Clinical review and assessment of contrast sensitivity testing

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Abstract
The contrast sensitivity function (CSF) provides additional information concerning visual function. An explanation of contrast sensitivity and its physiological basis is given. An examination of the two most widespread clinical methods of testing, the Arden plates and the cathode ray tube (CRT), follows. The confounding variables inherent in the testing method and the uses, as reported in current literature, of the CSF in the clinical setting in the examination of various diseases is presented. Because of the lack of standardized testing procedures, the CSF is of limited value in the diagnosis. The individual practitioner is encouraged to formulate his/her own parameters and norms if the CSF is to be utilized in the testing regime.

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CLINICAL REVIEW AND ASSESSMENT OF CONTRAST SENSITIVITY TESTING

SENIOR THESIS PROJECT
Submitted in partial fulfillment for
DOCTOR OF OPTOMETRY DEGREE

PACIFIC UNIVERSITY COLLEGE OF OPTOMETRY
MARCH 1984

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The contrast sensitivity function (CSF) provides additional information concerning visual function. An explanation of contrast sensitivity and its physiological basis is given. An examination of the two most widespread clinical methods of testing, the Arden plates and the cathode ray tube (CRT), follows. The confounding variables inherent in the testing method and the uses, as reported in current literature, of the CSF in the clinical setting in the examination of various diseases is presented. Because of the lack of standardized testing procedures, the CSF is of limited value in the diagnosis. The individual practitioner is encouraged to formulate his/her own parameters and norms if the CSF is to be utilized in the testing regime.
Introduction

Measurement of the contrast sensitivity function (CSF) has been widely promoted as a practicable way of evaluating the visual system. Laboratory and clinical studies have indicated notable success in using the CSF to thoroughly assess a patient’s entire visual potential. In turn, this allows the practitioner to utilize the CSF to evaluate a wider range of visual capabilities, whereas Snellen acuity evaluates only a portion of these capabilities. For example, a patient with 20/20 acuity reporting difficulty in attaining low spatial frequency demands, such as facial recognition, would be a prime candidate for this type of testing. The CSF has also been utilized to chart pathology progression and evaluate subclinical manifestations by assessing specific losses that are not normal in comparison to the typical contrast sensitivity curve.

Even though contrast sensitivity has contributed a vast amount of information concerning the visual system, it has come under increasing criticism due in part to lack of standardization and other factors. With the onset of commercial marketing efforts of clinical CSF testing instrumentation, the practitioner should note and understand the critical factors that can affect the CSF before relating past experimental claims to present clinically based results.

The following thesis covers issues relative to clinical utilization of contrast sensitivity testing. Definition, physiological basis, current clinical methodologies, confounding
variables and pathology diagnosis relative to the CSF are presented. The following assessment of clinical CSF testing is derived from a survey of past literature and personal experiences. It is hoped that upon completion of this thesis, the reader, who may have limited knowledge regarding this topic, may gain insight and a better understanding of the clinical potential of the CSF.
In the clinical setting, central vision is commonly assessed by means of the Snellen chart. Using the Snellen chart, visual acuity is expressed as a fraction in which the denominator is the distance from a critical measure of the smallest detectable interval subtends one minute of arc on the retina. The Snellen chart actually measures resolution of fine spatial detail.

Relative to contrast sensitivity, visual acuity testing only utilizes small high contrast spatial detail and doesn’t describe how the entire visual system performs with objects of all sizes and contrasts. Sekuler et al (1981) and Leibowitz et al (1981) have noted that many daily perceptual activities do not require high spatial frequency foveal resolution. On the other hand, low spatial frequencies provide most of the information for routine perceptual activities, including facial perception, figure-ground discrimination and visual stabilization of posture (Gilinsky 1968). In addition, as implied above, visual acuity is generally taken under maximum producable contrast conditions on the Snellen chart. It is never known, when using a Snellen chart, what minimal degree of contrast is needed for an observer to continue to be able to recognize the given spatial frequency demand of the Snellen chart. Studies using varying degrees of contrast relative to a given Snellen acuity level have not been reported. This is probably due to technological production problems, but the closest way of doing this to date is to use contrast sensitivity measurement.

