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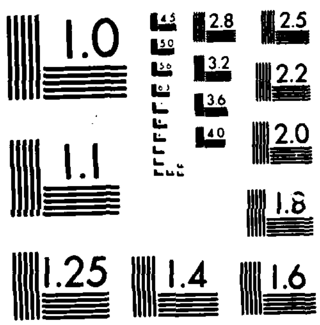

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FLIGHT SIMULATOR: COMPARISON OF RESOLUTION THRESHOLDS FOR TWO LIGHT VALVE VIDEO PROJECTORS

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This project was conducted to measure resolution thresholds, from several observers, for the General Electric PJ5155 and Sodern SVS-14 Light Valve Video Projectors. Thresholds for stationary targets were measured using a stairstep-constant stimulus procedure at two luminances and five screen positions; data were collected from three observers. Results show that thresholds were lower for the General Electric projector at 60 footlamberts (fL), while the thresholds were equal at 100 fL. Thresholds for moving targets were measured using a two-stage, double stairstep procedure. Data were collected from three observers for targets moving horizontally, vertically, and diagonally at 3.75°, 7.5° and 15°/second. For all conditions, the General Electric projector had lower thresholds than did the Sodern. With horizontally moving targets, however, the General Electric projector's thresholds were elevated compared to thresholds for vertically or diagonally moving targets. This threshold elevation is thought to be due to a pattern of vertical bars, which is visible only when tracking a horizontally moving target. A hypothesis for this effect is discussed.

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SUMMARY

The Air Force Human Resources Laboratory/Operations Training Division is developing a visual system for advanced tactical air combat simulators. As part of this work, two light valve video projectors were evaluated on their ability to display small, high-contrast images. The angular size of the smallest detail which could reliably be identified by an observer was determined for the General Electric PJ5155 and Sodern SVS-14 Video Projectors for stationary and moving targets under a variety of conditions. Several observers evaluated the projectors using variations of the stairstep procedure to determine minimum resolvable target size. For almost all conditions, observers were able to recognize smaller targets on the General Electric system than on the Sodern. With targets moving horizontally, however, minimum resolvable target size for the General Electric projector was significantly larger than for targets moving vertically or diagonally at the same speed. A hypothesis for this effect is discussed.

PREFACE

This project was conducted in support of the Air Force Human Resources Laboratory's Technical Planning Objective 3, Aircrew Training. The goal of this effort is to develop cost-effective simulator training strategies and systems to develop and maintain the combat effectiveness of USAF aircrews. The project was conducted under Work Unit Number 2363-00-01, Advanced Visual Technology System. The objective of this work unit is to develop an advanced tactical air combat simulator visual system. This visual system will be used to validate engineering concepts and to define specifications for future operational simulators through the collection of behavioral research data.

The goal of the present experiment was to determine the resolution thresholds for two light valve video projectors under a variety of conditions. These projectors have potential applications in flight simulator visual systems. Results show that for both stationary and moving targets, the General Electric PJ5155 projector is able to display more finely detailed targets than can the Sodern SVS-14 projector.

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FLIGHT SIMULATOR: COMPARISON OF RESOLUTION THRESHOLDS FOR TWO LIGHT VALVE VIDEO PROJECTORS

I. INTRODUCTION

This project was part of a series of tests comparing two light valve projector systems for potential applications in visual flight simulators. These two systems, the General Electric PJ5155 and Sodern SVS-14, are three-color video projectors built using different technologies (see Gerlicher, 1985). Tests of these projectors have been conducted at the Air Force Human Resources Laboratory/Operations Training Division (AFHRL/OT) and include measurements of luminance, contrast, and modulation transfer. The results of these tests have been described by Gerlicher (1985).

In the present study, each projector displayed a small, high-contrast target to the observer. The size of the target was then decreased until the observer was unable to resolve small details. The size of the smallest resolvable detail, measured in minutes of angle, is the perceived resolution threshold for that observer. Thresholds were measured for a variety of conditions using stationary and moving targets. The observer's task was to identify the location of a gap in the test target; the gap was positioned either up, down, left, or right at random. This task has been used by many investigators for measuring an observer's acuity thresholds in both experimental and clinical settings; see Riggs (1965) for a review. Clinically, a gap size of one arc-minute is considered normal acuity (Riggs, 1965, p. 321).

