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TECHNICAL REVIEW AND APPROVAL

AL/CF-TR-1994-0076

This report has been reviewed by the Office of Public Affairs (PA) and is releasable to the National Technical Information Service (NTIS). At NTIS, it will be available to the general public, including foreign nations.

The voluntary informed consent of the subjects used in this research was obtained as required by Air Force Regulation 169-3.

This technical report has been reviewed and is approved for publication.

FOR THE COMMANDER

KENNETH R. BOFF, Chief
Human Engineering Division
Armstrong Laboratory

U.S. Government Printing Office 1994 580-087 00012

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*

2. REPORT DATE
May 1994

3. REPORT TYPE AND DATES COVERED
Final (November 1993-April 1994)

4. TITLE AND SUBTITLE
Visual Acuity vs Field-of-View Light Level
for Night Vision Goggles (NVG) (U)

5. FUNDING NUMBERS
PE - 62202F/63231F
PR - 7184
TA - 18
WU - 07

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Dayton OH 45431-7258

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Armstrong Laboratory, Crew Systems Directorate
Human Engineering Division
Human Systems Center
Air Force Materiel Command
Wright-Patterson AFB OH 45433-7022

10. SPONSORING/MONITORING AGENCY REPORT NUMBER
AL/CF-TR-1994-0076

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT

Approved for public release; distribution is unlimited.

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

Parameters typically used to characterize night vision goggles (NVG) are visual acuity (resolution) and field-of-view (FOV). An increase in FOV is accomplished by providing higher magnification of the image intensifier tube. However, increased magnification means that the pixels will subtend a larger angle, thus leading to lower NVG visual acuity. An inverse relationship between visual acuity and field-of-view is expected based upon this optical/geometrical relationship. This relationship should be examined as production of NVG resolution quality increases. A trade-off study examining FOV and resolution was conducted with three observers having 20/20 corrected Snellen acuity. The NVGs had fields-of-view of 40, 47, and 52 degrees, respectively. Five levels of ambient scene illumination (corresponding to output luminance levels of 0.01, 0.03, 0.08, 0.26, and 1.4 ft-L) were provided by a 2856K light source. The targets used in the study were 95+% contrast square wave targets ranging in size from 45 cycles/degree to 5 cycles per degree. A walk-back method of adjustment was employed. The results indicate that the geometric relationship between field-of-view and visual acuity is valid.

14. SUBJECT TERMS
Night Vision Devices, Visual Acuity, Night Vision Goggles

15. NUMBER OF PAGES
19

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	Unlimited

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PREFACE

The work described in this technical report was funded under Program Element 62202F Project 7184-18-07 entitled "Night Vision Devices" and Program Element 63231F Project 3257 entitled "Helmet-Mounted Systems Technology" (HMST). This report documents an initial effort by this laboratory to conduct a series of night vision goggle parameter trade-off studies which will impact future design of night vision devices by the 6.3 and 6.4 program offices. The authors wish to thank our volunteer subjects, Ms. Maryann Howes-Barbato, Mrs. Martha Hausmann, and Mr. David Sivert who graciously donated their time to participate in the study. We would also like to thank ITT Corporation of Roanoke, Virginia for their generous loan of the NVGs used in this study.

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INTRODUCTION AND BACKGROUND

Two key parameters used to characterize night vision goggles (NVGs) are visual acuity (resolution) and field-of-view. An increase in field-of-view is accomplished by providing higher magnification of the image intensifier tube. However, since the image intensifier tube has a fixed linear resolution at its output screen, increased magnification means that the "picture elements" (pixels) will subtend a larger angle with respect to the eye, thus leading to lower visual acuity when viewing through the NVGs. An inverse relationship between visual acuity and field of view of NVGs is expected based solely upon this optical/geometrical relationship (see equation 1 and Figure 1).

$$R = \frac{N}{2\phi} \qquad (1)$$

where:
- N = number of pixels across the display (no units)
- R = acuity (resolution) in cycles per degree
- ϕ = field of view in degrees

An underlying assumption of this relationship is that the observer's visual system is much better than the resolution seen through the NVGs. As NVGs are produced with increased resolution, this simple geometric relation..hip between field of view and visual acuity may no longer be valid; especially for lower light levels where the human observer baseline visual acuity is considerably poorer.