Contrast sensitivity measurement (CSM) is made by taking
vertically oriented alternately dark and light sinusoidal gratings of a given width and quantifying an observer's contrast threshold for the given spatial frequency. The gratings are sinusoidal rather than square wave configuration as optical blurring does not affect spatial configuration of sinusoidal gratings, but only affects the contrast levels (Bodis-Wollner et al 1980) (fig. 1). Blurring of a square wave grating causes a contrast change as well as a change in the spatial configuration of the grating patterns (Bodis-Wollner et al 1980). Average luminance of the grating must be kept constant regardless of the change in contrast and/or change in spatial frequency. This removes any effect that luminance may have on observer sensitivity to spatial resolution. This is important to insure that contrast sensitivity rather than luminance sensitivity is being measured. The mean or average luminance coming from the pattern is equal to half the sum of the bright and dark bar luminance. On the other hand, the contrast of the grating pattern is defined as the luminance difference between light and dark bars divided by the sum of their luminances (see appendix).

A dark bar and its adjacent light bar comprise one cycle of the grating pattern. The number of cycles subtending one degree of visual angle on the observer's retina is called the spatial frequency of the pattern. The closer the grating is to the observer the larger the angle subtended on the retina because there will be fewer cycles in one degree, thus lowering the spatial frequency (see appendix). High spatial frequency in turn
presents many cycles of the pattern included within one degree of visual angle. Therefore 'contrast' and 'spatial frequency' will be used in the manner defined above, as both are convenient terms for describing normal and abnormal contrast sensitivity.

The observer's contrast sensitivity is defined by the minimum contrast which is required to distinguish that there is a bar pattern rather than a uniform screen. Contrast sensitivity is the reciprocal of contrast threshold. Consequently the lower the threshold the higher the contrast sensitivity. Each spatial frequency has its individual contrast threshold. Therefore contrast sensitivity can be plotted for each spatial frequency to obtain a contrast sensitivity function (CSF). Clinicians generally use the term CSF while laboratory researchers refer to this as the modulation transfer function (MTF). Figure 2 shows the contrast sensitivity curve for normal observers. The bottom point on the ordinate represents a contrast of 1; at that point the observer needs the maximum possible contrast, i.e. 100% contrast. The ordinate is scaled logarithmically from low sensitivity (bottom), where it takes more contrast to detect the pattern, to high sensitivity (top), where less than 1% contrast is necessary to obtain threshold. The abscissa is also scaled logarithmically from low spatial frequencies of less than 1 cycle per degree (CPD) to spatial frequencies of greater than 30 CPD. This figure demonstrates that the sensitivity varies markedly with each spatial frequency. The contrast sensitivity function (CSF) peaks at approximately 5 CPD, with sensitivity falling off at the higher and lower spatial frequencies. By plotting a log/log scale, higher spatial frequencies become linear in function and
this makes it relatively easy by extrapolation to figure the cutoff spatial frequency (i.e., visual acuity) from the CSF. Since 100% contrast is rare, the maximal detectable spatial frequency is difficult to determine. Therefore by taking three different high spatial frequency points of greater than 10% contrast, one can extrapolate the just detectable spatial frequency or potential visual acuity. This can yield a more exact value than the commonly used Snellen acuity letters (Bodis-Wollner et al 1980).

As alluded to above, visual acuity can be predicted from the CSF but the converse of predicting the CSF from visual acuity is not possible. Observers with normal 20/20 acuity will have very similar CSFs, but even in these observers there can be variations of contrast thresholds at middle and low spatial frequency regions of the CSF that would not be detected by 20/20 Snellen acuity. For example, figure (2) demonstrates that the two functions have the same projected spatial frequency but two different CSFs. Function B demonstrates an abnormal curve due to contrast loss while function D shows an abnormal curve with a shift to the left due to a decreased sensitivity peak at lower spatial frequencies. Thus from previously determined anomalous CSFs it may be possible to infer clinically what type of pathology is present.