II. STATIONARY TARGET THRESHOLDS

For the Stationary Target Thresholds test, resolution thresholds were measured from three subjects for both projectors, using two levels of luminance and five locations on the projection screens. A combination of two psychophysical techniques, the stairstep method (Cornsweet, 1962) and the method of constant stimuli (Engen, 1971), was used for measuring thresholds.

Method

Subjects. Data were collected from three male observers, 35 to 45 years old, with normal or corrected-to-normal vision.

Design. The experiment employed a 2 x 2 x 5 within-subjects design. The factors were as follows: projectors: Sodern or General Electric; background luminance: 60 or 100 footlamberts (fL); and screen locations: center, 11 degrees above or below, 14 degrees left and right of center.

Apparatus. Images were displayed using the General Electric PJ5155 and Sodern SVS-14 light valve projectors. Each projector was positioned behind a 110 cm x 85 cm rear projection screen with the observer located 2 meters in front of the screen center (see Figure 1). The observer initiated a trial and responded using a five-button box which he held during data collection.

Target images were generated using the Advanced Simulator for Pilot Training (ASPT). The target modeled in the ASPT data base was a square Landolt C (see Figure 2). The size of the gap and the width of a line element were one-fifth the height of the target. Gap orientation was randomly positioned up, down, left, or right. Target size was manipulated by having ASPT alter the range (in feet) from the model to the observer's eyepoint. Measurement of target sizes on the projection screens shows that gap size, θ, in arc-minutes can be determined for any range, R, by the power function

