Contrast Sensitivity, Drivers' Visibility, and Vision Standards

ARTHUR P. GINSBURG

The vision standard presently used to evaluate drivers' vision is Snellen visual acuity. Visual acuity, however, has not been found to relate well to everyday visual performance such as driving. Because acuity tests the optics of the eye—the ability of the eye to focus an image—it is a measure of quantity, not quality, of vision. Furthermore, the black letters on the white background impose a high-contrast test condition that cannot be related to common low-contrast situations found in the real world like dusk, fog, or rain. However, contrast sensitivity, a more comprehensive method of evaluating vision, has recently been shown to be related to visual task performance in studies involving highway sign discriminability and pilot target detection. Contrast sensitivity has also been found to more accurately correlate with functional vision loss due to a disease such as cataracts. From health and safety aspects, detecting functional vision losses is extremely important. Cataract patients, for example, may have severely impaired functional vision but still measure 20/30 or 20/40 on the standard visual acuity test. Although acuity may not show a significant loss of vision, contrast sensitivity can detect many such losses and alert both the individual and the tester to the problem. In sum, the serious health and safety issues presented by the inability of acuity to measure losses of functional vision and visual quality should be addressed, especially with regard to driver visual standards. A reasonable replacement for acuity appears to be contrast sensitivity, which relates to visual performance and can detect visual deficits.

Because about 90 percent of our sensory input is visual, visual capability of drivers will remain an important determinant of whether or not an individual may drive vehicles. Although standards may vary from state to state, all drivers' licensing bureaus maintain some visual capability requirements. The relevance of the Snellen visual acuity standard currently used to distinguish individuals who cannot see well enough to drive safely is a matter of increasing concern. Major limitations of this vision standard and an emerging new contrast sensitivity technology for evaluating the health and performance of vision are discussed. Eye diseases such as cataracts represent a major safety problem for drivers and are not being properly detected by visual acuity testing. Several studies relating to visual performance and contrast sensitivity, including pilot target detection, highway sign discriminability, and alcohol are reviewed along with arguments supporting the necessity of new vision standards based on contrast sensitivity.

Vision Research Laboratory, Vistech Consultants, Inc., 1372 N. Fairfield Road, Dayton, Ohio 45432.

THE CURRENT VISION STANDARD—VISUAL ACUITY

The Snellen visual acuity test, the current measure used to evaluate vision, is designed to evaluate an individual's ability to see black letters on a white chart background. Because it tests the resolution ability of the eye, or how well the eye can focus an image, Snellen acuity corresponds to the quantity rather than the quality of vision. Although Snellen acuity has been the primary measure of visual capability since 1862, it has not related well to everyday visual performance such as that of driving vehicles. One of the reasons for this lack is that the Snellen acuity is a high-contrast vision test. This type of test indicates the state of a person's vision in an ideal high-contrast situation such as reading well-lit black letters on a white background. Objects in the real world, however, are rarely black on an unrelieved white background; real-life objects have different sizes, shapes, and contrasts and are viewed under such diverse conditions as dusk and twilight, rain, snow, fog, or smoke, all of which are low-contrast environments. Other conditions frequently experienced by drivers, such as bright sunlight and headlight glare, also affect a driver's visual capability. Looking through a windshield, especially one marred by dirt or glare, further degrades a driver's ability to optimally detect or identify an object such as a road sign, car, or pedestrian. On the basis of a single-sized, high-contrast format, Snellen acuity simply cannot measure how well an individual will be able to see under such variable and less-than-ideal conditions. Therefore, the facts that Henderson and Burg *(1)* and Kinney *(2)* found low correlation between visual acuity under high and low illumination levels and that Shinar *(3)* found a poor relationship between visual acuity and driving are not surprising.

Emerging as a more comprehensive way to measure vision, contrast sensitivity evaluates the ability of the eye-brain system to distinguish between an object and its background. Previous research has shown that, unlike visual acuity, contrast sensitivity does relate to visual performance in real-world situations *(4–9)*. In addition, contrast sensitivity also overcomes many of the drawbacks of the Snellen acuity chart in detecting and describing a wide variety of eye diseases such as cataracts *(10)* and poor contact lenses *(11)*.

In visual processing, the retinal image is converted into a visual code by the retina-brain system. Contrast sensitivity tests this part of vision, which processes an object's size, shape, and contrast. Because objects have such varied sizes, shapes, and contrasts, testing with only one size and contrast of object, such as with the Snellen letters, does not provide comprehensive results. Targets capable of relating to any object size, shape, and contrast are needed.

Sine Wave Gratings

Sine wave gratings of different sizes and contrasts are ideal targets providing the most sensitive testing of contrast sensitivity *(12, 13)*. Below each grating is the luminance profile, made up by the grating's spatial frequency and contrast (Figure 1). A contrast sensitivity curve or function is obtained by measuring the minimum contrast required to just see the sine wave grating. This curve is plotted on the Vistech consultant's evaluation form (Figure 2). The shaded area in Figure 2 represents the 5 to 95 percentile of the normal population. Just an audiogram is generated by using single-frequency tones at different sound frequencies to measure hearing threshold, a contrast sensitivity curve is generated by using pure space waves from sine wave gratings at different spatial frequencies (sizes) to measure visual threshold. Thus, just as loudness and sound frequency relate to hearing, contrast and spatial frequency relate to seeing. Similarly to how an audiogram describes the performance of the auditory system, the contrast sensitivity curve shows how well the visual system is functioning.