In general there are three broad categories of anomalous CSFs that can be classified (1). "High frequency" and "level loss" correspond to two different predictions based upon size or contrast loss respectively (fig. 2). Most abnormal functions
fall into one of these two categories. The third category is described as a 'notch loss'. This is a contrast sensitivity deficit in the mid spatial frequencies leaving the low and high spatial frequencies unaffected. Because of the variety of CSF characteristics it is important to realize that a visual acuity score, no matter how precisely obtained, cannot measure the patient's ability to resolve larger target details. Before going on to discuss the clinical application of these categories, the development of the neural processing model must be presented in order to understand the processes that are hypothesized to make up the contrast sensitivity curve.
The visual system is thought to create images by means of a spatial frequency analysis performed via channel size-selection detectors. Just as hearing can be tested for its amplitude threshold of a given frequency, vision can be evaluated in a similar manner. Any visual pattern can be broken down into basic components just as sound stimuli can be broken down and analyzed into a series of simple frequency components. This is known as Fourier analysis. A grating of alternating black and white bars can be considered a stimulus analogous to a pure musical tone. By obtaining an observer’s contrast level to the given bar widths, or spatial frequencies, a ‘visuogram’ profile can be determined. This is analogous to an auditory profile known as an ‘audiogram’. While pure auditory tones occur frequently in nature, there are few natural visual equivalents. In addition, it has been established that single cells in the visual cortex respond much more vigorously to narrow frequency band gratings of sinusoidal nature rather than square wave gratings of the same spatial frequency bandwidth (Glezer et al 1977).

Shade (1956) is credited with the introduction of the CSF psychophysical testing methodology. Campbell and Green (1965) developed the test as it is known today. Originally these investigators utilized laser interference fringe techniques to form sinusoidal patterns of given contrast directly on the retina; this bypasses any loss of information caused by interference of the eye’s refracting structures. At the same time external grating patterns produced by an oscilloscope were
presented to match the grating frequencies produced by the laser. The CSF differences between these two techniques were examined to see how refracting structures affected the CSF. It was found that high spatial frequencies seemed to be affected primarily by the refractive components with neural input having little effect on the high spatial frequencies of the CSF. Further studies have indicated that neural input is responsible for the contrast threshold at lower spatial frequencies (Arden, 1976; Rodieck-Wollner, 1980). Campbell and Gubish (1966) found human contrast sensitivity doesn't follow the performance of an ideal optical system. Their studies indicated that the refractive structures of the eye were important for spatial frequencies higher than ten cycles per degree; from this they postulated the possibility of spatial frequency channels in the human visual system.

Campbell and Robson (1968) postulated that the human visual system behaved as a series of independent channels. These channels could be compared to narrow band spatial filters, each tuned to a separate band of frequencies. The number of channels and the extent to which they are independent were determined by the retinal areas in which spatial integration occurred. From this study low, medium and high frequency channels characteristic of the CSF were postulated.

Enroth-Cugell, and Robson (1966) recorded evoked potentials from single ganglion cells in the cat retina. They found that receptive field types related to ganglion field diameters are specific but have different spatial frequencies. Consequently, two different types of cells designated as X and Y cells were defined. X and Y cells were differentiated by the recorded
differences at specific locations of cat retina in response to low frequency or flickering patterns. Even though these cell types were determined by cat retina experimentation they have been empirically applied to the human CSF in order to further define the channel model.

Tolhurst (1975) proposed that the human visual system be broken down into a two channel system providing parallel processing. These channels were equated to the X and Y cells found in previous animal studies. X cells are sustained channels that respond to mid and high spatial frequencies and detect fine detail. They are found in the central visual area while Y cells are located in the surrounding periphery. Y cells are concerned with transiently recording channels that respond to low and mid spatial frequencies and movement. Y cells detect fluctuating (temporally varying) stimuli more readily and are strongly stimulated under high contrast levels. There is an overlapping of the two types of cell channels with both responding simultaneously to a range of mid spatial frequencies. Tolhurst claims that regardless of the temporal aspects, a spatial frequency of less than .25 CPD will always be detected by transient cell channels and frequencies greater than 10 CPD will always be detected by sustained channel cells.

From the above cited research, arguments can be made in favor of a component processing system for visual stimuli. Refractive elements, and X and Y channel components all contribute individually to the CSF. By knowing what anomalies affect these components and how to evaluate these components
effectively, proper evaluations can be made from any CSF.
Clinical Contrast Sensitivity Testing Instrumentation

Two basic types of clinical contrast sensitivity testing instrumentation are available for clinical use. One type is composed of fixed preprinted plates of given spatial frequencies while the other type utilizes a cathode ray tube (CRT) display with computerized input controlling spatial frequency and contrast. Both methods have their drawbacks and benefits. They are marketed as supplementary testing devices complementing the usual battery of clinical testing presently available.