Many different methods have been used to determine visual acuity through NVGs for different contrast and light levels. These have included the use of Landolt "Cs," tumbling "Es," square-wave and sine-wave gratings, and lettered charts [1-4]. For purposes of this study we have selected the square-wave grating approach as the one that most closely parallels the theoretical basis for this study. Using this target pattern, the limiting resolution (acuity) for the NVGs corresponds to the highest spatial frequency square-wave grating (with 100% contrast) that can just barely be resolved when viewing through the NVGs. This limiting resolution can theoretically be thought of as the spatial frequency at which the modulation threshold function (MTF) of the NVG intersects the contrast threshold function (CTF) of the human observer as depicted in Figure 2. Therefore, the limiting resolution is due to both display limitations (MTF) and visual limitations (CTF). Since the visual contrast threshold function is a monotonically increasing function (for spatial frequencies higher than about 5 cycles per degree), this means the cross-over between the MTF and the CTF will take place at higher contrast levels for NVG MTFs that are higher. In the hypothetical case of Figure 2, the two MTFs shown are produced by using two different optical systems in conjunction with the same image intensifier tube. The wide field of view (FOV) MTF is exactly half of the narrow FOV MTF since the wide FOV is exactly twice as large as the narrow FOV. The implicit assumption in this example is that the optical system MTF in each case is considerably better than the image intensifier MTF. If the model of limiting resolution presented in Figure 2 is correct, then calculating limiting resolution from only geometric considerations is perhaps an oversimplification.[5-6]

If it is true that the limiting resolution can be calculated only from geometric considerations then the contrast threshold criteria would have to be constant across spatial frequency as shown in Figure 3. In this case the wide FOV NVG would have exactly one half the limiting resolution as the narrow FOV (i.e. $R_w = 1/2\, R_n$).

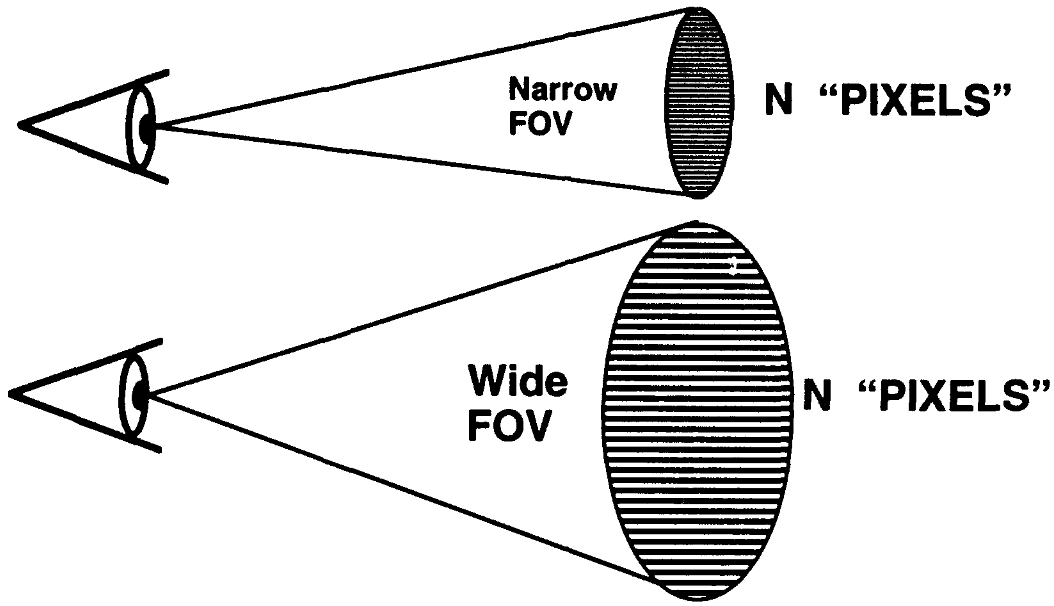

Figure 1. Geometric trade-off between field of view and resolution. Since there are a fixed number of picture elements (pixels) in the image intensifier output the angular subtense of each picture element will be larger (and therefore poorer resolution) with a wider field of view.