Indeed, contrast sensitivity testing is standardizing vision testing as pure tone audiological testing standardized audiology in the 1940s. After 20 years of scientific and clinical testing, contrast sensitivity, the ability to discern subtle changes in shades of gray, is emerging as a more comprehensive way to describe vision than Snellen acuity *(8–10)*.

In addition to measuring the optical quality of vision, contrast sensitivity evaluates the quality of contrast perception at the next stage of visual processing—the retina-brain system. The retina-brain system converts the retinal image into a neural code based primarily on the shape and contrast of the image. Because visual objects have a wide variety of sizes, shapes, and contrasts, the sensitivity of the visual system should be tested with a set of simple targets that can represent any object size, shape, or contrast. The sine wave gratings shown in Figure 1 work well as such targets.

Threshold visibility to sine wave gratings has been used extensively to describe individual visual mechanisms (channels) and overall visual sensitivity to spatial objects. Because sine wave gratings are special targets mathematically, the spatial information in any object can be converted into a combination of sine wave gratings. Simply put, any complex object can be built up or broken down using sine wave gratings of different spatial frequencies, amplitudes, and orientations. This process, known as Fourier analysis, is similar to the way complex sounds like speech and music can be broken down or built up using single-frequency sound waves of different amplitudes and phases. Thus, an evaluation of visual sensitivity to more complex everyday targets such as letters, faces, aircraft, and road signs *(4–7, 14, 15)* can be made by use of Fourier analysis.

For example, although disks have Fourier components in all orientations, sine wave gratings have Fourier components in only one orientation, exciting only one visual channel. Differences between disks and sine wave gratings result in different visual threshold functions whereby sine wave gratings are considerably more sensitive visual stimuli than disks *(12, 13)*. In addition, any complex object can be broken down into sine wave gratings, but not into disks. This ability is an important requirement for establishing performance-based relationships between the visibility of complex objects and observer contrast sensitivity functions. Thus, contrast sensitivity functions using sine wave gratings offer throughput capability. They not only describe relevant spatial information in objects but also the transmission characteristics from the object to the observer and the observer's sensitivity to those objects. The capability of contrast sensitivity functions to predict simulated and real complex target acquisition such as road sign discrimination is discussed later.

Comprising a repeated series of light and dark bars, sine wave gratings are defined in terms of spatial frequency,

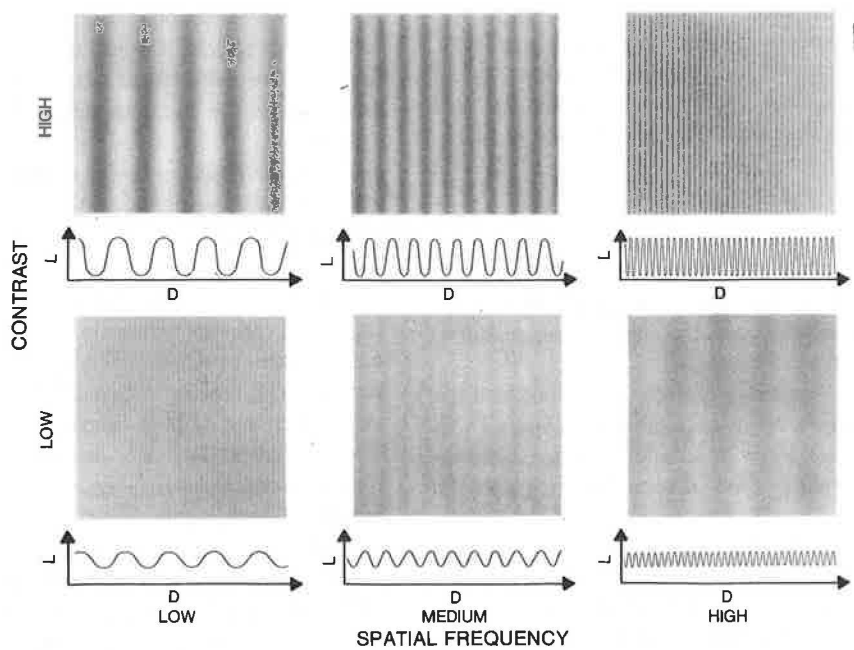

FIGURE 1 Sine wave gratings, simple targets capable of representing any target size, shape, or contrast, with different spatial frequencies and amounts of contrast.