Arden Plates

The first method of contrast sensitivity testing to be covered is known as Arden Plates. G.B. Arden developed this type of test in response to laboratory information found via oscilloscope and CRT types of testing. The test is made up of five test plates, in four of which the spatial frequencies of .2, .4, .8 and 1.6 cover the entire plate. The last plate has the spatial frequencies of 3.2 and 6.4 divided on the left and right respectively. The plates gradually increase from uniform gray at the top of the plate, numerically designated as 0 on the scale at the side of the plate, to maximum contrast at the bottom designated as 20 on the side scale. The plates are positioned 57 cm from the eyes so the above mentioned spatial frequencies are duplicated. The Arden Plates are geared to measure the low spatial frequencies which are generally affected by peripheral neuroretinal anomalies (Arden 1979A).
Recommended illumination is 100 foot candles which can be approximated by a 60 watt bulb 14 inches above the target. It is important not to allow shadows and to minimize any reflections as these can affect the measurement (Arden 1979A).

Presentation is begun by occluding one eye. The observer is directed to scan the top edge of the pocket rather than holding fixation on a central spot. An observer is assumed to have a normal pupil size and the proper nearpoint prescription if needed. Initially the observer is allowed to see a preview of what (s)he is to respond to and then the plates are returned inside the masking pocket to the starting position. The testing begins by pulling up the plate, called the removal process, at a slow and constant rate until the patient first responds. When this occurs the scale value at the side of the plate is the individual plate score for that particular spatial frequency. This value is recorded and the subsequent gratings are tested in the same manner.

Scoring of the Arden Plates is primarily based upon summation of the plate score norms previously determined by Arden. From the summation, the scores are categorized as average, borderline suspect and definitely abnormal. Other criteria for testing failure are a score on any plate of greater than 16 and a difference interocularly of any plate score of 11 or more (Arden 1979A).

Plate results below 3.2 CPD are interpreted as a neural deficit while above 3.2 CPD are attributed to an optical defect. Acuity charts are assumed to determine high spatial frequency

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losses. Low spatial frequency losses may indicate peripheral retinopathy, field defects, visual pathway anomalies or corneal edema (Arden 1979A). The Arden Plates are marketed as an efficient screening mechanism for those at risk of developing conditions within the visual system that could be further investigated by a more sensitive diagnostic tool.

There are a number of favorable strongpoints in using the Arden Plates. Compared to the CRT testing systems, they are simple to use, take approximately 15 minutes to administer and are relatively inexpensive (A/D $275.00). The Arden Plates come with a manual that explains how to administer the test properly. The testing manual provides consistent protocol so that results can be compared to subsequent testing and other testers. The testing methodologies detailed utilize the psychophysical method of increasing contrast. This type of methodology avoids problems such as threshold changes due to adaptation. The test provides straightforward guideline criteria for figuring average, borderline and abnormal results based on norms from Arden.

There are a number of drawbacks in the Arden system also. The primary drawback is the limited information drawn from the test. As mentioned earlier, the test only measures the approximate contrast threshold at low spatial frequencies and doesn’t allow a visuogram interpretation to determine the type of anomaly which may be present. Direct comparisons of the Arden grating results with those of the CRT results are not easily made. The Arden results are not as precise and reliable as those of the CRT results. Luminance is an external factor that varies due to the limitations of the photographed grating plates. Other
external factors that can affect the Arden Plates are shadows, reflections, and the fading or dirtying of the plates over time. There can be considerable variability in the manner of test administration, i.e., instructions to the observer and the removal rate of the plates. Also, there can be subjective variability in the psychophysical responses. Readaptation of the covered eye can slow down the test process in addition to potentially changing the threshold of the test. The last plate of the test has two different spatial frequencies of 3.2 CPD on the left side and 6.2 CPD on the right side that may cause confusion or interference with one another. Although it is not known how much variability the above-mentioned factors induce into the final measurement, they are factors that must be recognized when determining whether or not to use the Arden Plates.

