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# Spatial Contrast Sensitivity Through Aviator's Night Vision Imaging System

(Reprint)

By

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Aircrew Health and Performance Division



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Visual acuity is often used to assess vision through image intensifying devices such as night vision goggles (NVG). Fewer attempts have been made to measure contrast sensitivity through NVGs. Such information would be useful to better understand contrast processing through NVGs under various stimulus conditions. In this study, computer-generated letter charts were used to measure contrast sensitivity through third generation NVGs for a range of letter sizes. The red phosphor of a standard color monitor proved to be an effective stimulus for third generation devices. Different night sky conditions were simulated over a 3 log unit range. The results illustrate the profile of contrast sensitivity through third generation NVGs over a range of night sky conditions. Comparison of measurements through NVGs to measurements obtained without the device but at the same luminance and color distinguish between effects of luminance and noise on contrast sensitivity.


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# Spatial Contrast Sensitivity Through Aviator's Night Vision Imaging System

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**Visual acuity is often used to assess vision through image intensifying devices such as night vision goggles (NVG's). Fewer attempts have been made to measure contrast sensitivity through NVG's. Such information would be useful to better understand contrast processing through NVG's under various stimulus conditions. In this study, computer-generated letter charts were used to measure contrast sensitivity through third generation NVG's for a range of letter sizes. The red phosphor of a standard color monitor proved to be an effective stimulus for third generation devices. Different night sky conditions were simulated over a 3 log unit range. The results illustrate the profile of contrast sensitivity through third generation NVG's over a range of night sky conditions. Comparison of measurements through NVG's to measurements obtained without the device but at the same luminance and color distinguish between effects of luminance and noise on contrast sensitivity.**

VISUAL ACUITY has been used extensively to evaluate and to describe vision through image intensifying devices (night vision goggles). These studies determined the resolution limit of night vision devices under various conditions of ambient illumination and contrast (5,6,10,14). Fewer attempts have been made to measure contrast sensitivity through image intensifying devices. Such information would be useful since acuity provides only the limit of resolution, while contrast sensitivity can provide a more comprehensive index of visual function over a range of stimulus sizes. Wiley and Holly (15) used sinusoidal gratings to measure contrast sensitivity through second generation image intensifiers over a range of spatial frequencies. Their results defined the limits of human contrast sensitivity for a range of night sky conditions.

It has been technically more difficult to quantify contrast to third generation image intensifiers. This is because third generation devices have a spectral sensitivity in the near infrared, which is largely outside the visual range. Thus, one must have quantitative control over intensity and intensity differences (contrast) in the near infrared (600–900 nm) to activate third generation devices with meaningful stimuli. In a recent study of visual acuity Kotulak and Rash (5) provided an effective stimulus to third generation devices by using a light source with spectral characteristics which simulated different night sky conditions.

In the present study a simpler approach was used to measure contrast sensitivity through third generation image intensifiers contained in the Aviator's Night Vision Imaging System (ANVIS). The red phosphor of a standard color monitor provided a spectrally narrow stimulus within the ANVIS sensitivity range. Computer-generated charts consisting of letters of different contrasts were used to measure contrast sensitivity through ANVIS over a range of letter sizes. Neutral density filters were used to produce larger changes in intensity to ANVIS to simulate different night sky conditions over a 3 log unit range. The results provide an index of contrast sensitivity through ANVIS over a range of night sky conditions. In addition, measurements through ANVIS were compared to measurements obtained without the device, but at the same luminance and chromaticity. Regression equations were derived from these data to estimate effects of luminance and noise on contrast sensitivity through ANVIS.

## METHODS

The stimuli for measuring contrast sensitivity through ANVIS were letter charts software-generated on a VGA color monitor. Only the red phosphor of the monitor was used to limit the spectral composition of the stimuli to the spectral range of ANVIS. Although ANVIS has maximal sensitivity in the near infrared (750 nm), little infrared radiation is emitted by the red gun of the color phosphor (P22) such that its output between 600–720 nm constitutes the primary stimulus for ANVIS. Because neutral density (ND) filters are fairly flat over this spectral range, it was possible to introduce large reductions in monitor intensity with ND filters. Smaller intensity

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differences necessary to generate letters of different contrast were produced by software control.