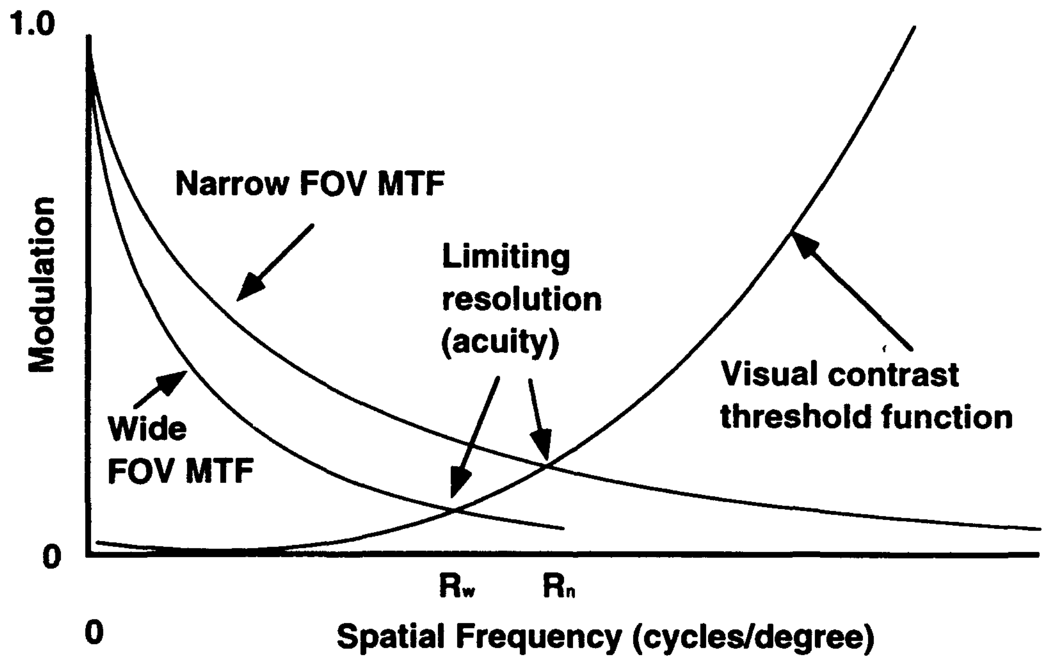

Figure 2. Determination of limiting resolution from the intersection of the NVG modulation transfer function (MTF) and the human visual system contrast threshold function (CTF). Note that even though the narrow field of view (FOV) is exactly one half of the wide FOV, the wide FOV limiting resolution is greater than one half of the narrow FOV limiting resolution due to the slope of the visual CTF.

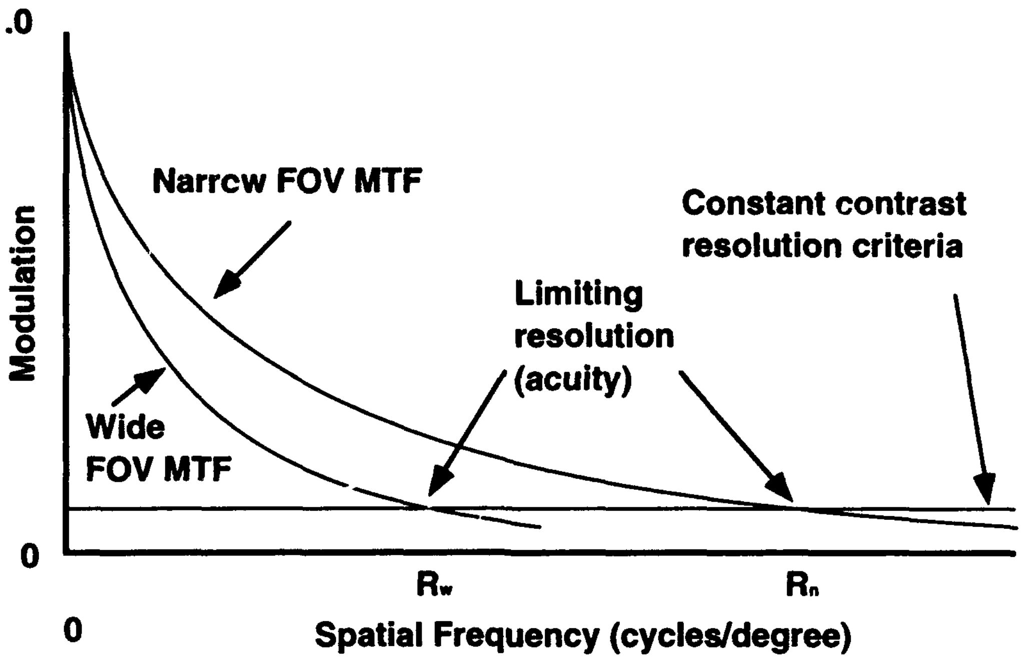

Figure 3. Modulation transfer function (MTF) of a hypothetical image intensifier tube as viewed through two optical systems (wide and narrow) with the wide field of view (FOV) set at twice the size of the narrow FOV.

To test this hypothesis, a small study was conducted using a 40 degree FOV NVG and a 47 degree FOV NVG borrowed from ITT Corp. of Roanoke, VA. The visual acuity of nine subjects was tested viewing through both NVGs for five different illumination conditions. The visual acuity was recorded in terms of Snellen acuity with the assumption that 20/20 Snellen acuity corresponds to 30 cycles per degree. Figure 4 is a graph of the results of this study. The graph of Figure 4 shows the actual average acuity obtained for the 40 degree FOV and 47 degree FOV NVGs compared with the acuity that would be predicted for the 47 degree FOV NVG based on the results of the 40 degree NVG and simple geometry. The 47 degree FOV predicted curve was obtained by multiplving the 40 degree data by (47/40) thus making acuity worse (higher Snellen fraction) by a factor equal to the ratio of the increase in FOV. As is apparent from the graph, the predicted curve was quite close to the actual curve with the exception of the very lowest luminance level. At the lowest luminance level the actual Snellen acuity was slightly better but still not significantly different ($p>.05$) than the predicted acuity that would be expected if limiting resolution can be based on the model presented in Figure 2. With this encouraging result we were ready to do a more extended study when NVGs with three FOVs became available for a relatively short time (40 deg, 47 deg, and 52 deg FOV). However, a multiplicity of problems too involved and embarrassing to expound upon here resulted in inconclusive results. With only a short time remaining on the availability of these NVGs we decided to do a brief study involving only three highly trained observers to compare the effects of luminance on the question of field of view versus visual acuity trade-off. To eliminate some of the problems that caused our inconclusive results of the ill-fated "main" study we used only one ocular of each of the NVGs and we selected a single image intensifier tube (which was moved from NVG to NVG) to be used for all conditions. The pathways of scientific investigation never run smoothly!