Cathode Ray Tube Method

The second type of contrast sensitivity method is composed of a cathode ray tube with computerized input allowing unlimited ranges of spatial modulation programming options. Nicolet Optronics had the first commercially available CRT unit on the market known as the CS 2000. Other models such as one made by Cadwell have recently been marketed. Since Nicolet was the forerunner in this field, subsequent discussion regarding CRT contrast sensitivity testing will refer to this unit. The computer input allows creation of the full spectrum of spatial frequencies with a contrast range of 1% to 95% while keeping a
constant preprogrammed luminance level. The computer allows for programming of standard and nonstandard testing. Standard testing conditions are taken at 3 meters allowing an angular screen size of 4.5 degrees in width. The observer is allowed to dark adapt to the surroundings and is exposed to the preset mean illumination of the screen. The standard test utilizes a psychophysical testing method known as the von Bekesy tracking method. This method consists of eight separate trials each of which are presented by static sinusoidal gratings. In the first two trials, gratings of .5 and 6 CPD are previewed to provide practice for the observer. One eye is covered and a preview of the grating pattern to be tested is demonstrated for two seconds. The test then begins, initially from zero or a random subthreshold contrast level, until contrast reaches threshold to which the observer responds by depressing the control button on the response box. The observer continues to depress the control button until the grating disappears. This is done four times for each of the six spatial frequencies of .5, 1, 3, 6, 11.4 and 22.8 CPD while the computer tracks the threshold means and standard deviation. There are some drawbacks to using this method of testing, that will be discussed later. If there is too much variation in the response of the observer, making the standard deviation unacceptable, the trial can be deleted or more trials can be added to calculate a more accurate threshold for a given spatial frequency. Finally when the programmed spatial frequencies have been tested for both eyes and the means found to be acceptable, the graph of the CSF can be evaluated. Other nonstandard testing methodologies allow the programing of a
variety of factors. The choice of other preprogrammed method options apart from the von Bekesy tracking method, as described above, are: (1) Visual Evoked Response Mode (for presentation of counterphasing or reversal patterns in conjunction with signal-averaging equipment); (2) Method of Adjustment, using the turn knob on the response box; and (3) the Method of Increasing Contrasts, which is similar to the von Bekesy method, except that contrasts only increase from low values in successive repeats, instead of moving alternately up and down in reversals.

Nonstandard testing variations can be made by self-programing individual stimulus options. The operator can specify the number of stimuli, spatial and temporal wave forms i.e. sinusoidal and square wave, spatial and temporal frequencies and presentation rates. There are a variety of stimulus patterns to choose from. These patterns are static grating patterns, moving grating patterns, counterphasing grating patterns, full field flicker patterns and intermixed patterns which allow for the programing of different types of stimuli to appear during different trials. These pattern options are very convenient as they provide further evaluation of lower spatial frequencies that are more sensitive to moving rather than stationary patterns.

CRT testing devices are extremely versatile in their programing options and thus have a manifold array of benefits. The most obvious benefit is the sensitive and detailed information given by such testing. The CSF information can be graphed out across the entire spatial frequency spectrum and
analyzed for anomalous results which in turn can be compared with previous patient norms, past individual findings and individual interocular differences. Information concerning the variability of the observer response can be readily analyzed. A decision can then be made concerning the reliability and sensitivity of the observer response. In case of good observer response, progress in treating a subtle disorder can be monitored closely.

Another major benefit of CRT instrument testing is the versatile nature of the programming. The previously mentioned standard and nonstandard options allow for programmable changes of the individual factors affecting the CSF and thus never allow a standard program to become outmoded by a new testing methodology. Other test benefits include test design factors that don’t allow variables such as luminance, shadows or reflections to add to the confounding variables that may affect the CSF. Finally, once the standard testing method is understood, the system is relatively easy to operate.

Although the information given via the CRT testing is relatively good compared to other methods, there are a number of drawbacks to the CRT system. The biggest drawback of the Nicolet Optronics CS 2000 system at present is the lack of specific clinical guidelines for instrument usage and analysis of data. Due to the lack of protocol of previous CSF research (e.g. differences of distance, luminances and methodology), there is difficulty in properly comparing clinical results with previous laboratory results. Therefore the Nicolet CRT diagnostic results must be interpreted from personal clinical experience much like that of interpreting a VER or EKG. Because of the previous
variation in the way laboratory results have been taken, research can only give ideas and not specifics relative to the CSF.

The standardized von Bekesy test that the Nicolet Optronics CS 2000 utilizes has a number of drawbacks. Data from this testing methodology can be highly variable making the difference between a subtle defect and normalcy difficult to interpret and diagnose. Allowing the subject to see the spatial frequency gratings for any period of time, as the von Bekesy method allows, can create perceptual afterimages and spatial frequency fatigue subsequently changing the observer threshold. Also, observer testing time is approximately 40 minutes for both eyes provided the proper adaptation precautions are taken using this methodology. By using nonstandardized options, the complexity of the Nicolet system can create increased demand for working knowledge of programming capabilities and usage.

