section three

Seeing the Invisible

chapter five

*On the Psychophysics of Night Vision Goggles**

William R. Uttal and Randall W. Gibb

Contents

Keywords: *light amplification, psychophysical methods, visual noise, contrast sensitivity, form detection, form recognition, visual acuity*

*This chapter contains material that has been abstracted and updated from previous publications (Uttal, Baruch, and Allen, [17]; Gibb, [7]).

5.1 Introduction

Perhaps more than any other of the remote sensing systems described in this book, the most intimate and personal is the night vision goggle (NVG). This device literally sits on the face of the observer and acts as an extended and immediate transducer of the physical stimulus in a way that is not too different from the transduction mechanism of the human eye. As such, the NVG can be considered an "extension" of the visual system and can be studied in terms of its fundamental psychophysics.

Scientific psychophysics is not a familiar concept for many engineers and other physical scientists. Psychophysics is the science responsible for the study of the relationship between human psychological responses and the physical aspects of stimuli. For over a century, a set of highly structured experimental methods (see [6,13,14,16]) has been developed that are designed to minimize experimenter and procedural bias to produce both reliable and valid measures of human performance. The discussion of our experimental results in this chapter has the additional role of introducing psychophysical methodology to our readers.

The results obtained when using the methods of psychophysics are particularly precise and valid in the study of the sensory processes. We now have very accurate measures of the sensory effects of wavelength, contrast, luminance, and many other parameters of visual perception. We know the dynamic range of vision as well as the other senses. Readers interested in these topics will find them fully described in two of our earlier books.[14,15]

The application of the highly structured psychophysical methodology to NVG technology has not been used as often as less formal experimental designs. There has been considerable study of NVGs in complex visual settings; it is only in recent years that highly controlled laboratory studies have been carried out in which the quantified parameters of the situation have been carefully manipulated and precisely measured.[2] In most earlier studies, simple comparative tests were made between situations in which NVGs were used and when they were not. Typical of the traditional approach was the work of Wiley, Glick, Bucha, and Park[18] in which the effect of NVGs on depth perception was studied using a modified Howard-Dohlman apparatus (a simple device that tested the limits of depth perception by the alignment of two vertical sticks). The basic independent variable in this case was only the presence or absence of the NVG device. Other applied problems such as the compatibility of aircraft cockpit lighting (e.g., [3]), the adjustment procedures for setting up the NVG for optimum use (e.g., [1]), or even the biomechanics of helmet loading when a NVG is attached (e.g., [5]) are still the targets of most contemporary investigations.

There is, however, another direction not often taken in this applied field, in which the goal is to consider the variables of the NVG to be continuous—to define independent and dependent variables, and then to manipulate one and measure the other. This is the classic psychophysical approach and the one we pursue in this chapter. To show how this can provide important insights into NVGs that may be obscure, we present the results of two series of experiments, both of which explore the fundamental differences between unaided normal vision and NVG enhanced vision.

5.2 A brief tutorial on NVGs

To understand the substantial effects of NVGs on human visual perception, it is necessary to understand the engineering underlying these devices that permits humans to see in nearly total darkness. NVGs provide an intensified image of scenes illuminated by ambient light in the red and near infrared part of the electromagnetic spectrum, with wavelengths varying from approximately 600 to 1000 nm. The level of ambient light in which an NVG can operate is surprisingly small. Scenes become visible in situations that may seem to be totally dark to even a moderately dark adapted eye. Reflected star light is sufficient illumination to produce a bright image. An example of a light-amplified image appears in Figure 5.1.

It should also be appreciated that NVGs work only because they are used at night. During the daytime, the huge amount of red and near infrared light produced by the sun would swamp the devices. It is only when the amount of this radiation is small that the device will work; fortunately, that is also only when it is needed. The near infrared region is also a desirable range to work in because it greatly simplifies the engineering complexity of the device. Longer wavelengths of infrared radiation would require refrigerated sensitive media.

Figure 5.1 A light-amplified scene showing forested area including a workshed (background) and a rock pile (foreground). See color version of this figure in the color section following page 114. (Image courtesy of American Technologies Network Corporation.)

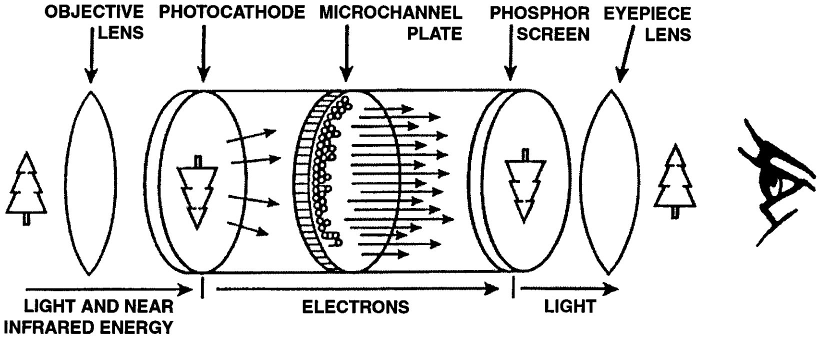

Figure 5.2 A diagram of a typical night vision viewing device.