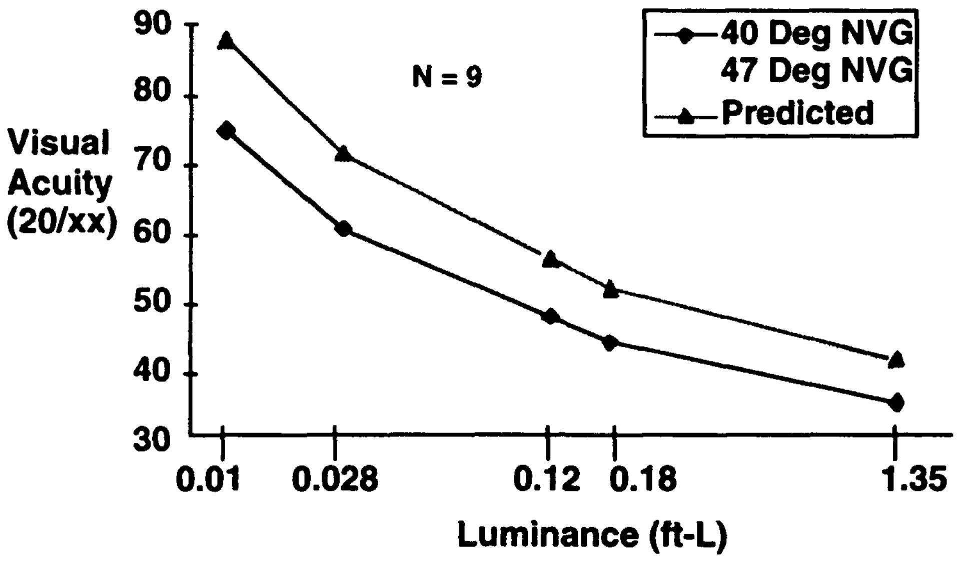

Figure 4. Average visual acuity of nine subjects for two different NVGs having 40 degree and 47 degree fields of view. Visual acuity for the 47 degree FOV NVG is compared with predicted visual acuity for this NVG based on the subjects visual acuity obtained for the 40 degree NVG.

METHOD

Observers

Three well trained observers, two females and one male, ranging in age from 33 to 42 years participated in the study. All of the subjects had 20/20 or corrected to normal binocular acuity as measured by a standard Snellen eye chart. The three observers who participated were laboratory personnel that were selected for their superior visual capability and their familiarity with focusing techniques and operation of NVGs. These were the same observers that routinely assess the resolution of NVGs acquired for evaluation.

Apparatus

The three NVGs used in the study were prototype NVGs having serial numbers of #004, 008, and 009 manufactured by ITT Corporation of Roanoke, VA. The NVGs were manufactured such that they presented intensified fields of view of 40, 47, and 52 degrees. ITT fitted the left tube of each pair of NVGs with an image intensifier which had a high signal to noise ratio. Image intensifier #80270 was chosen by laboratory personnel to be swapped among the three pairs of NVGs. This swapping method was chosen because previous pilot studies with "matched" tubes indicated variations in visual performance most likely due to individual tube differences. Prior to each experimental session, a telescope with 8x magnification was used to ensure that the left tube diopter lens focus was at about 30 feet (about 0.1 diopters). The right tube of each pair of NVGs was covered with a black cap during the experimental session. The non-dominant eye of the observer was covered with an eye patch.

NVG output luminance was provided by a 2856K light source which was filtered by aluminum aperture plates. The four aperture plates were chosen such that they would give rise to NVG output luminances of 0.01, 0.03, 0.08, 0.28, and 1.9 fL. These output luminance levels correspond roughly to what would be seen if ambient conditions were between overcast starlight and full moon. Uniformity of test target luminance was checked before and after each experimental session using a Pritchard 1980B photometer.

The test targets used in the study were linear square-wave targets similar in format to those employed by the AF 3X3A NVG Resolution Chart [7] which is widely used by aircrews to check their NVGs prior to a mission. Four test charts were employed which had alternating horizontal and vertical square-wave patterns ranging in Snellen size from 20/15 to 20/120, corresponding to 45 cycles/degree to 5 cycles/degree. Modulation contrast for the targets was approximately 95%. A typical example of one of the four test charts used in the study is shown in Figure 5.