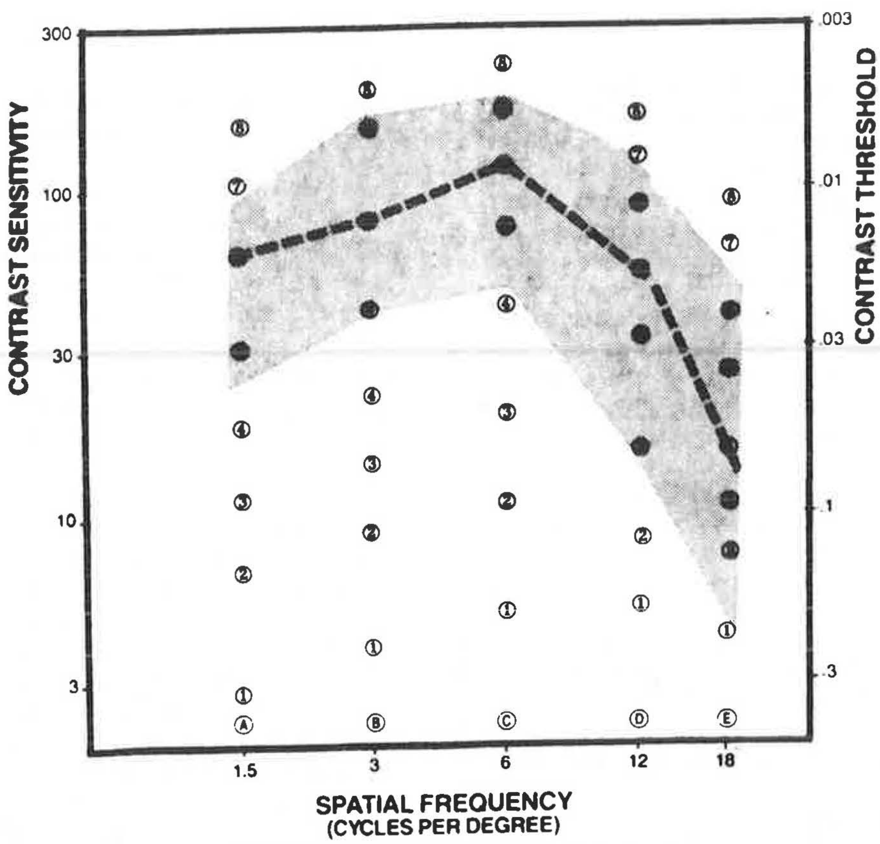

FIGURE 2 A typical contrast sensitivity function.

contrast, and orientation. Spatial frequency is defined as the number of cycles over a particular distance, or the number of cycles per degree (cpd) of visual angle. One light and one dark bar of a grating constitute one cycle. As the bars become more closely spaced, the frequency of the cycles increases. The spatial frequency is the number of cycles of the grating that occur over a particular distance.

Another important aspect of sine wave gratings is their contrast. The luminance difference between the light and dark bars, each with its own luminance, determines the grating's contrast. The Michelson definition is generally used to define contrast *(C)*.

$$C = \frac{L_{max} - L_{min}}{L_{max} + L_{min}}$$

where L_{max} and L_{min} are the maximal and minimal luminances of the grating bars. Sine wave gratings having low, medium, and high contrast are shown in Figure 1.

The grating's spatial frequency and contrast constitute the luminance profile, as shown below each grating in Figure 1. An increase in frequency results in a smaller distance between cycles, whereas an increase in contrast causes the height of the cycles to increase.

Increasing the contrast of a grating from below its visibility or decreasing it until it is invisible to the point at which the grating is just seen or just not seen establishes a condition called threshold contrast. Different amounts of contrast are needed for the observer to reach threshold with gratings of different spatial frequencies. The reciprocal of the threshold contrast is contrast sensitivity and is plotted as a function of spatial frequency. This plot is termed the contrast sensitivity function or curve.

Shown in Figure 3 is a characteristic contrast sensitivity function. The wide, inverted U-shaped curve shows the visual window that limits the range of the size of objects that can be seen under threshold contrast conditions. Above the curve is the region of low contrast below threshold, meaning that objects cannot be seen. Objects can be seen in the higher-contrast region above the curve if spatial frequency is sufficient. Peak sensitivity of the visual system typically occurs at about 3 to 6 cpd. Sensitivity decreases for spatial frequencies greater than and less than peak sensitivity with the physiological limit being about 60 cpd, depending on viewing conditions. Similarly to the auditory system, only a limited range of spatial information can be conducted by the visual system.

The narrower curves shown within the contrast sensitivity function represent relatively narrow-bandwidth mechanisms called channels, which make up the overall contrast sensitivity function (Figure 3). Again similarly to independently-tuned auditory channels, these channels represent the activity of functionally independent, size-selective cells in the visual system that are considered to play a major role in filtering relevant target information such as contrast, size, and basic form *(14–16)*. Just as auditory testing requires pure tones of different sound frequencies to test the independent auditory channels, vision testing requires sine wave gratings of different spatial frequencies to test the independent visual channels.