NVG technology depends upon principles of photoelectric emission and multiplication that are well known. As shown in Figure 5.2, ambient light enters the goggle through an objective lens that brings the image into sharp focus on a photocathode—a source of photoelectric electrons. The relatively small number of electrons emitted from the photocathode is then amplified and accelerated by an ingenious device called a microchannel plate. It is this device that mainly accounts for the fine resolution of the scene achieved by an NVG. The microchannel plate maintains the spatial focus of the image but greatly increases the number of electrons that were originally generated by the infrared light. The enhanced output of the microchannel plate is then projected, under the influence of an accelerating voltage, onto a phosphor screen which converts the stream of electrons into a perceptually useful luminance level. The final image is viewed directly through an eyepiece lens.

The emitted visible light, typically of a greenish hue, varies only in intensity and, thus, although not literally monochromatic, mimics a black and white colored image more than it does a fully colored one. The key factor, however, is that the increase in both the total number of photoelectric electrons and their velocity results in an intensified image on the NVG that can be 3000 times or more brighter than the original scene. Output luminances from a typical NVG can be as high as 5 or cd/m^2 (candles per square meter). Image resolution is diminished compared to a daylight scene but can be improved by placing the objective lens, the photocathode, the microchannel plate, and the phosphorescent screen close together. The entire system may be only a couple of inches long in a well-designed modern system such as the F4949 or the AN/PVS-7.

NVGs employ an automatic brilliance control (ABC) feature that acts to maintain a constant overall image luminance by decreasing the gain across the microchannel plate when the total input light level exceeds a predetermined threshold. This helps to minimize the blooming or veiling when an intense light source emits energy in that portion of the electromagnetic spectrum in which the goggle is sensitive. Otherwise, the details of the image would be obscured or (occasionally) the display phosphor burned.

The main advantage of NVG devices is that they raise scene luminance sufficiently to allow the observer to see in what would otherwise be visually a completely dark situation. Unfortunately, this enormous advantage is counterbalanced by a number of image distorting and degrading visual effects that pose serious challenges to the human perceptual system. It must be clearly understood that NVGs do not provide anything close to normal visual conditions. These distortions must be understood by the user if these devices are to be used in effective ways and to avoid demanding more from the technology than should be reasonably expected. These distortions are not always understood by the user. A common problem is that the user may get overconfident when using these image enhancing devices, creating a feeling of invincibility. In reality, the typical NVG provides a visual experience that is drastically deficient compared to normal daylight vision.

Understanding the perceptually relevant properties of existing devices is also important for the design of future generations of NVGs so that they can be progressively improved. All too often, the design engineers responsible for improving these devices are oblivious to the implications of engineering changes for these primarily visual devices.

The list of visual distortions introduced by the use of NVG is not long, but includes some parameters that are familiar to vision scientists, if not to engineers. It includes:

1. Monochromatic (typically greenish) images
2. Low contrast (especially at high luminance levels because of the ABC)
3. Low resolution
4. Nonlinear luminance changes
5. Scintillation interference
6. Geometrical artifacts (Honeycomb patterns)
7. Susceptibility to interference from other sources of ambient light other than that which is desired such as lightning
8. Image persistence effects due to the long decay time of the phosphors used in NVGs; this distortion can lead to trails as the field of view of the NVG is swept across point sources
9. Reduced depth perception, both because of a reduction in monocular cues and binocular cues such as stereopsis. (There is still uncertainty in the literature concerning the impact of NVG on stereoscopic viewing. It is not yet agreed that it is possible to have good stereopsis with this viewing device, but it is clear that the absence of this cue to depth perception has played a role in some formation flying accidents, particularly with helicopters.)

Clearly, NVGs do not provide anything like normal views and extensive basic research is needed to understand the fundamental limits and aberrations that are introduced into this very different kind of visual task. In this chapter, we report two series of psychophysical studies that we carried out to study NVG vision. The first used a model display in which we simulated the distortions that were introduced by NVG so that they could be studied under well controlled laboratory conditions. It was aimed at gauging the effects of the luminance, contrast, and scintillation distortions just mentioned. The second series was concerned with contrast sensitivity and the influence of colored ambient light, a common problem in aircraft cockpits. The second series, unlike the first, used a real, rather than a simulated NVG. Because of the application of precise psychophysical techniques, both series led to an enhanced understanding of how a human perceives when using these devices.

5.3 *Experiment Series I: psychophysical studies using an NVG simulation*

It is difficult to manipulate the parameters of actual NVG devices in a way that permits controlled psychophysical studies. For example, the ABC overrides any effort to manipulate contrast or luminance by the experimenter. Therefore, we developed a simulation of the device. An important issue when one substitutes a model for the reality is, how close does the model we use fit the actual system? There will be some obvious discrepancies. For example, the "greenish" appearing emission spectrum of night vision displays is different from that of the black-and-white computer display used in this study. The critical issue, however, is that both the model and the actual devices display images that vary only in luminosity and are essentially constant in their respective chromaticity.