Figure 5. Test Chart Used in Study

Procedure

Prior to viewing the test charts, the subject dark adapted for 20 minutes. After dark adaptation was complete, the subject was positioned at a distance of 30 feet from the test chart, and an eye patch was placed on the non-dominant eye. The right tube of the NVGs was covered with a black cap, and the subject looked at the test chart through the left tube using the dominant eye. (The left tube of the NVGs was set at 0.1 diopters using a dioptometer). The subject looked at the test chart and identified the smallest resolvable vertical square wave target, and then walked backwards until that same pattern was no longer resolvable. The observer then moved forward until the vertical pattern again became resolvable. The final distance from the acuity chart was recorded, and the resulting acuity was calculated using the following formula:

$$SA = \frac{30}{D} xx \qquad (2)$$

where **SA** = Snellen acuity (denominator) at threshold
xx = Snellen denominator of vertical grid chosen by observer
D = subject's distance from chart at threshold (in feet)

This walk back procedure was repeated four times for each of the five NVG output luminance levels for a total of 20 trials per session. Order of output luminance level was randomized within each testing session. Only one NVG was tested during each experimental session, with order of NVG presentation randomized. The sessions were conducted on three consecutive days for each subject.

RESULTS

The average visual acuity as a function of light level for each of the NVG systems (40, 47, and 52 deg) for the three observers is depicted in Figure 6. Qualitatively, the results are somewhat similar to the previous study in that visual acuity does get worse as light level is reduced and as field of view is increased. However, since the visual capability of the three trained observers is not uniform the grouped results of Figure 6 hides these individual effects. Table 1 is a summary of the results for each observer.

Table 1. Summary of results: average Snellen acuity for the three subjects, three NVG fields of view and five output light levels

	SUB 1			SUB 2			SUB 3		
OUTPUT LUM	40	47	52	40	47	52	40	47	52
0.01 ft-L	81	88	117	70	80	96	55	67	73
0.03 ft-L	57	64	77	55	67	70	44	53	55
0.08 ft-L	50	53	61	46	56	60	37	46	48
0.28 ft-L	36	46	50	39	47	49	30	40	41
1.91 ft-L	33	39	43	34	39	41	25	34	34

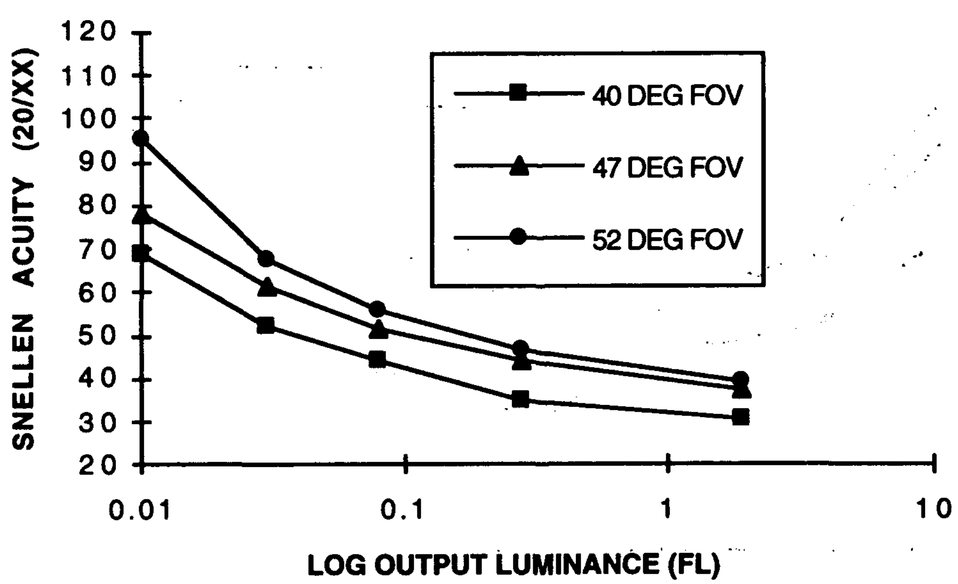

Figure 6. Visual acuity as a function of NVG output luminance for a single image intensifier tube viewed through three different NVG optical systems for the three trained observers.