The letter charts were patterned after the Pelli-Robson contrast sensitivity chart (8). This chart consists of letters of constant size but progressively lower contrast as one reads down the chart. The measurement is designed to provide an index of sensitivity for spatial frequencies near the peak of the contrast sensitivity function. In the present study, a series of four charts was generated, each consisting of letters which differed by a 2× factor in size. Assuming that recognition of letters at threshold depends primarily on spatial frequencies of 1.5–2.5 cycles/letter (4), then the dominant spatial frequencies of the four letter charts used in this study were 0.5, 1.0, 2.0, and 4.0 cycles/degree at a test distance of 40 cm. Each chart consisted of six rows of letters with five letters per row. Due to the larger size of the 0.5 cycle/degree letters, only three letters were included in each row. Contrast was varied by altering the intensity of the letter by software control, while the background was held constant at the maximum level used (letters portrayed as decrements relative to a fixed background). Contrast was computed using the Michelson (7) equation, defined as the luminance difference between letter and background over the sum of these values, and decreased in 2× steps from 64% at the top of each chart down to 2% at the bottom. Photometric measurements of the ANVIS display in response to software-controlled steps in monitor intensity revealed excellent agreement between changes in monitor luminance and ANVIS display luminance. Thus, for uniform field stimulation, differences produced by software control of the stimulus produced equivalent differences in the ANVIS display luminance.

ND filters were used to introduce larger changes in effective stimulation to ANVIS in order to simulate different night sky conditions. The irradiance of the night sky in the spectral range of ANVIS (600–900 nm) decreases by approximately 3 log units between full moon and overcast starlight conditions (5,9). To simulate this reduction in effective stimulation to ANVIS with decreasing night sky illumination, measurements were obtained with 0, 1, 2, and 3 log units of stimulus attenuation relative to the full moon condition. These four conditions were designated full moon, ¼ moon, starlight, and overcast. The amount of monitor attenuation (3.5 log units) necessary to achieve full moon stimulation was determined by several criteria. First, the luminance of the stimulus to ANVIS (0.01 $cd/m^2$) was equal to the value specified for night sky luminance under full moon conditions (5,9). Second, photometric measurement of the ANVIS display with different amounts of stimulus ND attenuation revealed an intensity range over which the ANVIS display luminance remained constant and then began to drop with further decrements in stimulus intensity. This eventual decline in ANVIS display luminance presumably reflects the point at which the automatic gain control of the device stops operating. Inspection of the display with small increases in intensity (0.1 log steps) above this point revealed a second region at which visual noise (scintillations) appeared minimized, and further increases in intensity revealed no further improvement in perceived image quality. This, again, corresponded to 3.5 log unit attenuation of the red screen producing a stimulus with a luminance of 0.01 $cd/m^2$. This condition corresponded to our simulation of full moon illumination.

Contrast sensitivity was measured at a distance of 40 cm from the monitor to the halfway point of the ANVIS tube. All measurements were performed monocularly using the subject's right eye and the right tube of a binocular ANVIS mounted on a table. The left tube was occluded. Except for the monitor, all sources of illumination were extinguished, and the monitor intensity was reduced by placing ND filters in a filter holder directly against the objective side of the ANVIS tube. The tube was initially focused by the experimenter, and then rechecked for each subject by inspection of a small patch of vertical square wave grating centered in the monitor screen. Each chart was then displayed at the full moon condition, and the subject was asked to read as far down as possible. Guessing was encouraged and the subject was advised to take ample time to perform each letter recognition (3). The measurements were then repeated with 1, 2, and 3 log units of stimulus attenuation corresponding to our simulation of ¼ moon, starlight, and overcast conditions. Scoring was performed by letter in log contrast sensitivity units (1). Because there were 5 letters per row, and each row changed by 0.3 log units, each letter represented 0.3/5 = 0.06 log units contrast sensitivity. The largest letters had only three letters per row making each letter worth 0.1 log units. Five subjects (age 21–40; mean = 29.5 years) with normal vision and visual acuity corrected to 20/20 participated in this study.