$$\theta = [\mathrm{TAN}^{-1}(10^{a} \cdot R^{b}/10{,}000)] / 60$$

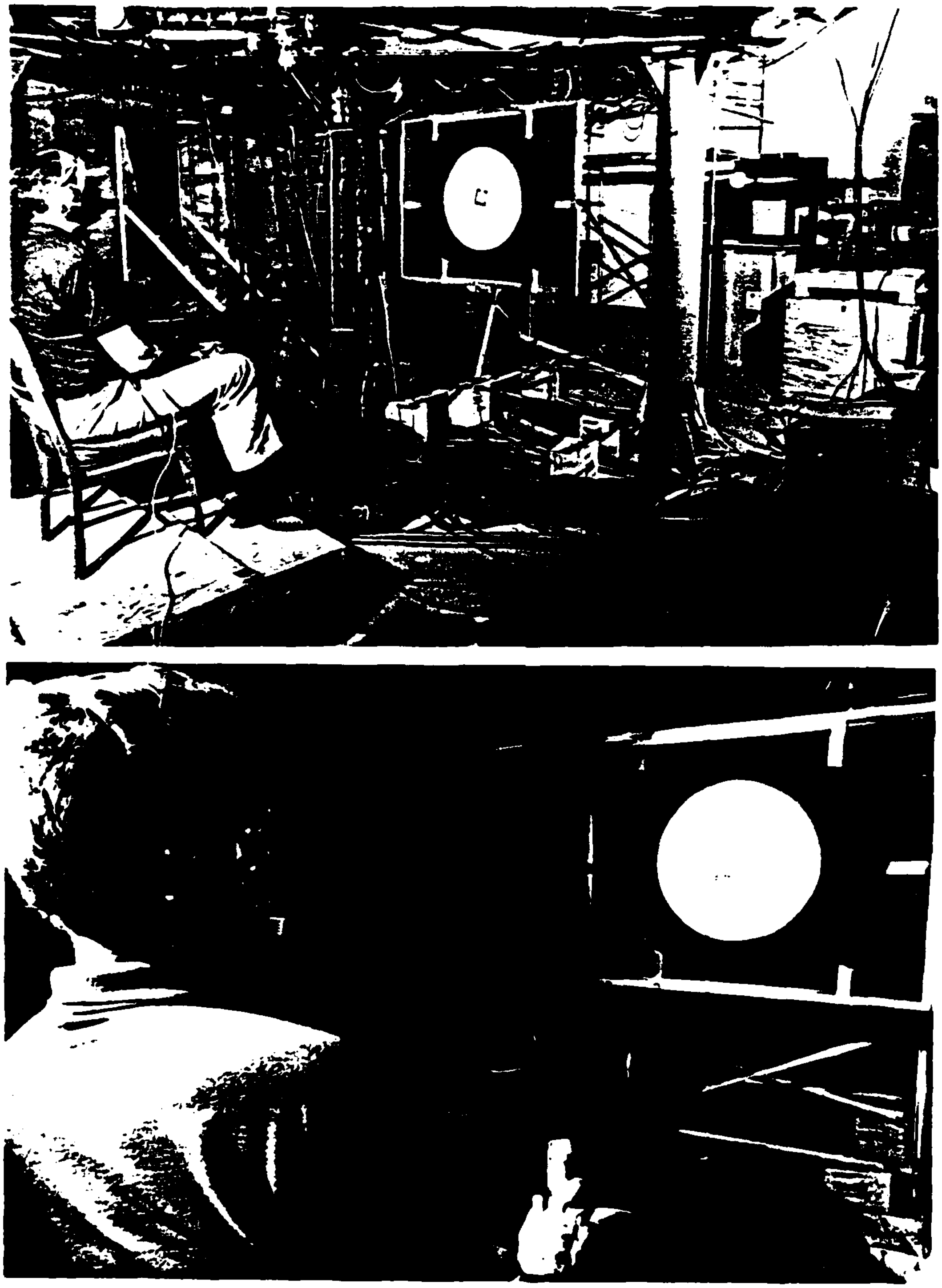

Figure 1. Upper photo: Experimental setup. Observer is seated at left, 2 meters in front of the screen in the center of the photo. The projectors can be seen at right.

Lower photo: Observer viewing a stationary target. Response box is in the observer's right hand.

where a and b are weights determined by regression analysis for each projector and screen position. Thresholds were measured for targets projected at the screen center and at positions 11° above and below screen center and 14° to the left and right.

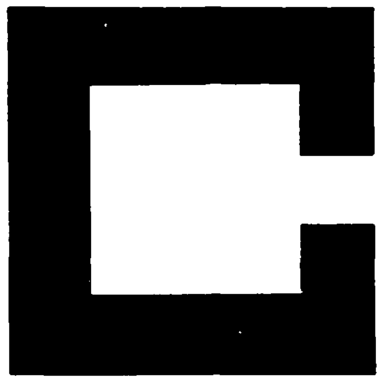

Figure 2. Landolt C target. Stroke width and gap size are 20% of target height.

Luminance and contrast were manipulated using each projector's controls. With the Sodern projector, it was also necessary to use a polarizer as a neutral density filter to further reduce its output. Screen luminance and target contrast were set at the start of each experimental session using a Prichard Model 1901A Photometer. The target was black against a white background. Luminance of the background was set to 60 or 100 fL; contrast was 13:1 for all conditions.

Procedure. A two-stage procedure was used to determine thresholds. First, a narrow range of gap sizes which included the approximate threshold was determined by an alternating, double stairstep procedure. Gap sizes of 0.5 and 5 arc-minutes were used as starting points; the step size was 0.5'. A target was presented when the observer pressed the initiate button and remained on until he pressed a response button, indicating the perceived gap orientation. For the descending series, gap size was decreased after each correct response until the subject responded incorrectly. Four trials were then presented at the same gap size. If at least three of these trials were responded to incorrectly, the gap size was assumed to be below threshold. This size was increased by 0.5' and used as the upper bound for the second stage. On alternating trials, an ascending series of targets was presented starting with gap size of 0.5'. The size of the target was increased by 0.5' after each incorrect response until the observer could correctly identify the orientation of the gap on three out of four trials. This target was assumed to be above threshold; its size was decreased by 0.5', and this value was used as the lower bound for the second stage. The interval between the upper and lower bounds was divided into five equal steps, and the method of constant stimuli was then used. The five target sizes were presented, in random order, once at each of the four orientations. The median of the distribution of target sizes for correct responses was recorded as the resolution threshold in arc-minutes.

The observer's task was self-paced and no feedback was provided. Threshold measurement for a given luminance, screen position, and projector required 2 to 4 minutes to complete.

Results

Observers were able to maintain 60% to 80% correct responses for the constant stimulus portion of this task. Figure 3 shows the mean resolution thresholds for each projector and luminance combination. The resolution threshold for the General Electric PJ5155 was significantly lower than for the Sodern SVS-14: General Electric mean threshold = 2.25', Sodern mean threshold = 2.60', $F(1,38)=18.2$, $p < .001$. However, the luminance x projector interaction was significant, $F(1,38)=35.3$, $p < .001$. At 100 fL, the General Electric projector's threshold was not different from the Sodern's; at 60 fL, the General Electric threshold was lower (see Figure 3). The projector x position and projector x position x luminance interactions were not significant.