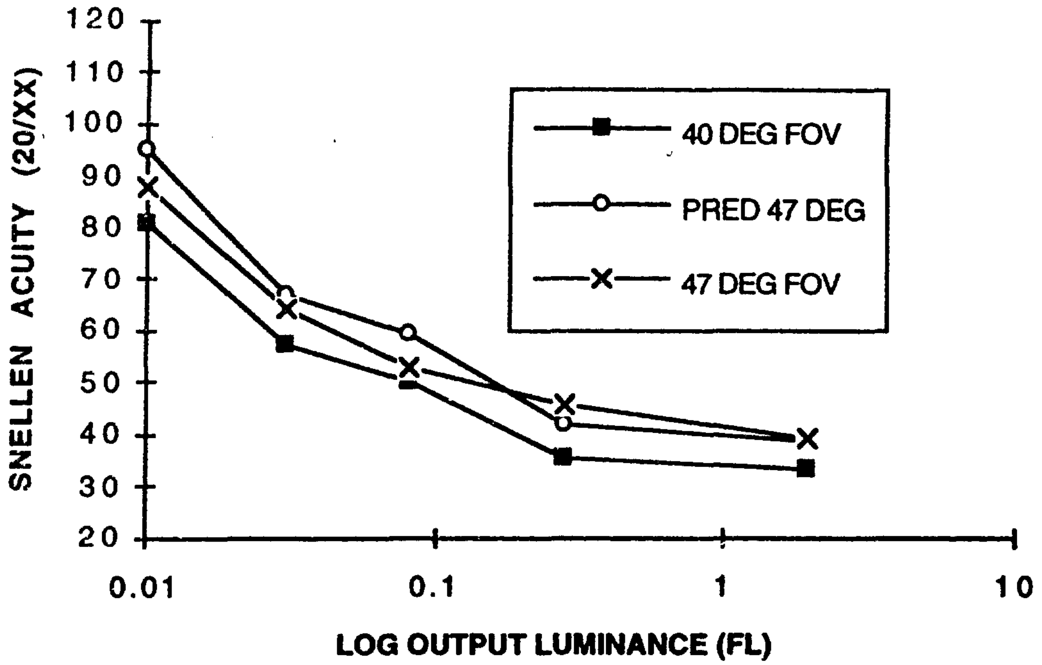

Figure 7. Predicted and actual acuity of subject one for 47 degree FOV.

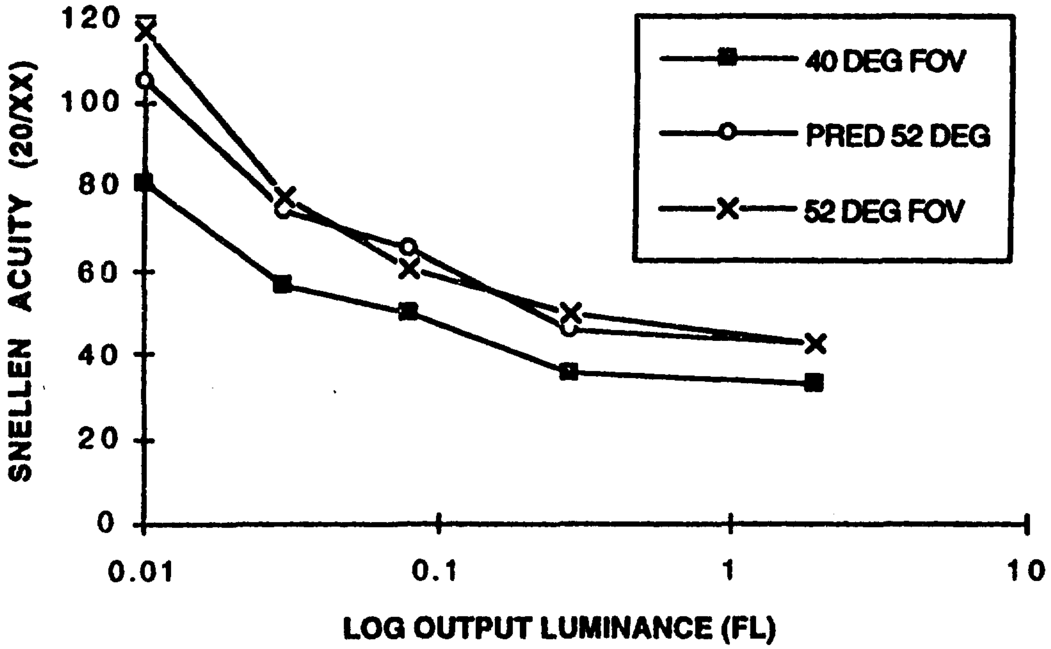

Figure 8. Predicted and actual acuity of subject one for 52 degree FOV.

