences. To a first approximation, linear summation of a spatial-temporal signal within a velocity sensing network can account for the sequential effects. However, a detailed analysis of the results suggests that a small non-linear facilitation produced by sequences may exist in the human motion-detecting system.

C. Local detection of acceleration

Basically, our research has supported earlier work that demonstrated that acceleration of visual targets is not detected by human observers. The reason for this deficiency is that timing signals from adjacent

4. Publications

McKee, S.P. and Nakayama, K. The detection of motion in the peripheral visual field. Vision Research 24:25-32, 1984.

McKee, S.P. and Welch, L. Sequential recruitment in the discrimination of velocity. J. Opt. Soc. Am., 1985 (In press).

Nakayama, K. Biological motion processing: A review. Vision Research, 1985 (In press).

Mitchison, G.J. and McKee, S.P. Interpolation in stereopsis. (Accepted by Nature, revisions in progress), 1985.

McKee, S.P., Silverman, G. and Nakayama, K. Precise velocity discrimination despite random variations in temporal frequency. (In preparation. To be submitted to Vision Research).

Kowler, E. and McKee, S.P. The precision of smooth pursuit. (In preparation. To be submitted to Vision Research).

5. Professional Personnel

Dr. Suzanne P. McKee, Senior Scientist, Smith-Kettlewell Institute of Visual Sciences, San Francisco, CA.

Dr. Ken Nakayama, Associate Director, Smith-Kettlewell Institute of Visual Sciences, San Francisco, CA.

Dr. Gunilla Haegerstrom-Portnoy, Senior Scientist, Smith-Kettlewell Institute of Visual Sciences, San Francisco, CA.

Dr. Graeme J. Mitchison, MRC Staff Scientist, Molecular Biology Laboratory, Cambridge, England.

Mr. Gerald Silverman, Research Assistant, Smith-Kettlewell Institute of Visual Sciences, San Francisco, CA.

Ms. Leslie Welch, Research Assistant, Smith-Kettlewell Institute of Visual Sciences, San Francisco, CA.

6. Interactions

a) Spoken Presentations:

Formal talk at the Association for Research in Vision and Ophthalmology (ARVO) in Sarasota, Florida on April 30, 1984.

Formal presentation at the AFOSR meeting, Sarasota, Florida on May 5, 1984.

Invited talk at symposium entitled "Mechanisms of Spatial Vision" held June 27-30, 1984 at the Center for Visual Sciences, University of Rochester, Rochester, New York.

regions of visual space are pooled, in order to establish a more accurate estimate of retinal velocity. For example, if three short lines, separated spatially by 9 min of arc, are presented in a sequence, the temporal separation separating the first pair of lines is not detected independently of the temporal separation separating the second pair. Thus, the sequence 30 msec-10 msec is difficult to discriminate from 10 msec-30 msec. The appearance of third target following an asynchronous pair can disturb judgments of timing and judgments of direction, but only if the position of the third target lies close to the axis of motion defined by the first pair of targets.

The velocity-averaging process which obscures information about acceleration means that generally the human visual system treats objects as though they were moving at a constant velocity. This assumption of constancy can result in some peculiar illusions. For example, if a three-line sequence similar to that described above is created with the temporal interval between the first pair equal to 5 msec and the temporal interval between the second set of 35 msec, the lines defining the targets appear to be irregularly-spaced, even though the spacing between the lines is physically equal. The visual system varies the spatial position of the lines, in order to partially compensate for the temporal irregularity, consistent with a target moving at constant velocity.

D. Binocular Correspondence in Simple Patterns

This research was not part of the original proposal, but questions concerning binocular matching are important in computational vision and can be related to similar problems in motion-processing. These experiments provide useful experimental data for work supported by the Air Force Office of Scientific Research at other laboratories.

Any repetitive pattern can be potentially fused in one of several different depth planes (wallpaper effect), so such patterns can be used to probe the general physiological rules governing binocular fusion. Our stimulus, viewed foveally, consisted of a regular grid of small bright points, the entire grid being 1.7 degrees wide and 0.75 degrees high. The points were spaced about 5 minutes apart. The disparity of the end columns was manipulated so that the ends should have appeared in front of the central grid. As the disparity difference between the end columns and the central grid was increased, the <u>entire</u> grid appeared to move forward in depth although the physical position of the central points was unchanged. To minimize the influence of convergence, the pattern was presented for only 160 msec and the disparity of the end columns was varied randomly from trial to trial. Observers were forced to judge whether the central grid was in front or behind a test point placed below the center of the grid. These shifts in the depth of the whole grid are not merely 'edge' effects, because if the points in the central grid are spaced irregularly, the grid remains fixed in the back depth plane behind the ends. The steep disparity gradient, created by moving the end columns forward, between the end columns and the central grid seems to force an alternative binocular matching solution in regularly-spaced patterns.

Informal talk at University of California, Berkeley on March 16, 1984.

Informal talk at University of Washington, Seattle on May 28, 1984.

Informal talk at University of California, Santa Cruz on June 1, 1984.

Informal talk at NASA Ames Research Center, Moffett Field, CA. on Octrober 4, 1984.

b) Consultative Functions at Other Laboratories

Dr. Eileen Kowler, Dept. of Psychology, Rutgers University, New Brunswick, New Jersey.

Dr. Donald I.A. MacLeod, Dept. of Psychology, University of California, San Diego, CA.

7. No inventions or patents.

Suzanne P. McKee, Ph.D.
Principal Investigator
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