As shown in Figure 3, many parts of the visual system are needed to make up a clear, complete image. When one or more of these areas does not function properly, it affects the

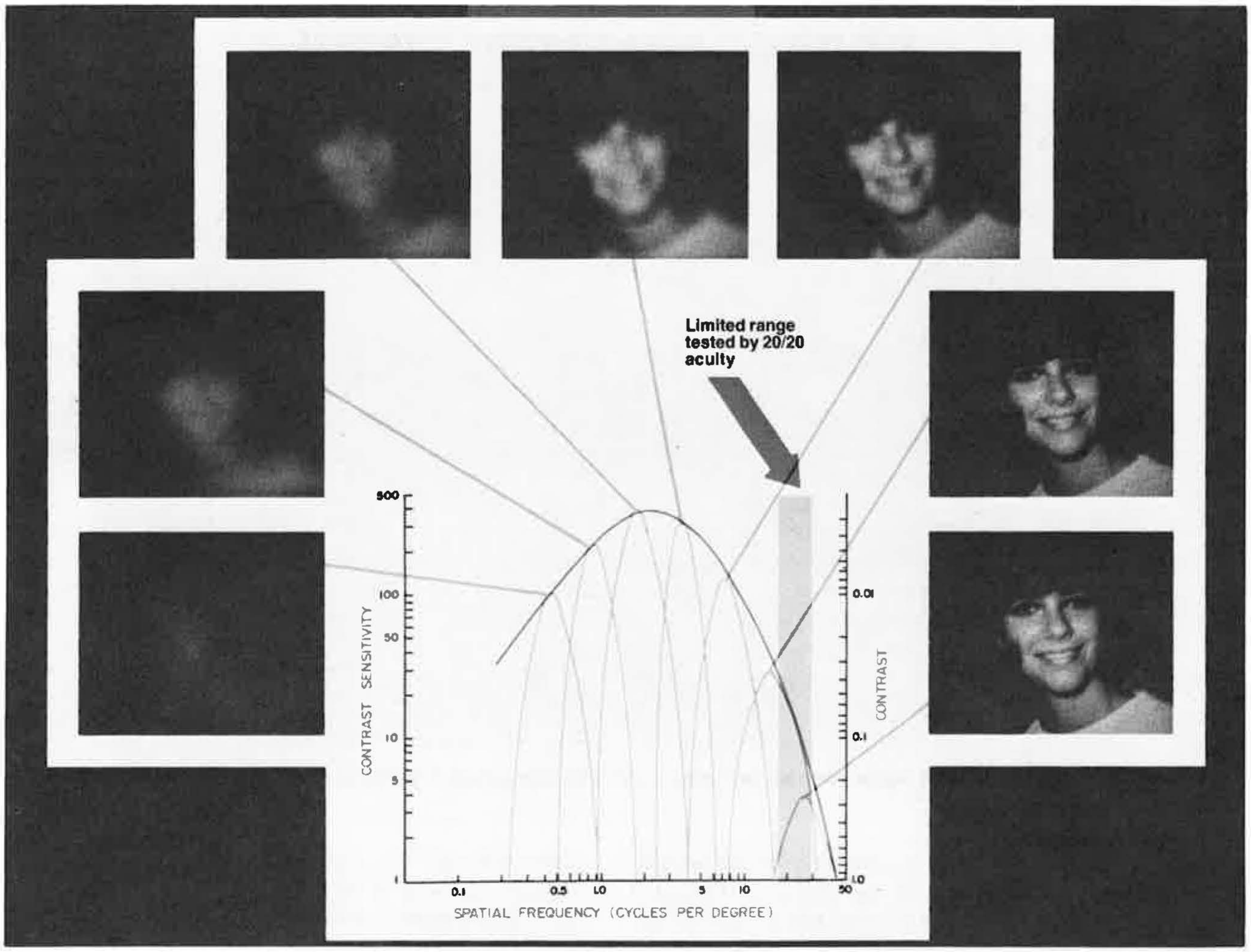

FIGURE 3 In this CSF, the large inverted U–shaped curve outlines the area where objects are visible at threshold.

overall image. Because Snellen visual acuity is affected only when the small portion of the visual system relating to acuity is affected, from 18 to 30 cpd as represented by the gray band, dysfunctions in other parts of the visual system can go undetected by visual acuity tests. Contrast sensitivity, on the other hand, can detect problems not only in the area measured by acuity but also throughout the complete range of the visual system. A measure of functional vision loss, contrast sensitivity losses because of various causes such as cataracts or other problems can be related to practical losses in everyday visual function.

Although computer-video systems that test contrast sensitivity have been available for a few years, these were primarily used by researchers due to their considerable expense, complexity, and the significant time required to master the system, perform the daily calibrations, and test patients. To overcome these limitations, a new vision test chart, the Vision Contrast Test System (VCTS) shown in Figure 4, was developed *(17, 18)*. Now used by over 4,000 doctors in the United States and 28 countries, the VCTS provides highly repeatable contrast sensitivity data similar to computer-video systems but at only $^{1}/_{30}$ the cost and $^{1}/_{12}$ the test time, and does not require daily contrast calibration *(10)*. Patches of sine wave gratings with different contrasts and spatial frequencies are visual targets used for testing. The patient is instructed to identify the orientation of lines within patches. Furthermore, the VCTS can be used to evaluate both near and distant vision, both important to drivers. Initial results of the VCTS show contrast sensitivity losses for a wide variety of visual pathologies similar to those found using the computer-video systems *(18)*.