In separate sessions, contrast sensitivity was measured on the same subjects with a stimulus that simulated the ANVIS display at each night sky condition. The same charts were used, but modulated in contrast using only the green phosphor of the color monitor to simulate the green phosphor of the ANVIS display. To determine the display luminance for each night sky condition to use in the simulation, the luminance of the ANVIS display was measured over a range of intensities produced with a series of ND filters. As noted above, this revealed a region at which the display luminance was initially constant (measured as 1.8 fL) and then declined as the automatic gain control stopped functioning. The relation between log ANVIS luminance and ND filter attenuation is shown in Fig. 1 for decreasing portion of the curve. The simple linear equation derived from these data enabled us to estimate the display luminance for each night sky simulation (1.8, 1.2, 0.2, and 0.03 fL for full moon, ¼ moon, starlight, and overcast conditions, respectively), and these values were used to simulate the ANVIS display under each condition. Contrast sensitivity was measured on each subject under these simulated conditions in the same manner described for the ANVIS measurements.

## RESULTS

In this study spatial contrast sensitivity was measured as a function of letter size, night sky illumination level, and viewing condition (ANVIS vs. simulation). A repeated-measures three-way analysis of variance re-

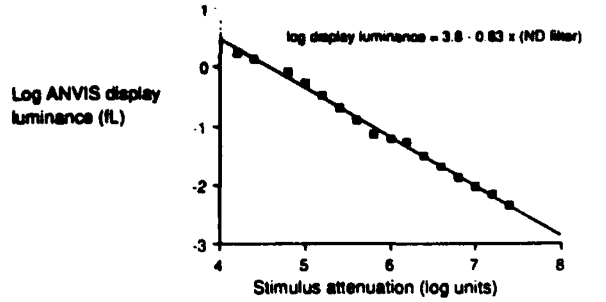


**Fig. 1. Photometric measurements of ANVIS display luminance are plotted against log stimulus attenuation produced with ND filters of different amounts. The regression equation allowed us to estimate display luminance for simulated night sky conditions which encompassed 3 log unit range.**

vealed significant main effects of letter size ($F_{3,64}$ = 122.64, $p < 0.0001$), night sky ($F_{3,64}$ = 206.96, $p < 0.0001$), and viewing condition ($F_{1,64}$ = 595.54, $p < 0.0001$), and a significant interaction between letter size and night sky for the ANVIS condition ($F_{9,64}$ = 6.42, $p < 0.0001$). We will first consider contrast sensitivity through ANVIS, and how it depends on letter size and night sky. ANVIS measurements will then be quantitatively compared to simulated ANVIS measurements to estimate effects of display luminance and electro-optical noise on contrast sensitivity.

### *Contrast Sensitivity Through ANVIS*

Fig. 2 shows mean (±1 S.E.) contrast sensitivity plotted against the four dominant spatial frequencies tested. Separate plots are shown for each simulated night sky condition (full moon, ¼ moon, starlight, and overcast). As shown in many previous studies (2,11,12,13), contrast sensitivity peaks at moderate frequencies and then declines with increasing spatial frequency. The absence of low spatial frequency attenuation in these plots suggests that recognition of the largest letters depends on both low and moderate spatial frequency components in these letters. Measurements with a spatially less complex stimulus (sinusoidal gratings) would probably show a decline in sensitivity at frequencies <2 cycles/degree.

In view of problems noted above with describing letters in terms of spatial frequency, the data from Fig. 2 were replotted in Fig. 3 as contrast sensitivity vs. Snellen letter size for each night sky condition. It is of interest that the peak of the function under optimal, full moon conditions (log contrast sensitivity = 1.5) corresponds to a Michelson contrast threshold of about 3.2%. This threshold is 2–3× higher than values reported without image intensifying devices (2,3,13). Thus, the best contrast sensitivity through ANVIS is about 2× less than one would predict from the assumed luminance and contrast of the ANVIS display. Another important feature illustrated in Fig. 3 is the reduction in contrast sensitivity with decreasing night sky illumination. Similar contrast sensitivity findings have been reported for second generation image intensifiers (15) and for visual acuity through both second and third generation devices (5,6,10,14). The present results complement and extend these findings by showing that contrast sensitivity through ANVIS decreases over a range of letter sizes with decreasing night sky illumination.