The range of luminosity values (2 to 14 cd / m^2) used in the experiments reported here overlapped the maximum luminance range required for night vision devices by the U.S. Air Force (USAF) (2.77 to 5.54 cd / m^2). [Values obtained from USAF specifications document MIL-A-49425(CR).] Direct measurements were made with a Tektronix J17 photometer of the luminance of an ITT ANVIS model 6(4) night vision system. Luminance values varying between 4.0 and 4.5 cd / m^2 for a white field and 3.3 to 3.7 cd / m^2 for a field containing high contrast gratings were obtained. Since our experimentally controlled luminance values (2 to 14 cd / m^2) bracketed these empirically measured values, our model system both conforms to and exceeds the actual photometric luminance levels obtainable displayed by NVGs. Since the light levels of the NVG are technically constrained, it would not have been possible to use them as the experimental tools for exploring the luminance variable.

The viewing region defined by the visual interference was 512 $\times$ 480 pixels and 10.9 $\times$ 12.2° of visual angle in extent on the face of an Apollo 3000 graphic work station. As a general calibration procedure, the luminance of a test pattern consisting of fully illuminated screen (i.e., all pixels set to white) was regularly adjusted to 36 cd / m^2 with the Tektronix photometer in the presence of the ambient veiling light.

There is one major way in which our simulation differed from the real viewing situation. We chose to use a brief exposure (100+ msec) rather than the continuous observation time typical of real NVG usage. Brevity of exposure is traditionally used as technique to separate the psychophysical properties of preattentive visual processes from the processes involved in long term attentive scrutiny or search within a complex visual scene. Unless this form of temporal degradation is used, it would be impossible to distinguish the immediate psychophysical effects in which we were interested from those "higher level" and longer-term search processes.

5.3.1 Stimulus materials

A typical stimulus frame (one of two sequentially presented in the same position showing the appearance of the image presented in moderate amounts of visual interference) is shown in Figure 5.3.

The task required the observer to detect a simple geometrical form (e.g., a square, see Figure 5.3) outlined by illuminated pixels embedded in a background of variable amounts of randomly positioned illuminated pixels. The randomly illuminated pixels tend to degrade the image. As their density

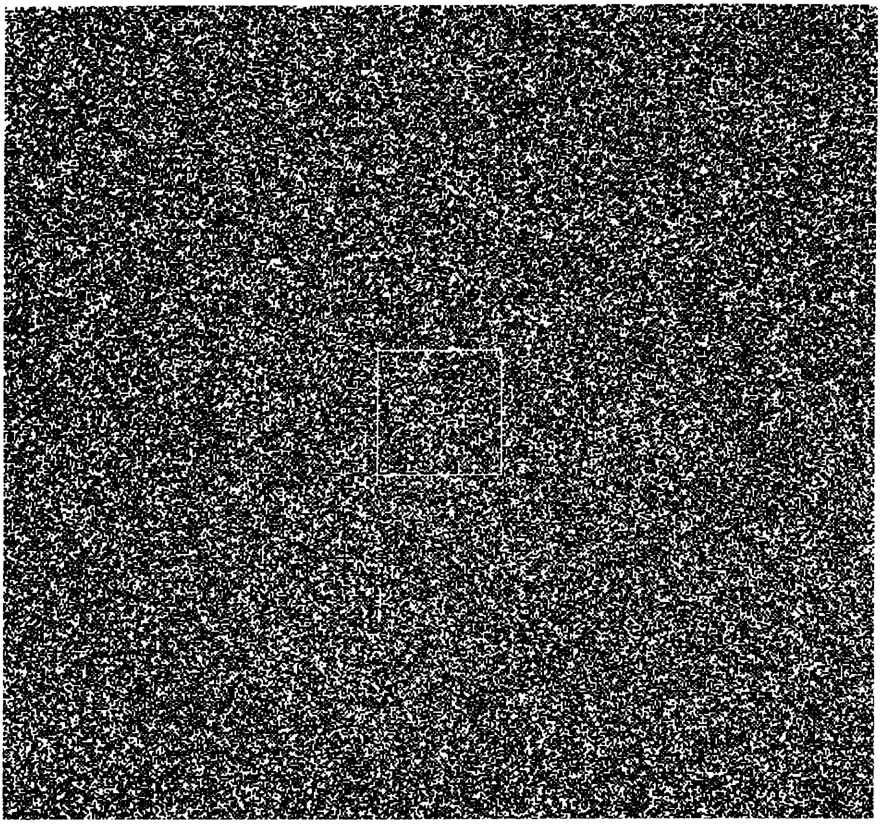

Figure 5.3 A typical stimulus frame showing one of the target stimuli embedded in visual interference with a density of 40%.

increases, these “visual noise” dots make the detection task more difficult in a manner that is analogous to the degradation of target detectability in night vision viewing devices when scintillation artifacts increase. The density of this visual interference is defined as the proportion of illuminated pixels (i.e., pixels set to the “white” level for each condition of this study). The visual interference was generated by applying a probabilistic rule that determined whether a white dot was placed in each of the 245, 760 pixel locations of the viewing region on the display screen. The higher the probability, the more pixels were present and the more difficult it is to detect the target stimulus. Of course, as the number of illuminated pixels increased, so did the overall luminance of the screen. As we shall see later, however, overall luminance has a negligible effect on this task.