PILOT STUDIES

The main power of contrast sensitivity relevant to driver vision standards has been its ability to measure performance-related visual capability. For example, significant research on the predictive capabilities of contrast sensitivity with regard to actual performance has been accomplished with pilots. One such study was done in 1983 under field conditions *(6)*. A total of 84 Air Force pilots were tested for acuity and contrast sensitivity in this study. Aircraft detection testing using a T–39 was performed the day after vision evaluation. Aircraft altitude, speed, and azimuth were maintained at constant values, in order to reduce differences between trials. This ground-to-air target detection task was completed under diverse visibility conditions, including fog and dusk, ranging from 0.5 to more than 15 mi. Visual acuity and contrast sensitivity measurements were taken and correlated to the pilot's detection range in 10 completed field trials.

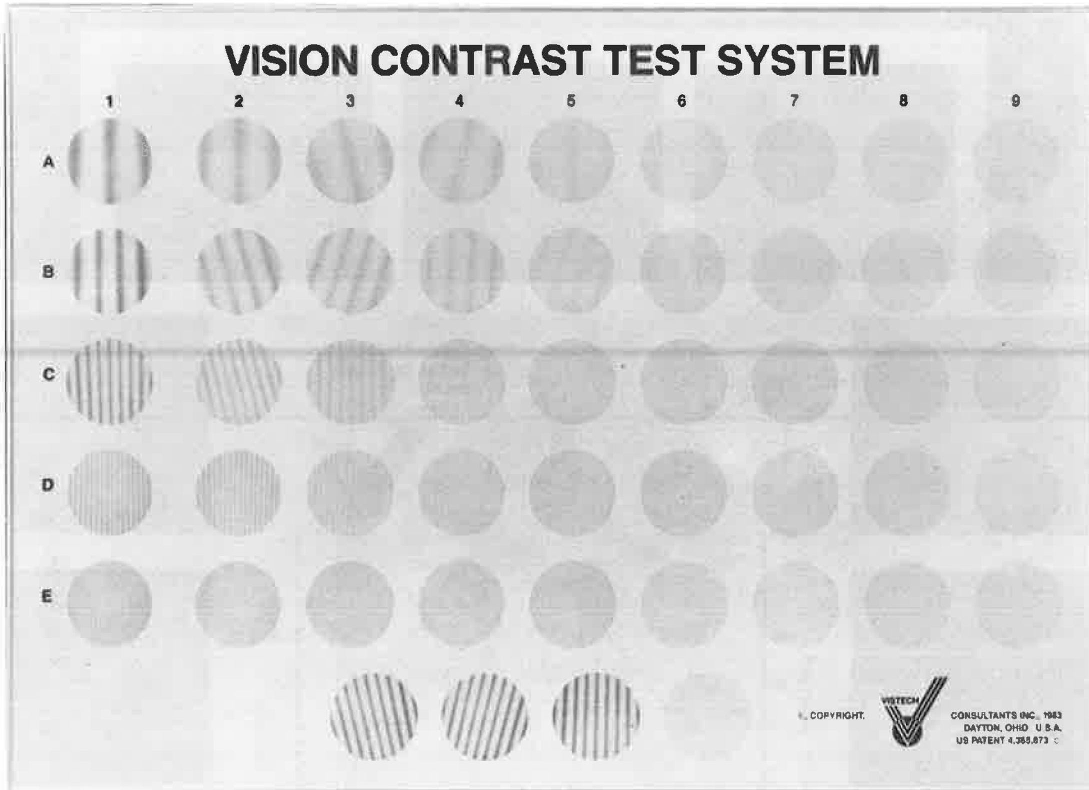

FIGURE 4 Vistech vision contrast test system (VCTS) photographic plates used to evaluate contrast sensitivity.

There was a significant positive correlation for contrast sensitivity in 8 of these field trials. Of the 10 trials performed, 3 showed correlation for acuity, 2 positive and 1 negative. Because of bad weather that curtailed data gathering, one of the trials had no correlation with either contrast sensitivity or acuity. The average differences for all conditions in detection range and time between the most and least sensitive pilots were 2.2 mi and 56 sec.

These individual differences are significant factors, not only to the ability of pilots to fly an aircraft but also to drivers of automobiles, trucks, and heavy equipment, and others who perform visually oriented tasks. Here again, contrast sensitivity showed these large differences in detection range, not acuity.

Similar results were seen in the trial with meteorological visibility of 15 mi. The differences in detectability between the most and least sensitive pilots were 6.5 mi and 2.8 min. In this instance, the corresponding Snellen results ranged from 20/10 to 20/20, but their contrast sensitivity differed by a factor of 3.4. Data from another trial included a visibility factor of 1 to 2 mi, and a 0.42-mi (9.2-sec) difference in detection range between the two pilots, with Snellen acuity ranging from 20/13 to 20/20 and a factor of 3.7 difference between the two pilots' contrast sensitivity.

In another study using Air Force instructor pilots, a set of simulated landings focusing on air-to-ground target detection was performed at Williams AFB *(4)*. On spotting a MIG craft at the end of the runway, 11 Air Force instructor pilots each pressed a button. Comparisons were made of the detection range and visual ability, including contrast sensitivity and standard visual acuity measures. Contrast sensitivity was found to be the most accurate predictor of the pilots' detection range in these trials also. The correlation between target detection and contrast sensitivity of the pilots was 0.83; for visual acuity the correlation was −0.13. Recent Canadian studies have confirmed large differences in contrast sensitivity between Canadian pilots even when their acuity was 20/20 or better. Another study using 55 search-and-rescue scene analysts had high correlation to the complex scene task performance and contrast sensitivity but negative correlation to acuity *(19)*.