Whereas the reduction in contrast sensitivity with decreasing night sky illumination was observed over a range of letter sizes, this effect increases somewhat with spatial frequency (decreasing letter size). Fig. 4 shows mean (±1 S.E.) contrast sensitivity plotted against the four night sky conditions for the largest (20/1200) and smallest (20/150) letters used in this study. As indicated in this figure, the total reduction in contrast sensitivity with decreasing night sky illumination was greater for the smaller letters (1.1 vs. 0.6 log units), and this difference was significant ($t = 7.32$, $p < 0.005$). Hence, the reduction in contrast sensitivity through ANVIS with decreasing night sky illumination is greater for objects of smaller size.

### *Noise and Luminance Effects On ANVIS Contrast Sensitivity*

To determine factors which govern the decline in ANVIS contrast sensitivity with decreasing night sky illumination, measurements through ANVIS were compared to measurements made without the device, but at the same luminance and chromaticity as the ANVIS display. These comparisons between actual ANVIS contrast sensitivity and simulated ANVIS revealed higher contrast sensitivity in the simulated condition at all night sky illuminations. However, because we were

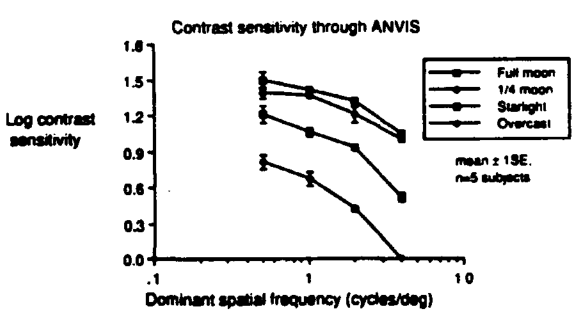


**Fig. 2. The mean (±1 S.E.) log contrast sensitivity is plotted against the dominant spatial frequency of the four letters tested. Separate plots are shown for each night sky condition.**

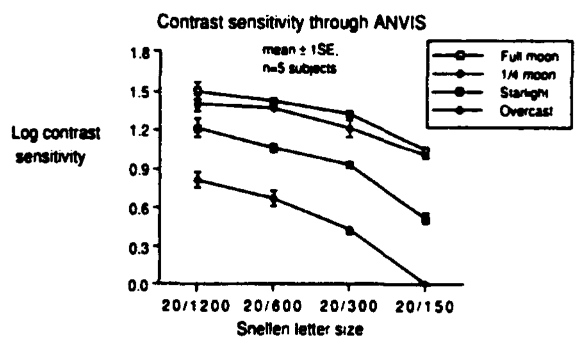


**Fig. 3. The mean (±1 S.E.) log contrast sensitivity is plotted against Snellen letter size for each of the four night sky conditions.**



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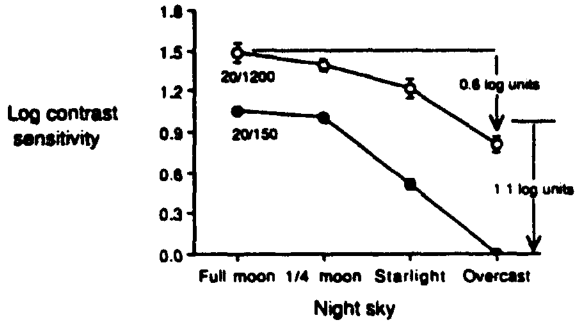