The target stimuli usually consisted of samples chosen from a library of three different sizes of four outlined polygonal forms (i.e., a triangle, a square, a pentagon, and a hexagon). The outlines defining the forms were one pixel wide so the forms were constructed from what appeared to be fine lines.

In each trial, the target stimulus was placed at random anywhere within the region of the screen defined by the visual interference. A limit of displacement was used to avoid any stimulus being clipped as it extended over the edge of the visual interference-defined viewing region. The variations in shapes, sizes, and positions were utilized to add uncertainty to the observer’s task and to avoid detection based on partial features or familiarity with a repeated location. Large differences were observed in the detachabilities of the different shapes. However, most of these differences were attributable to artifactual distortions due the staircase aliasing of diagonal lines. Outline forms of the kind used here do not, therefore, permit us to answer the question of the effect of form on detection. It should be noted that this is a distortion produced by our simulation and would not occur in the actual NVG where the resolution is somewhat finer.

5.3.2 General procedure

Observers signed into each session by typing their names on the computer keyboard. This initiated a sequence of actions in which the experiment assigned for that session was loaded and the computer configured to present the appropriate stimuli.

The experimental task utilized a two-alternative, forced-choice design. Observers were instructed to specify which of two sequentially presented stimuli in each experimental trial contained a target form. Since the observers were not required to specify which form had been presented, this was a detection task. Although the form of the target might affect detection, no form recognition or discrimination response was required. At random, either the first or second of the two stimulus presentations contained the target form. The other consisted solely of visual interference.

A trial consisted of a sequence of visual displays on the CRT. The observer was first presented with a fixation point at the center of the display. This was followed by a 500 msec blank period. The first stimulus display was then presented for 100 msec (plus the persistence time of the display). A blank screen was then presented for 1025 msec. It was followed by the second stimulus display; the temporal duration of which was the same as the first. Following another 500 msec blank period, the observer was presented with a question mark and was instructed to only then respond by pushing the left or right mouse button to indicate that the first or second display, respectively, appeared to contain the target stimulus. As soon as the observer responded, the fixation point for the next trial was displayed and the cycle repeated. Observers were instructed to rest as needed during the course of the experiment by simply delaying their response. The activity level of the observers was monitored in an adjacent room by means of another computer display.

The dependent variable in each case was the percentage of correct responses (i.e., the proportion of the time that the observers correctly specified in which of the two sequential presentations the target form had been inserted). Since this was a two-alternative paradigm, purely random behavior associated with total nondetectability would produce a score of 50%. Scores above 97% were considered to represent perfect detectability diluted by a few random response selection errors or flagging attention. Furthermore, since this was a forced choice procedure, variations in the observer's personal criterion level were tightly controlled. This is a very important advantage of this method—observers are forced to make a positive decision and, therefore, are not permitted any uncontrolled flexibility in deciding where their threshold for accepting or rejecting the perceptual existence of a stimulus lay.

5.3.3 Experiment 1

In the initial experiment, the density of the visual interference was the main independent variable. In our simulation, this interference is analogous to the scintillation artifact. The percentage of illuminated pixels varied from 20% to 60% in 10% steps. All twelve stimulus polygonal forms (3 sizes $\times$ 4 shapes) were used in this experiment and, as noted previously, presented in random positions in the field of visual interference.

Figure 5.4 plots the major results of this experiment averaged across sizes and for the three stimulus sizes separately. Observers are able to read through the visual interference virtually perfectly at low (20%) interference density levels. Performance at this interference level is in the high 90% range for the detection scores. As the visual interference density increased to 60%, there was a progressive decrease in performance to a detection score of 58%. Throughout Experiment 1, for the range of stimulus sizes we used, Figure 5.3 also shows that the larger the stimulus, the more detectable it was. We

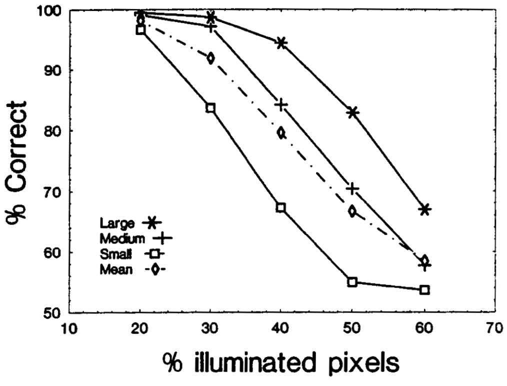

Figure 5.4 The results of Experiment 1 of Experiment Series I, showing the effect of variations in the visual interference density on target detection for the three stimulus sizes separately and for the mean values of the scores for the three sizes.

believe, however, that this size effect is largely determined by the length of the component lines in each form rather than its overall geometrical form.

Long term learning effects on performance were not measured, but supplementary experiments did show improvements in performance in some, but not all, stimulus conditions. Since all conditions were present in each daily session, learning effects were controlled over the course of each experiment.