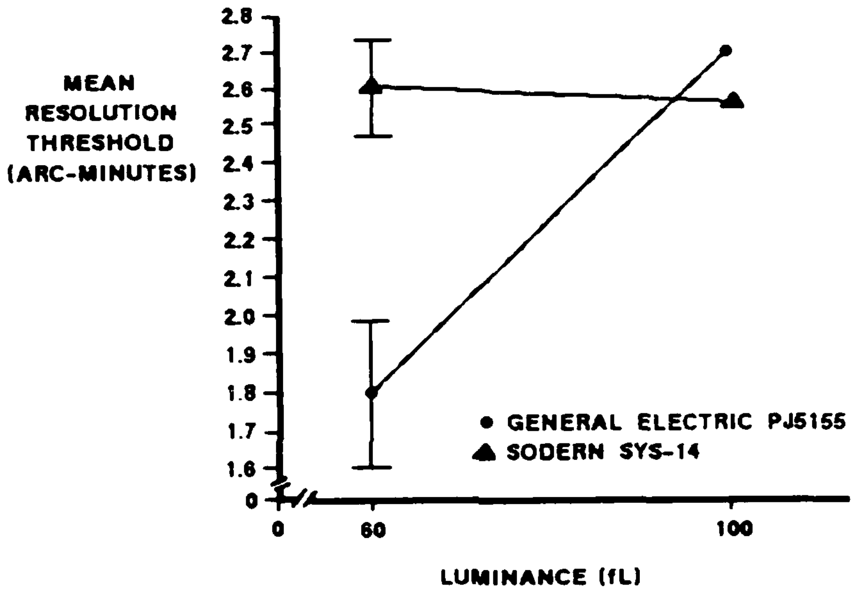

Figure 3. Mean resolution thresholds for the General Electric and Sodern projectors at 60 and 100 fL with stationary targets. Error bars are 95% confidence limits.

Discussion

Comparing resolution thresholds at 60 fL shows that the General Electric projector is capable of displaying finer detailed images than can the Sodern. The mean threshold for the General Electric projector was 0.83' less than for the Sodern. There was no significant difference in acuity thresholds at 100 fL.

The increase in threshold for the General Electric projector as background luminance increased is puzzling. Moon and Spencer (1944) measured recognition acuity as they increased background luminance from .001 to 1000 fL; as luminance increased, acuity thresholds decreased from 10' to 0.5'. In the range from 60 to 100 fL, however, Moon and Spencer's data indicate that there should be only a minimal decrease in threshold. The increase in threshold for the General Electric projector is therefore unexpected. It is probable that increasing the General Electric projector's output to produce 100 fL screen luminance approached its performance limits, and the image was degraded.

III. MOVING TARGET THRESHOLDS

For the Moving Target Thresholds test, acuity thresholds were measured for three observers using both light valve projectors. Targets were displayed moving horizontally, vertically, or diagonally at three rates of motion. Luminance was not manipulated.

Acuity for moving targets has been measured by a number of investigators (see Berens, 1958, and Burg, 1966). Ludvigh and Miller (1958) and Reading (1972) measured recognition acuity for targets moving from 10°/second to 170°/second. Both investigations found that while acuity thresholds increased as angular velocity increased, the change in threshold was minimal up to 50°/second. In the present experiment, stationary targets and targets moving at 3.75°, 7.5°, and 15° per second were tested.

One difficulty experienced when using the two-stage procedure developed for measuring stationary target thresholds with moving targets was the observer's guessing rate. If, during the stairstep procedure, the bounds for the constant stimulus stage were set low, the observer's percentage of correct judgments during the constant stimuli stage would also be very low. Conversely, high bounds resulted in high rates of correct responses. When this procedure was used with moving targets, the results were inconsistent. In order to maintain stable data, a new procedure was developed.

Method

Subjects. Data were collected from three male observers, 35 to 45 years old, with normal or corrected to normal vision.

Apparatus. The projectors, screens, and image generator used in the stationary target evaluation were used for moving targets. Because ASPT was designed to generate images for curved screens, the images were distorted near the edges of the flat screens used in this test. To avoid this distortion, a piece of black cardboard was placed over the screen blocking all but a 15° circle in the center. The cardboard mask is visible in Figure 1. Background luminance was adjusted to 80 fL and contrast to 13:1 for all conditions.

Procedure. A two-stage, random double stairstep procedure was used to measure thresholds (Cornsweet, 1962). In the first stage, a narrow range of gap sizes around the threshold was determined. Starting points for the ascending and descending series were 0.5' and 5.5', respectively. For both series, the gap size was decreased following a correct response and increased following an incorrect response; step size was 0.5'. The gap sizes on the fourth reversal of each series were used as the starting points for the second stage. Step size was decreased to 0.3', and the random double stairstep procedure was continued. There were 40 target presentations after the gap size was decreased, 20 from each series. Resolution threshold was computed as the average of the gap sizes on correct response trials for the ascending series and for incorrect response trials for the descending series.