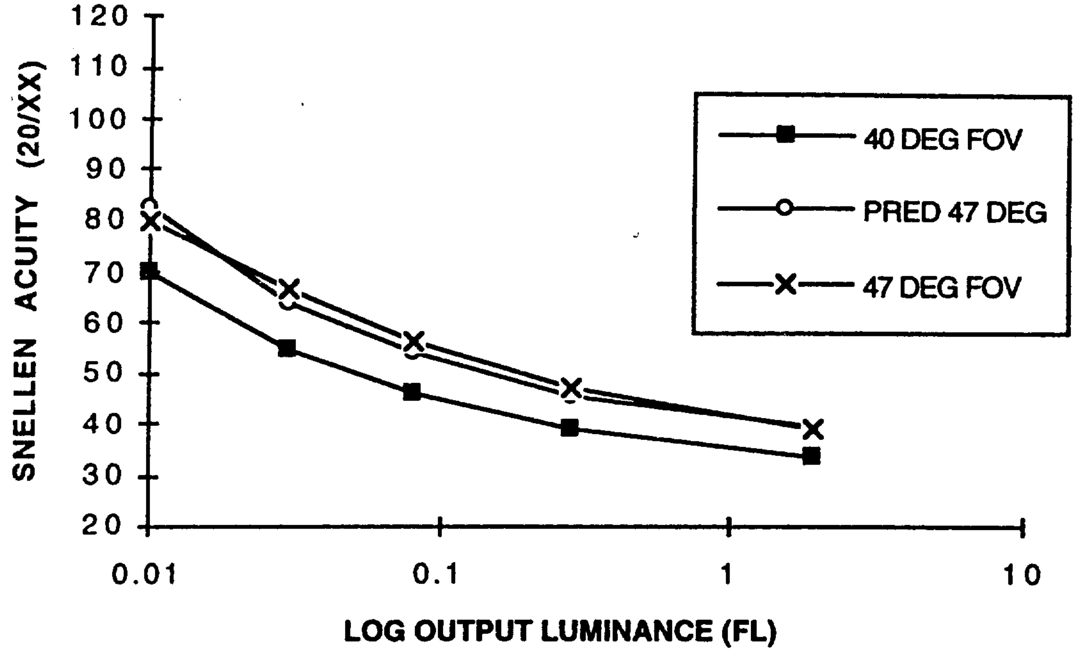

Figure 9. Predicted and actual acuity of subject two for 47 degree FOV.

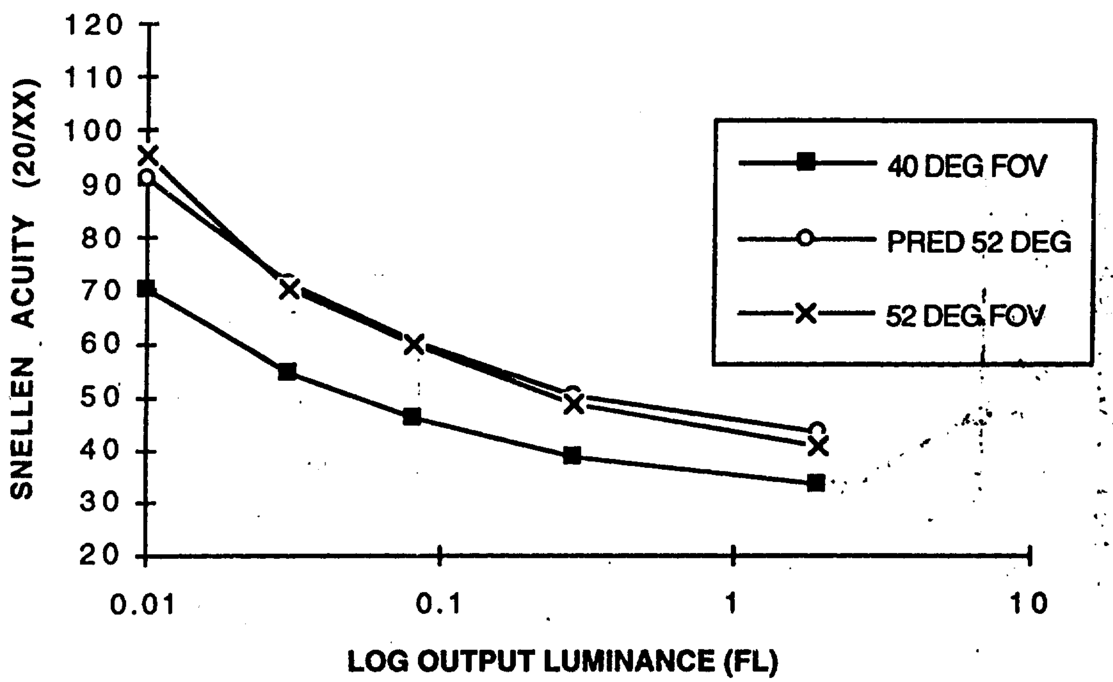

Figure 10. Predicted and actual acuity of subject two for 52 degree FOV.