5.3.4 Experiment 2

In Experiment 2 we varied another of the variables specifically identified as being significant in the operation of amplified night vision viewing devices—the overall luminance of the image. We asked: "What is the effect of image luminance on the detectability of the outline polygonal target stimuli?" This is an important issue because it is often the case that when image luminance is increased, artifacts (e.g., the hexagons produced by the fiber optics of the microchannel plate and reductions in image contrast) are spuriously introduced. Although, some readers may have an *a priori* intuition that increasing the luminance of the screen should improve performance during amplified night vision tasks, this cannot be taken for granted. Luminance-related artifacts are countervailing conditions that suggest that simply increasing luminance should not be done indiscriminately.

It should be noted that our display did not insert any other of the artifacts that the actual night vision viewing devices do. Therefore, the results of this experiment are relatively "pure" estimates of the effect of variation in image luminance unencumbered by these other artifacts.

Luminance was varied in this experiment by adjusting the binary code for image gray-level scale within the computer program and indirectly calibrated with a Tektronix photometer. This luminance level was varied in random order between five binary coded pixel gray levels (112, 144, 176, 208, and 240). These binary codes corresponded to luminances of 1.6, 3.6, 6.4, 9.8, and 13.5 cd / m^2, respectively, as measured on a static image of a 42% visual interference density field at each of the luminance levels. These values determined the luminance of both the pixels in the interference and the target stimuli. We did not use lower display luminance, in order to avoid floor effects with the smallest target stimuli utilized.

This means of controlling stimulus luminance (instead, for example, of using neutral density filters) was chosen to meet the needs of a subsequent experiment in which the luminance of the stimulus pattern and the visual interference would be manipulated separately.

The same 12 shapes and sizes of polygonal stimuli used in the first experiment were also utilized in the second experiment. A normative visual interference level of 42% illuminated pixels was used in this experiment to adjust the performance level to about 80% as described in the results of Experiment 1.

Figure 5.5 plots the averaged results for the three stimulus sizes utilized in this experiment for the three stimulus sizes. The main result is a gradual, but relatively slight, diminution of the detectability scores with decreasing luminance. The decline in detectability is not nearly as profound as that produced by increases in the visual interference density obtained in Experiment 1, nor, as we shall see, as that produced by contrast difference between the target stimulus and visual interference as obtained in Experiment 3. In fact, the total decline in detectability over the full range of luminance used in this experiment is comparable to that produced by only a few percent change in visual interference density, as shown in Figure 5.3.

The results of this experiment confirm that the human visual "gain control" mechanism is well adapted to accommodate wide ranges of stimulus

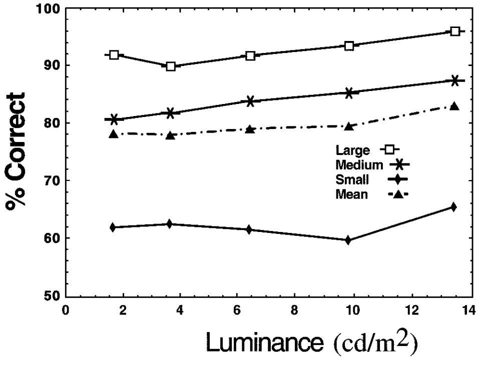

Figure 5.5 The results of Experiment 2 of Experiment Series I, showing the minimal effect of variations in overall display luminance for the three stimulus sizes separately and the mean values of the scores for the three sizes.

luminance with minimal effects on performance, at least in this simulated viewing situation. This human property is complemented by the automatic brilliance control (ABC) of the night vision devices to further mitigate any putative effects of display luminance on performance. In other words, there may be little to be gained by engineering higher luminance NVGs.

5.3.5 Experiment 3

Another major display image factor impacting on target stimulus detectability is the contrast between the target stimulus and the background.[2] The purpose of Experiment 3 was to measure the effect of contrast when the visual system was challenged by the presence of visual interference. We controlled this important contrast variable by using different coded gray-level values for the visual interference and the target stimuli, respectively. In this experiment, as previously, the visual interference density was kept at 42% illuminated pixels and was displayed with a coded gray-level luminance level of 240. The independent variable was the gray-level luminance of the target stimuli, a factor which was randomly selected in each trial from five coded pixel values (176, 192, 208, 224, and 240). These values correspond to photometric luminance measures of 6.4, 7.9, 9.8, 11.3, and 13.4 cd / m^2, respectively. These values were measured with the photometer from a static image consisting of 42% visual interference.

All four of the polygonal stimulus shapes were used, and sequential presentations plotted in random positions on the screen to add uncertainty. However, only the medium size stimuli were used in this experiment because of the proliferation of experimental conditions.

The results of this experiment are shown in Figure 5.6. Unlike the relatively modest effect of overall image luminance (over a wide range of 1.6 to

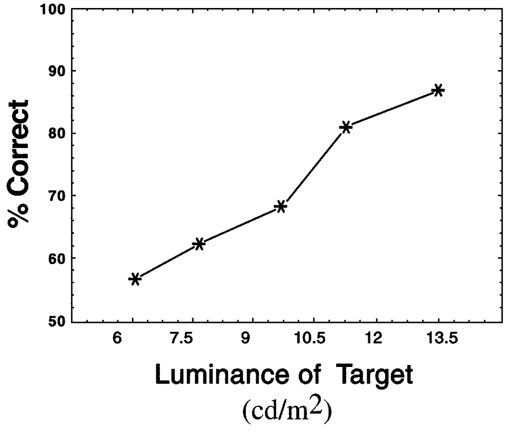

Figure 5.6 The mean values of the results of Experiment 3 of Experiment Series I, in which the luminance of the target stimulus was reduced to increase the contrast between the them and the visual interference.