Resolution thresholds were measured for targets moving horizontally, vertically, or diagonally at speeds of 3.75°, 7.5°, and 15° per second. The orientation of motion (e.g., vertical) was constant for a given session, but the direction of motion (e.g., top to bottom or bottom to top) was randomized from trial to trial. The task was self-paced with the observer initiating each trial; no feedback was provided to the subject. Threshold assessment required 2 to 4 minutes for each condition.

Results

Resolution thresholds were measured from three observers for both projectors displaying targets moving in three orientations and at three rates of motion. Due to equipment problems, thresholds for diagonal motion at 7.5° and 15°/second could not be obtained for one observer. Thresholds for the General Electric projector were lower than for the Sodern projector on all conditions. The mean threshold for the General Electric was 2.20' and for the Sodern was 2.86'. The data were analyzed by a series of planned comparisons testing the projector x orientation, projector x target speed, and projector x orientation x target speed interactions. The three-way interaction was not significant ($F < 1$).

Two sets of contrasts were used to test projector x orientation effects. Mean thresholds for each projector and orientation are presented on Figure 4. The first set of contrasts compared thresholds for vertical and diagonal motion. The interaction was not significant ($F < 1$), and least significant difference (LSD) tests show that vertical and horizontal thresholds are not different from each other for either projector. The second contrast compared thresholds for horizontal movement to thresholds for vertical and diagonal movement and found a significant interaction, $F(1,36)=5.17$, $p < .05$. LSD tests show no significant difference between thresholds for horizontal vs. vertical and diagonal motion for the Sodern projector. With the General Electric projector, however, mean thresholds for horizontal motion were 0.46' greater than were the mean thresholds for vertical and diagonal motion (see Figure 4).

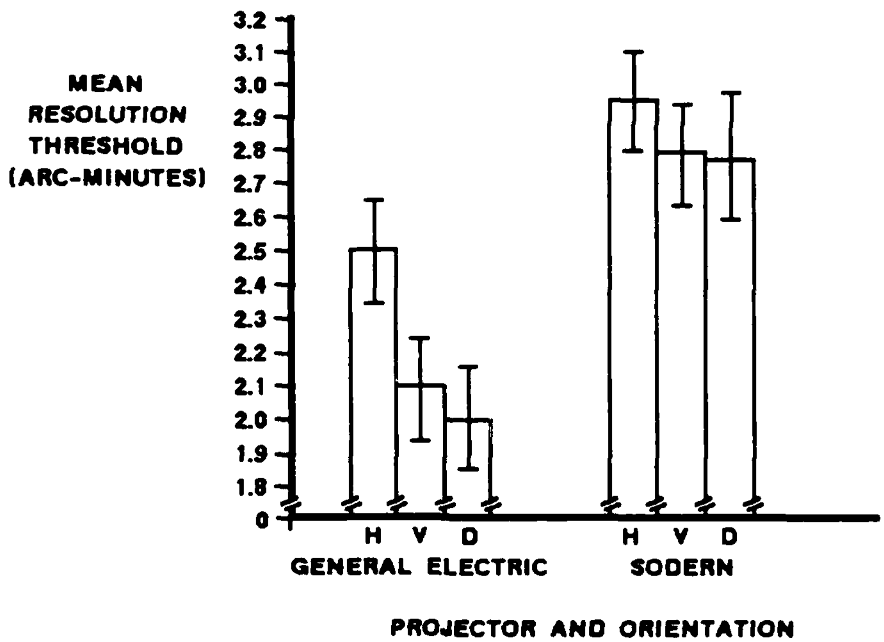

Figure 4. Mean resolution thresholds for (H) horizontally, (V) vertically, and (D) diagonally moving targets. Error bars are 95% confidence limits.