Contrast sensitivity provides additional practical applications both for the aviation field and the automobile field. In general, problems with target perception contrast in a heads-up display (HUD) are linked to one or more factors, including target background, atmosphere, windscreen, HUD optics, eyeglasses, visors, and of course, the visual system. Because the HUDs in aircraft are intended to allow the pilot to see HUD symbols and targets at the same time, the system should maximize visual ability. Instead, some HUD systems, designed without specific attention to or knowledge of contrast sensitivity, actually reduce perceived contrast *(20)*. This, in turn, reduces visibility.

A HUD system that reduces visibility and sensitivity supplies extra risk that could be avoided. Using contrast sensitivity to measure around and through the system, both HUDs and automobile windshields with especially impregnated and stick-on window tints can be better designed to aid in visual tasks rather than decreasing visibility.

HIGHWAY SIGN DISCRIMINABILITY STUDY

Another performance-related study more directly related to driver vision standards was concerned with the ability of contrast sensitivity to predict age-related differences in ability to discriminate basic road signs *(5)*. Contrast sensitivity, Snellen visual acuity, and discrimination distances for projected moving images of highway signs were measured for seven older observers, ages 55 to 79, and 13 younger observers, ages 19 to 30. Although all subjects had 20/20 visual acuity or better, the older group had significantly lower contrast sensitivity than the younger group at three spatial frequencies—3, 6, and 12 cpd of visual angle. The older group, having to get 24 percent closer to the sign, required a significantly larger sign symbol in order to determine if it denoted a + or T intersection. Correlations between measures showed that highway sign discrimination distance was significantly related to contrast sensitivity at two spatial frequencies, 1.5 and 12 cpd, but discrimination distance was not related to visual acuity. Implications for highway sign design and driver vision standards are evident.

The result of this highway sign discrimination study reiterated the results found in the pilot study. The younger group could discriminate the road signs at significantly greater distances than the older group, even though there was no difference in Snellen acuity between the groups. A significant age-related drop in visual capability was also found with contrast sensitivity. Furthermore, significant relationships were found between contrast sensitivities at two spatial frequencies and discrimination distance, although no significant relationship was found between Snellen acuity and discrimination distance.

Contrast sensitivity related directly to the observer's capability to discriminate highway signs. Contrast sensitivity, not acuity, appears useful in standardizing highway sign contrast, size, and lighting requirements for safe and effective driving. The inability of Snellen visual acuity to predict visual performance is shown by these results. Because contrast sensitivity can detect losses in visual capability that cannot be detected by current visual acuity techniques, especially for older subjects and others having low contrast sensitivity, it appears to be a suitable replacement for evaluating vision. These results do not mean that older drivers will necessarily be eliminated from driving but rather that road signs and highway lighting should be designed to compensate for the effects of decreased contrast sensitivity of the older drivers.

CONTRAST SENSITIVITY AND ALCOHOL

An area of paramount concern today with regard to drivers is that of driving and drinking. The main determinant for establishing intoxication when driving is blood alcohol content. A study on the effects of alcohol on contrast sensitivity provided interesting insights as to the ability of blood alcohol content to determine the effects on driver vision *(21)*.

Contrast sensitivity was measured for seven subjects having different levels of blood alcohol content (BAC) under photopic (daytime) and mesopic (dusk) luminance conditions. In general, a blood alcohol content of less than 0.1 percent resulted in contrast sensitivity changes at all spatial frequencies tested (1.5, 3, 6, 12, and 18 cpd). Although several gains in contrast sensitivity were found, these were all at the higher spatial frequencies and the higher luminance levels. Contrast sensitivity losses, however, were evident at all spatial frequencies.

Significant differences in the patterns of sensitivity gains and losses for individuals appeared in the data. The highest intoxication levels produced the greatest change in contrast sensitivity in some subjects, whereas a delayed change in contrast sensitivity was found in other subjects. Recovery of contrast sensitivity also varied; some subjects returned to baseline sensitivity as BAC decreased, whereas the contrast sensitivity of others increased or remained suppressed even after BAC returned to initial levels. The alcohol-based contrast sensitivity losses were significant when compared to previous performance-based target acquisition research. These results suggest that some serious loss in visibility of certain objects, especially under low luminance conditions, may be experienced when an individual ingests alcohol, even at moderate rates of alcohol ingestion.