13.5 cd / m^2), the effect of varying the contrast by reducing target luminance (over a narrow range of 6.4 to 13.5 cd / m^2) was profound. Performance declined from 87% to 57% over this reduced range of target stimulus luminance ranges.

This result is anomalous compared to the usual influence of contrast. Increasing contrast usually increases detectability. It may be that some new or secondary effect is overshadowing the usual kind of contrast effect. One possibility is that the bright visual interference pixels are disrupting the geometry of the stimulus lines. This disruption may overwhelm what would have been a more typical contrast-driven improvement in performance. Whatever the explanation, the result stands: with this stimulus type, reduction in target pixel luminance relative to the luminance of the visual interference definitely reduces detectability.

5.4 Experiment Series II: the effect of NVG viewing on contrast sensitivity

In the second series of experiments, we had two goals; one was general and the other specific. Our general goal was to demonstrate the value of a precise psychophysical methodology in understanding the function of complex display devices like the NVG. Our specific goal was to examine the effect of NVG viewing on the contrast sensitivity function and to evaluate the effect of colored ambient lighting on NVG viewing. Although visual acuity (VA) is the standard form of measuring visual performance among pilots in the U.S. Air Force, it has previously been noted that VA remains constant despite a substantial loss in visual contrast. Therefore, we hypothesized that contrast sensitivity (CS) might be a better measure of visual spatial acuity under degraded viewing conditions. Our research investigates and compares both NVG-aided CS and VA performance with two different kinds of incompatible cockpit lighting (and one baseline condition) used as a degrading parameter much in the same way we used the visual interference in the first series of experiments. By incompatible lighting, we refer to ambient lighting that interferes with the advantages gained when one uses an NVG, typically because of overlapping spectral curves. The fact that the green light used in this experiment was similar to that emitted by the NVG made it particularly important that its interfering effects be understood and the traditional VA measure obscures the performance decrement. We show that the combined assessment procedures in which both CS and VA were measured provided a superior assessment of NVG aided visual performance in conditions of ambient light.

5.4.1 Stimuli and apparatus

A modified Class B NVG filter was used on an ITT F4949D NVG. This combination yielded a 50% spectral response at 665 nm and 1% spectral response at 545 nm. Two charts were used to measure VA. The first was the standard

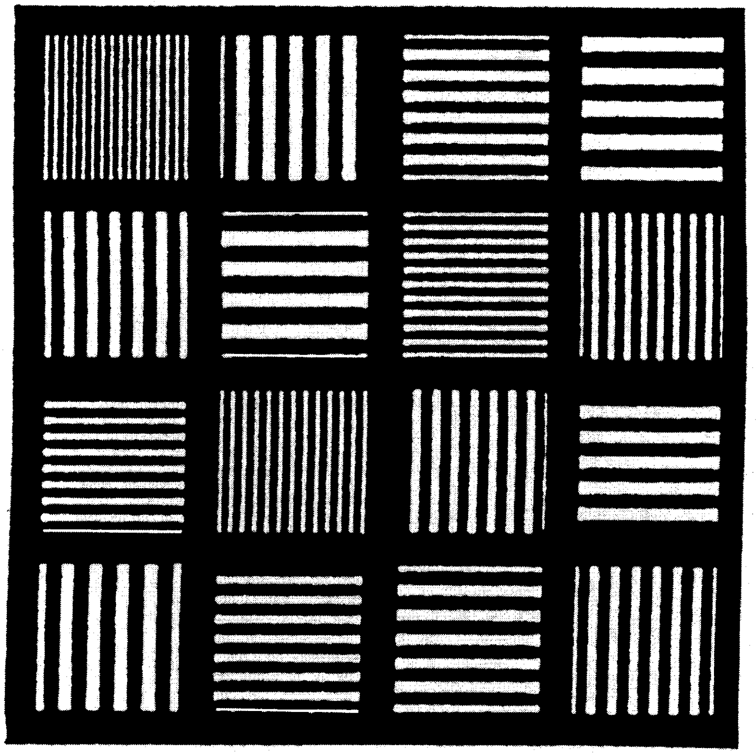

Figure 5.7 The standard NVG resolution test chart described by Reising, Antonio, and Fields.[12]

NVG Resolution chart described by Reising, Antonio, and Fields[12] used to assess NVG-aided VA. This is shown in Figure 5.7.

The second was the USAF 1951 Medium Contrast Resolution Resolving Power Target (otherwise known as the Tri-bar Chart). This is shown in Figure 5.8.

Both charts were positioned randomly in orientation but at a constant viewing distance of 6.1 m from the observer.