**Fig. 4. Mean (±1 S.E.) log contrast sensitivity is plotted against each night sky condition for the largest (20/1200) and smallest (20/150) letters tested. The total reduction in contrast sensitivity with decreasing night sky illumination is indicated for each letter size (0.6 log units for 20/1200 letters; 1.1 log units for 20/150 letters).**

unable to generate contrasts low enough to reliably measure simulated ANVIS thresholds for the larger letters (20/1200 and 20/600), direct quantitative comparisons were not possible in these cases. Our comparisons were thus limited to the 20/300 and 20/150 letters which approximate spatial frequencies of 2–4 cycles/degree. Inasmuch as the simulated thresholds were obtained at the same luminance and chromaticity as ANVIS, any difference between simulated and ANVIS thresholds could not be explained by luminance differences, but could reflect electro-optical "noise." To quantify this noise effect as a function of ambient stimulation, all within-subject contrast sensitivity *differences* (simulated ANVIS-real ANVIS) for 20/300 and 20/150 letters were plotted as a function of night sky illumination. Different night sky levels were assigned quantitative values of 0, 1, 2, and 3 corresponding to full moon, ¼ moon, starlight, and overcast conditions. These values are not arbitrary since each corresponds to about 1 log unit difference in stimulation to ANVIS. The least squares linear regression of the difference in contrast sensitivity plotted against night sky is shown in Fig. 5 and described by the relation:

$$\text{Difference in log contrast sensitivity} = 0.32 + 0.12 \times (\text{night sky}) \quad \text{Eq. 1}$$

This regression model is statistically significant ($F_{1,38} = 34.13$, $p < 0.0001$), and accounts for about 50% of the variability in contrast sensitivity differences between the simulated and ANVIS conditions ($r^2 = 0.47$). If we assume that scintillation noise effects are present only at lower light levels (night sky = 1, 2, or 3), then the noise term is given by the product:

$$0.12 \times (\text{night sky}) \quad \text{Eq. 2}$$

and this term drops out under full moon conditions. Nevertheless, the model indicates that even under optimal stimulation to ANVIS there is, on the average, a 0.3 log unit (2×) difference in contrast sensitivity unexplained by display luminance. Decreasing illumination below optimal levels reduces contrast sensitivity 0.12 log units per log unit reduction in stimulation.

In order to extract the effect of luminance on ANVIS contrast sensitivity, all ANVIS contrast sensitivity values for the letter sizes 20/300 and 20/150 were plotted against night sky stimulation in the manner described above. The best-fitting function to describe this relation was a second order polynomial illustrated in Fig. 6. This model of total contrast sensitivity as a function of ambient illumination was also significant ($F_{2,37} = 85.09$, $p < 0.0001$) accounting for 82% of the variation in ANVIS contrast sensitivity ($r^2 = 0.82$). Because the second coefficient in the polynomial expression was not statistically significant ($p > 0.9$), it was omitted from the equation such that total ANVIS contrast sensitivity is related exponentially to night sky illumination:

$$\text{Total contrast sensitivity} = 1.20 - 0.11 \times (\text{night sky})^2 \quad \text{Eq. 3}$$

Because in our model night sky was zero under full moon conditions, the total loss in contrast sensitivity with decreasing ambient illumination is given by the relation:

$$\text{Total contrast sensitivity loss} = 0.11 \times (\text{night sky})^2 \quad \text{Eq. 4}$$

By subtracting the effect of noise from total contrast

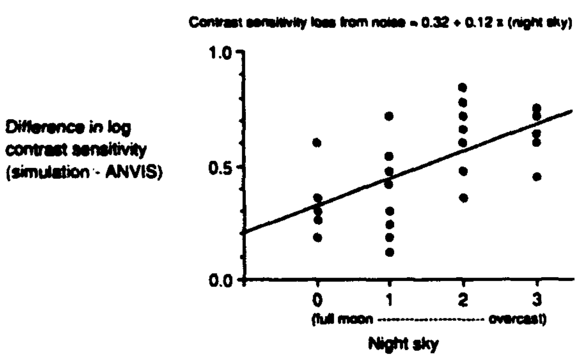


**Fig. 5. The within-subject difference in log contrast sensitivity for ANVIS and simulated ANVIS is plotted against night sky illumination where 0, 1, 2, and 3 correspond to full moon, ¼ moon, starlight, and overcast conditions, respectively. The data are for 20/300 and 20/150 letters. The least squares regression line and equation are shown.**