HEALTH AND SAFETY IMPLICATIONS FOR CATARACT PATIENTS

Perhaps one of the most serious health and safety issues concerning the inadequacies of visual acuity as a driving standard is its inability to measure the loss of functional vision of people having cataracts. Although used for medical and legal purposes as documentation, the 125-year-old Snellen eye chart is not an appropriate measure of vision loss due to cataracts. Acuity measures the effect of optical defocus on the ability to see small black and white targets. Cataracts are opacities of the lens that cause light scatter, and do not cause optical defocus. Accordingly, acuity cannot give a meaningful estimate of the severity of the cataract. Because the light scattering effect decreases contrast at the retina, the quality of vision is reduced, causing cataract patients to complain of washed-out or colorless sight. Bright sunny days or headlights at night greatly affect cataract patients because of the increased light that results in even more light scatter. This increased vision loss creates a serious dilemma for drivers. Although visual quality may be reduced, sometimes even severely, acuity may still be 20/30 or 20/40, still within the legal limit for drivers in all states. An example of the lack of relationship between visual acuity and the contrast sensitivity function is shown in Figure 5 *(18)*. Although each patient has 20/30 acuity, one patient has a considerably more severe loss in functional vision than the other patient. Under the current standard, these drivers would be considered equally capable of driving a car or piloting an aircraft. The patient can legally drive despite impaired vision. However, measuring functional vision would show the degradation of vision and alert both the driver and the licensing bureau to the patient's disability. With today's medical technology, cataracts can be quickly and economically removed allowing drivers now at risk to themselves and others to become safer and more effective drivers.

Similar losses in contrast sensitivity are found in young drivers having contact lenses that have been mishandled or have excessive deposits. One example is a 26-year-old male driver having 20/30 acuity whose contrast sensitivity due to deposited lenses was greatly reduced, especially at the middle spatial frequencies, worse than that of a healthy 80-year-old *(11)*. A deposited lens is like having a cataract in front of the eye.

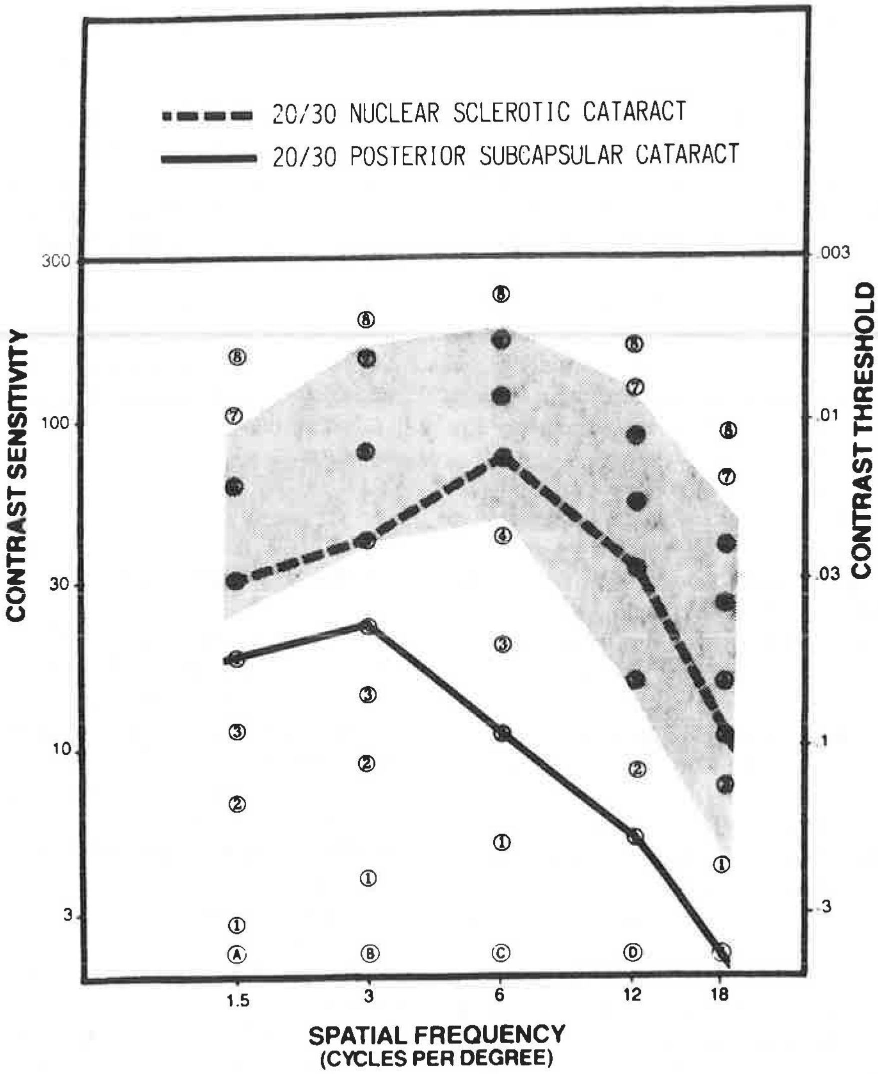

FIGURE 5 Lack of relationship between visual acuity and contrast sensitivity.

CONCLUSIONS

Research has shown that an individual's contrast sensitivity function, but not acuity, relates to letter and face recognition, discrimination distance of road signs, pilot detection range, blood alcohol content, and scene analyses. The results of these studies have great significance, especially in relation to the tasks required of drivers. For the safety of the driver and others, the driver needs to be able to detect and recognize objects at reasonable distances in a short time. As evidenced by previous studies, contrast sensitivity can help predict an individual's ability to see an oncoming target or stationary object at the first possible moment. Furthermore, contrast sensitivity can detect cataracts and poor contact lenses that go undetected by visual acuity testing. Therefore, driver vision standards should be based on a performance-related vision test for contrast sensitivity.