A different set of contrasts was used to analyze the projector x target speed interaction. Mean thresholds for each projector and target speed are presented on Figure 5. The first contrast compared target speeds of 3.75° and 7.5°/second on both projectors and found no interaction ($F < 1$). LSD tests show that the General Electric projector has significantly lower thresholds than does the Sodern for both speeds. Also, thresholds for 3.75°/second are significantly lower than are the thresholds for 7.5°/second for both projectors. A second contrast comparing thresholds for 7.5° and 15°/second shows a significant interaction, $F(1,36)=12.2$, $p < .001$. LSD tests indicate that thresholds for the General Electric projector were lower than were the thresholds for the Sodern at both target speeds. With the General Electric projector, however, thresholds do not change significantly from 7.5° to 15°/second, while with the Sodern projector, there was a mean increase in resolution threshold of 0.46' from 7.5° to 15°/second.

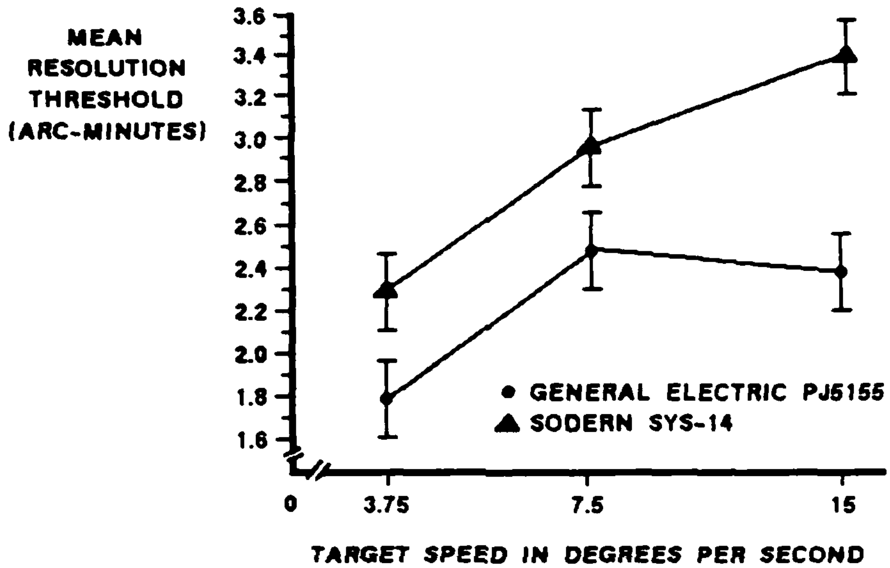

Figure 5. Mean resolution thresholds for targets moving at 3.75°, 7.5°, and 15°/second. Error bars are 95% confidence limits.

Discussion

For targets moving at any of the three speeds and orientations tested, the General Electric projector is capable of displaying finer detailed images than can the Sodern. The values of the thresholds for moving targets should not be compared to the thresholds for stationary targets in that the measurement procedures were different. In both cases, however, the General Electric projector's thresholds were lower than those of the Sodern.

The General Electric projector displayed an unexpected effect during the moving-target test. All three observers reported seeing a pattern of vertical bars on the background when tracking a horizontally moving target. This effect was visible at all three target velocities. The bars were not visible when tracking a target moving vertically or when the eyes were fixated to a point on the screen while the target moved in any orientation. Threshold elevations for horizontally moving targets confirm this effect. A possible explanation for the appearance of these bars can be found in the visual system's response to sustained and transient stimulation.

Breitmeyer and Ganz (1976) proposed that the visual system has separate channels for detection of pattern and motion. The pattern channel responds to sustained stimulation with maximum sensitivity between three and six cycles per degree; contrast sensitivity falls off for lower spatial frequencies. The motion channel responds to transient stimulation produced by image movement across the retina or by brief presentation. This channel has greater contrast sensitivity to low spatial frequencies than does the pattern channel. The General Electric

PJ5155 light valve projector is constructed with raster bars for two of the three color channels oriented vertically. When viewing a stationary target or fixating to a point on the screen, these bars are not visible. Since the observed vertical bar pattern becomes visible only when the eye scans across the field, a possible explanation is that a luminance difference exists between the vertical raster bars, which is below contrast threshold for the pattern channel but above threshold for the motion detector channel. This hypothesis has not yet been tested.

IV. SUMMARY AND CONCLUSIONS

Two light valve video projector systems were compared on their ability to display finely detailed, high-contrast images. Visual acuity thresholds were measured for stationary and moving targets under a variety of conditions. Overall, the General Electric PJ5155 was able to display higher resolution images than could the Sodern SVS-14. For two conditions, the General Electric projector's performance was poorer than for other conditions. When adjusted to maximum luminance, thresholds for stationary targets were increased. Thresholds were also increased for targets moving horizontally. In neither case, however, were thresholds greater than corresponding thresholds for the Sodern projector.

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