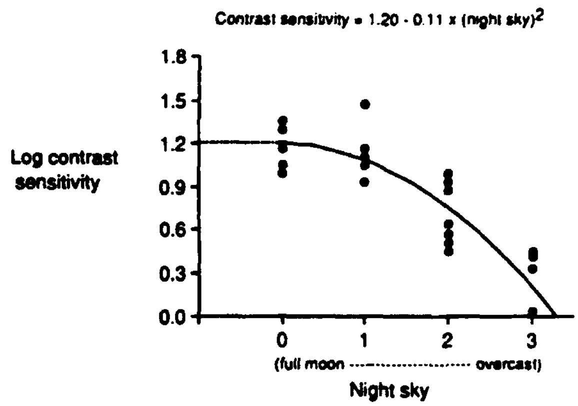


**Fig. 6. Log ANVIS contrast sensitivity for 20/300 and 20/150 letters is plotted against night sky condition as described in Fig. 5. The least squares polynomial regression function is shown with the corresponding equation. The second coefficient was omitted since it lacked statistical significance.**

sensitivity loss at each night sky condition, the influence of decreasing display luminance can be extracted. Table I shows the impact of electro-optical noise and luminance on ANVIS contrast sensitivity for various levels of stimulation.

## DISCUSSION

This study illustrates the profile of contrast sensitivity through ANVIS over a range of letter sizes. Maximum contrast sensitivity is about 2× less than sensitivity tested without the device under comparable conditions of stimulation. This suggests that, even under optimal ambient levels of illumination, contrast sensitivity is slightly attenuated through ANVIS over a range of spatial frequencies. Similar findings were reported by Wiley and Holly (15) for second generation image intensifiers, and can also be inferred from inspection of visual acuity measurements through second and third generation devices. The etiology of this small attenuation in contrast sensitivity under optimal stimulus conditions is unclear, but could reflect limiting electrical or optical properties of the device.

Contrast sensitivity decreased substantially with decreasing night sky illumination, and this reduction was observed for a range of letter sizes. These findings are consistent with previous measures of contrast sensitivity through second generation tubes (15), and with visual acuity measurements through second and third generation devices under different night sky conditions (5,6,10,14). While the sensitivity loss with decreased ambient illumination included large letters (lower spatial frequencies), the effect was somewhat greater for smaller letters (higher spatial frequencies).

A comparison of measurements through ANVIS to measurements made without the device at the same luminance and chromaticity revealed consistently lower contrast sensitivity through ANVIS over the range of night sky conditions. Since luminance was equated in the ANVIS and simulation conditions, other factors, such as electro-optical noise, impair contrast detection through ANVIS under reduced levels of illumination. Regression equations were derived from the data to quantify effects of noise and luminance on ANVIS contrast sensitivity. The reduction in sensitivity with decreasing night sky illumination was found to be a combined effect of lower display luminance and increased electro-optical noise. The development of image intensifiers which provide greater display luminance and lower noise at starlight and overcast levels of illumination will improve visual performance and enhance aviation safety. This study provides initial quantitative estimates of the impact of noise and luminance on ANVIS performance under low light levels.

It is noteworthy that the red phosphor of a standard color monitor can be used as an effective stimulus for third generation image intensifiers. Software-controlled steps in phosphor intensity provided quantitative control over contrast to ANVIS. Different night sky conditions were simulated by reducing monitor intensity with neutral density filters. This expedient approach will prove to be a useful tool for further assessment of vision through image intensifying devices in laboratory settings.

TABLE I. EFFECTS OF NOISE AND LUMINANCE ON ANVIS CONTRAST SENSITIVITY.

| | Reduction in Log Contrast Sensitivity | | |
|---|---|---|---|
| Night Sky | Total | Noise | Luminance |
| full moon | 0.00 | 0.00 | 0.00 |
| ¼ moon | 0.11 | 0.12 | 0.00 |
| starlight | 0.44 | 0.24 | 0.20 |
| overcast | 0.99 | 0.36 | 0.63 |

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