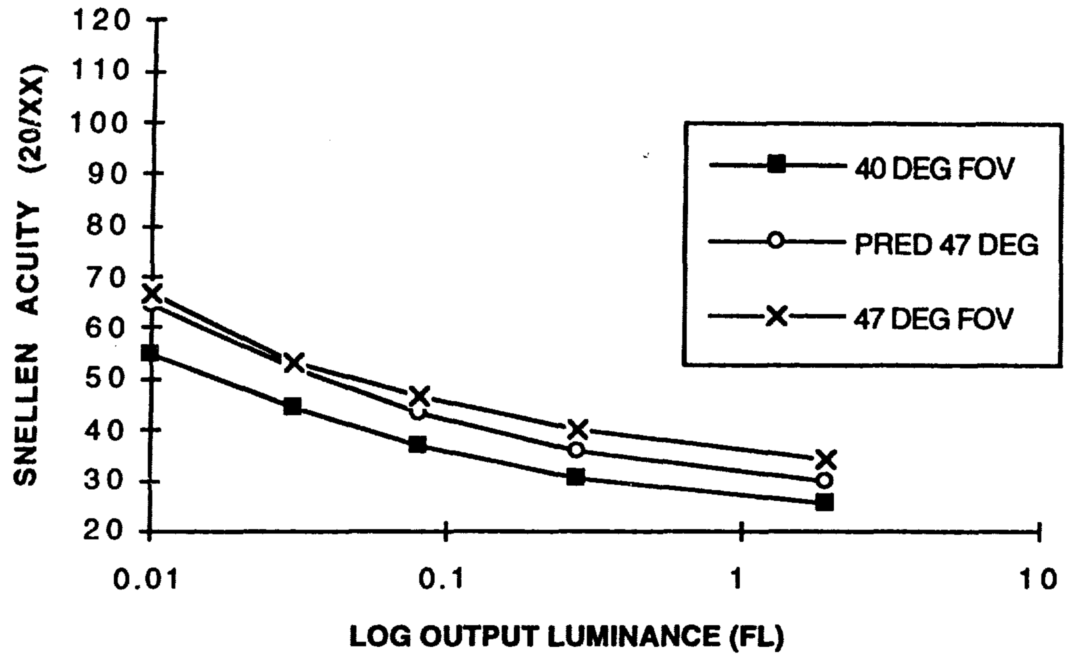

Figure 11. Predicted and actual acuity of subject three for 47 degree FOV.

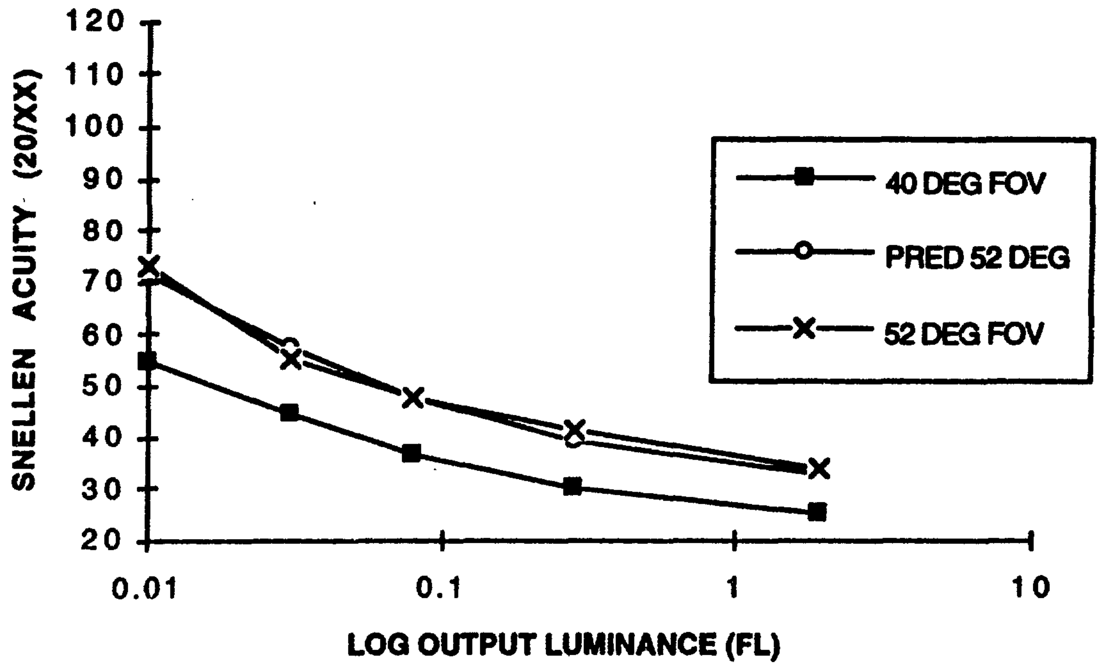

Figure 12. Predicted and actual acuity of subject three for 52 degree FOV.

DISCUSSION

For the 52 degree FOV data (Figures 8, 10 and 12) the predicted visual acuity (using geometric considerations only) came very close to the actual visual acuity for all luminances and all subjects with the exception of the lowest luminance level for observer 1. For this one point, the predicted visual acuity was notably better (lower number) than the actual acuity recorded although this difference was not statistically significant. This difference was also in the wrong direction for supporting the non uniform contrast criteria model depicted in Figure 2. For the 47 degree FOV data (Figures 7, 9 and 11), observer 2 provided results that support the geometric model very well but observers 1 and 3 results were less clean. Observer 1 was somewhat erratic as a function of luminance (we found out later that observer 1 had recently had a change of glasses prescription but used the old, undercorrected prescription during this study). Observer 3 seemed to be consistently worse than predicted (higher Snellen number) for the higher luminance levels which again is in the opposite direction from what one would expect using the visual contrast threshold function criteria model of Figure 2. The bottom line conclusion is that it appears that the simple geometric model of the inverse relationship between resolution and field of view is adequate for characterizing this particular design trade-off for current tube qualities.

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