REFERENCES

1. R. L. Henderson and A. Burg. *Vision and Audition in Driving.* Report TM(L)–5297/000/00. System Development Corporation, Santa Monica, Calif., April 1974.
2. J. A. S. Kinney. Clinical Measurement of Night Vision. In *Proc., Armed Forces NCR Committee on Vision,* National Academy of Sciences, Spring Meeting, 1968.
3. D. Shinar. *Driver Visual Limitations, Diagnosis and Treatment.* Institute for Research in Public Safety, Indiana University School of Public and Environmental Affairs, Bloomington, Ind., Sept. 1977.
4. A. Ginsburg, D. Evans, R. Sekuler, and S. A. Harp. Contrast Sensitivity Predicts Pilots' Performance in Aircraft Simulators. *American Journal of Optometry and Physiological Optics,* Vol. 59, No. 1, 1982, pp. 105–109.
5. D. W. Evans and A. P. Ginsburg. Contrast Sensitivity Predicts Age-Related Differences in Highway Sign Discriminability. *Human Factors,* Vol. 27, No. 12, 1985, pp. 637–642.
6. A. Ginsburg, J. Easterly, and D. Evans. Contrast Sensitivity Predicts Target Detection Field Performance of Pilots. In *Proc., Human Factors Society, 27th Annual Meeting,* Vol. 1, 1983, pp. 269–273.
7. R. D. Koppa. *Visibility Through Spray.* Texas Transportation Institute, Texas A&M University, College Station, Tex., 1984.
8. Committee on Vision, National Research Council. *Emergent Techniques for the Assessment of Visual Performance.* National Academy Press, Washington, D.C., 1985.
9. A. P. Ginsburg. Proposed New Vision Standards for the 1980's and Beyond: Contrast Sensitivity. In *Proc., AGARD/NATO Specialist Aerospace Medical Panel Meeting,* No. 310, Toronto, Canada, Sept. 1980, pp. 15–19.

10. A. P. Ginsburg. Spatial Filtering and Vision: Implications for Normal and Abnormal Vision. In L. Proenza, J. Enoch, and A.Jampolsky (eds.), *Clinical Applications of Visual Psychophysics*. Cambridge University Press, New York, 1981, pp. 70–106.
11. A. P. Ginsburg. The Evaluation of Contact Lenses and Refractive Surgery Using Contrast Sensitivity. *Contact Lenses, Update 2 (The CLAO Guide to Basic Science and Clinical Practice)*, O. H. Dabezies (ed.), Jan. 1987, pp. 56.1–56.17.
12. S. K. Guth and J. F. McNelis. Visual Performance: Subjective Differences. *Illuminating Engineering*, Vol. 64, No. 9, 1969, pp. 576–578.
13. A. P. Ginsburg. Sine-Wave Gratings Are More Visually Sensitive Than Disks or Letters. *Journal of the Optical Society of America*, Vol. 1, No. 12, 1984, p. 1301.
14. A. P. Ginsburg. Visual Information Processing Based on Spatial Filters Constrained by Biological Data. Air Force Aerospace Research Medical Laboratory Technical Report, 1978, pp. 78–129.
15. L. Spillman and D. R. Wooten (eds.). Visual Form Perception Based on Biological Filtering. In *Sensory Experience, Adaptation, and Perception*. Lawrence Erlbaum Associates, New Jersey, 1984.
16. R. L. DeValois and K. K. DeValois. Spatial Vision, *Annual Review of Psychology*, Vol. 31, 1980, pp. 309–341.
17. A. P. Ginsburg. A New Contrast Sensitivity Vision Test Chart. *American Journal of Optometry and Physiological Optics*, Vol. 61, No. 6, 1984, pp. 403–407.
18. A. P. Ginsburg and D. W. Evans. *Initial Results of Rapid Clinical Screening Using a New Contrast Sensitivity Vision Test Chart.* Presented at the Optical Society of America, Special Session on Medical Optics, Lake Tahoe, Nev., March 1985.
19. P. Stager and D. Hameluck. *Contrast Sensitivity and Visual Detection in Search and Rescue.* Defence and Civil Institute of Environmental Medicine, N. York, Canada, June 1986.
20. A. P. Ginsburg. Direct Performance Assessment of HUD Display Systems Using Contrast Sensitivity. In *IEEE: NAECON Mini-Course Notes*, Dayton, Ohio, May 17–19, 1983, pp. 33–44.
21. A. P. Ginsburg, D. W. Evans, L. McNinch, K. Blauvelt, and H. Siegal. The Effect of Alcohol on Contrast Sensitivity. Presented at the Annual Meeting of the Human Factors Society, Baltimore, 1985.
22. C. Owsley, R. Sekuler, and C. Boldt. Aging and Low-Contrast Vision: Face Perception. *Investigative Ophthalmology and Visual Science*, Vol. 21, No. 2, 1981, pp. 362–368.