Because of the unsuitability of commercially available spatial contrast sensitivity charts, a special CS chart for NVG-aided vision was developed for this research. Two factors had to be considered in the design of this special chart—the ranges of the spatial frequencies and the contrasts suitable for NVG studies. The range of contrasts to be used should range from a qualitative "easily discernible" to "unable to see." The best NVG-aided VA chart previously reported had been in the Snellen eye chart range of 20/45 to 20/60 (equivalent to performance on 13 to 9 c/deg gratings). This value, therefore, defined the highest spatial frequency to be used. The sharp low-frequency fall-off in the standard (high illumination) CS response specified that 3 c/deg would be a satisfactory lower limit for our new chart. The final version of the

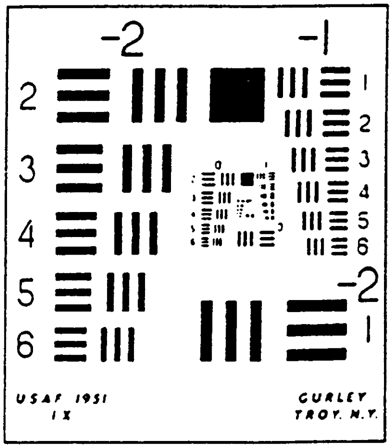

Figure 5.8 The USAF Medium Contrast Resolution Resolving Power Target. (The Tri-bar Chart.)

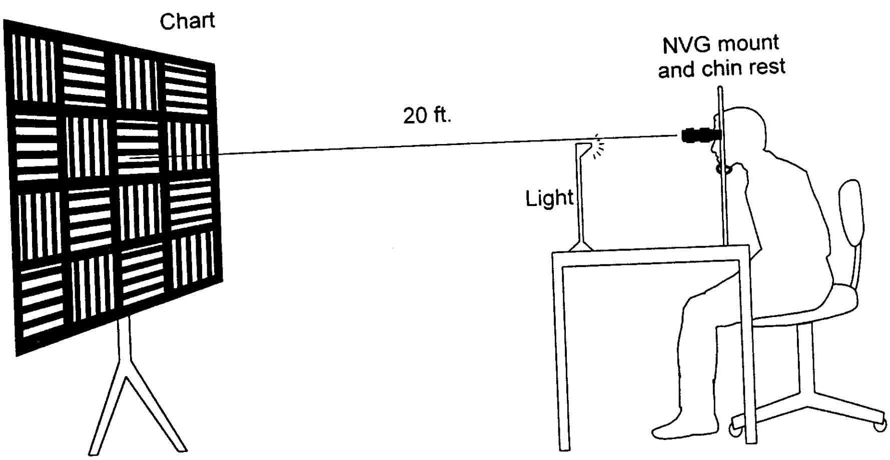

Figure 5.9 A diagram of the experimental apparatus used in Experiment Series II.

chart we developed consisted of 16 levels of contrast for each of the three test spatial frequencies we used—3, 6, and 12 cpd, respectively.

All visual performance charts were illuminated at the equivalent of starlight viewing conditions by a Hoffman Engineering Corporation LS-65-GS integrating sphere. The sphere provides near uniform light distribution on the charts. The illumination level was measured with a Photo Research PR-1530AR NviSpot radiometer fitted with a Class B filter.

The supplemental light source (simulating the ambient light from instruments in a aircraft cockpit) was positioned as shown in Figure 5.9, a diagram of the experimental apparatus. This supplemental light source was colored (in two of the three conditions) by inserting a filter in front of a calibrated incandescent bulb. The green filter that we used was a standard NVIS Green B(NV-2GB) and the red filter was a standard NVIS Red (NV6RC-10). A third lighting condition—no ambient lighting—was also used to establish a baseline condition.

5.4.2 Procedure

All observers were evaluated in a viewing lane that was approximately 10 m long and 2 m wide. Prior to dark adaptation, observers were instructed how to read the USAF 1951 Tri-bar Chart in normal room lighting. During this pre-adaptation period, the observer reported the minimum resolvable pattern from a distance of 6.1 m. This preliminary procedure ensured that each observer was familiar with the chart and also provided an unaided baseline VA score. The observer was then seated and the room lights extinguished in the viewing lane. Observers were then allowed 10 minutes to dark adapt and to set up and focus the NVG apparatus. Measurements were then made using all three of the test charts (the NVG Resolution Chart, the USAF Tri-bar Chart and the specially designed contrast sensitivity chart) for three lighting conditions (no simulated cockpit lighting; red ambient lighting; and green ambient lighting).

The procedure for determining the NVG-aided CS using the charts was taken from DeVilbiss and Antonio.[4] Each observer attempted to read all of the resolution patterns from left to right and top to bottom under each of the four possible chart orientations. They were instructed to indicate whether a pattern was vertical, horizontal, or could not be resolved (in which the case the pattern was reported as “uncertain”). Each pattern was viewed four times (twice vertically and twice horizontally). The number of correct vertical and horizontal responses was totaled, and the threshold contrast levels were determined using a 75% correct criterion. For example, if an observer using the NVG CS 12 CPD chart correctly identified the 42.3 contrast level four times of the four attempts for that pattern (100%), the 35.3 contrast level three times (75%), and the 31.5 contrast level only twice (50%), the value entered for that particular observer would be the contrast level of 35.5. If a pattern could not be resolved in any of the four trials, a score of 100 was entered, indicating 100% contrast was required for identification.

The two VA tests were assessed in a similar manner. However, the dependent measures were the Snellen values at which the 75% correct response criterion was achieved.

5.4.3 Results

First, we consider the results for the contrast sensitivity measurements. Table 5.1 lists the spatial frequencies and light condition contrast means and standard deviations.

Table 5.1 NVG-aided Contrast Sensitivity Means and Standard Deviations for a 75% Criterion*

	Baseline	**Green light**	**Red light**
12 cpd chart			
Mean Contrast	35.69	59.70	87.48
Standard Deviation	10.52	29.87	19.66
6 cpd chart			
Mean	9.48	11.13	14.96
Standard Deviation	2.94	5.31	7.04
3 cpd chart			
Mean	7.00	6.66	8.84
Standard Deviation	1.97	2.27	3.47

*Contrasts are determined by the values used in the special CS chart.

Table 5.2 NVG-aided Visual Acuity Means and Standard Deviations for a 75% Criterion Expressed in Snellen Scores*

	Baseline	**Green light**	**Red light**
NVG chart			
Mean	20/49.0	20/55.0	20/65.25
Standard Deviation	4.47	4.29	11.30
1951 Tri-bar chart			
Mean	20/48.50	20/55.45	20/65.43
Standard Deviation	4.23	5.74	8.56

*Standard Deviation values are calculated from the right hand side of the Snellen mean scores.

Table 5.2 lists the mean and standard deviation of the 75% criterion-meeting Snellen values for the corresponding six treatment combinations for the two VA charts and three ambient lighting conditions.

Table 5.3 compares the results for each of the five different charts for the green and red ambient light conditions, respectively. These values reflect the degradation from the baseline (no ambient light) condition. The comparison of the VA and CS results, of course, is being made between percentage difference of two different kinds of units—the Snellen measures and the contrast sensitivity scores. However, this procedure normalizes the scores in a way that permits us to carry out this comparison.

The substantially higher degradation (in terms of the percentage change) indicated in Table 5.3 for the CS tests indicates that the VA tests are not measuring the full effect of ambient lighting either in magnitude or in terms of

Table 5.3 Percentage Change from Baseline of the VA and CS Charts

	NVG chart*	**Tri-bar chart***	**12 cpd**	**6 cpd**	**3 cpd**
Green Light	11.9	12.5	40.2	14.8	0
Red Light	24.9	25.9	59.2	36.6	20.9

*The values are obtained by averaging the right-hand side of the Snellen values.

changes with size—a variable closely associated with spatial frequency. Subtle differences appear that confirm the earlier anecdotal observation that visual perception could be seriously degraded without substantially affecting the VA scores. For example, where the VA tests showed approximately a 25% degradation in performance with red ambient cockpit lighting, high spatial frequencies resulted in greater than twice that level of deficit.

Our research clearly demonstrates, therefore, that CS is a useful additional assessment tool of NVG visual performance under conditions of ambient light degradation. Both the spatial frequency of the test chart and the ambient light conditions significantly affected visual performance, particularly at the higher spatial frequencies, in a way that was not evident in the VA tests. As Rabin stated,

> . . . 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.[9]

This study supports the argument that CS charts sensitively assess a loss in visual performance that is not assayed by the VA tests. Thus, CS is more closely related to some of the most salient aspects of a stimulus that make it differentially detectable and recognizable. As such, it is an important supplemental measure of visual performance.

5.5 Discussion

The results of the two series of experiments in this study provide support for the main thesis of this chapter. That thesis is that classical psychophysics provides an important means of understanding complex visual behavior, one that is often overlooked by both engineers and users of devices like NVGs.

Above and beyond the specific details of the obtained results, we make two other general points in this chapter. The first is that it is necessary to simulate NVGs if we are to be able to study the specific effects on performance and to design better ones. Simulations of NVG viewing conditions are especially important simply because of the technological limitations of the NVG devices themselves. Using a real NVG would have made it impossible to study the effects of scintillation or contrast in the quantitative way that our first series of experiments did. Because of the simulation we used, we were able to demonstrate that the specific relations between luminance, contrast, and punctate interference in a precise manner that would have been impossible to demonstrate if we had used real NVG devices.

The second general point is evidenced by the stress we place on the CS measure in this chapter. The importance of the use of the concept of contrast sensitivity as a function of spatial frequencies cannot be overemphasized. Classical psychophysical researchers have long been aware of the sensitive nature of the CS as a predictor of detection, discrimination, and even recognition performance. For example, Ginsburg et al.[8] found that the higher spatial frequencies (8, 16, and 24 cpd) correlated with detection performance better than the lower frequencies. Rabin[10] and Rabin and McLean[11] stressed that the steep portion of the CSF is most vulnerable to a degraded visual scene. This is due to a small change in VA resulting in a large change in contrast threshold. Yet, for the most this part, it has been only recently that this fundamental idea in the study of vision has been applied to NVG operation and performance measurement. Our results make it clear that while a useful global measure, VA obscures many of the fine details of visual perception that are absolutely essential both for the design and use of NVGs and that the CS measure must be utilized as well in pilot training and evaluation.

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