Other drawbacks include the physical capabilities of the CRT screen display. At spatial frequencies greater than 20 CPD, with contrast at subthreshold level, the observer may report the grating. This may merely be the presence of the vertical raster lines and therefore invalidate any subsequent test results. Also, the physical size of the screen, 4.3 degrees in width at 3 meters creates limitations in which future testing methodologies may indicate the need for larger or smaller screens. One last drawback for the average clinician is the cost of the CRT system. The Nicolet Optronics CS 2000 system is about $11,000.00 while the Cadwell system is $9,000.00 which may or may not be a drawback for use as an auxilliary testing device.
Perhaps the biggest drawback for all types of contrast sensitivity testing lies in the fact that they are a subjective test. A given observer's response is influenced by a wide variety of external and internal variables that may or may not be pertinent to the investigation. Studies are just beginning to indicate how much some of these variables contribute to the final threshold and therefore it is important to mention some of these.
CONSOLIDATING FACTORS AFFECTING THE CSF

Of paramount importance in the clinical evaluation of the CSF is the establishment of normal testing protocol and controls. Previous research has not been consistent in this respect making it difficult to properly evaluate the literature. When comparing interocular CSF findings, many of the confounding variables affecting the CSF are significant. But when trying to compare CSF findings between subjects, it should be noted what confounding variables may contribute to the CSF. There are two broad categories that should be considered when using the CSF as a clinical investigational tool. The first deals with subjective testing factors or internal variables, while the second category deals with environmental factors or external testing variables. Studies are just beginning to indicate how much these individual elements may affect the CSF and therefore information is limited in this respect. What will be presented are factors that are either controversial or obvious when interpreting the clinically derived CSF.

Subjective Testing Factors

Luminance

One of the most cited factors relative to subjective response is the effect of mean luminance from the overall display on the CSF (Patel, 1966). It is well known that extreme illumination levels, e.g. driving in the sun, can decrease the
CSF. But, in the high photopic range, there is little...

As luminance decreases sensitivity decreases. A change in the normal inverted U shaped curve occurs at low illumination levels with the low spatial frequencies falling off and disappearing. The peak of the CSF shifts to lower spatial frequencies. The luminance parameter in itself could clinically be significant, since as in a few reported instances, luminance specific CSF abnormalities have been reported (Sodis-Wollner, 1980). Therefore it is important to note and specify luminance levels when testing the CSF.

Luminance also plays a part in the adaptation level in testing of the CSF. Typically, when testing the CSF, one eye is covered so the observer can respond with each individual eye. If the previously covered eye has not been properly adapted to the luminance of the test screen, an abnormal threshold may result. This is one of the confounding factors that can affect both interocular and intersubject CSF test results. The threshold changes may be small but this is a factor to recognize when administering the CSF test.

Adaptation

Another major factor of subjective testing is that of adaptation. Gilinsky (1968) first introduced the idea that prolonged exposure to different patterns of light would selectively decrease the viewer's visual discrimination threshold. Blakemore and Sutton (1969) demonstrated that prolonged exposure to gratings of a given spatial frequency disturbs the detection of other spatial frequencies. They found the CSF to be shifted away
from the adapting frequency, i.e. prolonged exposure to low frequency band gratings make the grating bars appear broader and when high frequency bars are utilized, the grating bars appear thinner. Blakemore and Sutton found that for shorter periods of time, 60 seconds or less, recovery of selective frequency sensitivity was completed in an amount of time comparable to the exposure periods. How much bearing this exposure has on clinical testing is not known but it is another factor to be considered when using certain testing methodologies.

Optical Factors

Optical factors that may affect subjective testing responses fall into three categories. Two of these categories are related to the refractive structures. They are optical blur effect and magnification effect. As mentioned earlier (Campbell and Green, 1965), differences between the external gratings of CRT findings, which include both ocular refractive and neuroretinal components of the CSF, and intracrurally produced gratings of laser interferometers, which bypass the ocular refractive structures, have shown that the ocular refractive structures predominantly affect the higher spatial frequencies (9 to 30 CPD). Lower spatial frequencies (1.5 CPD) are essentially unaffected by refractive errors and such losses in the CSF are primarily neuroretinal in origin (Arden, 1977A, Bodis-Wollner, 1980). Depending upon the distance between the observer and the test display, the observer's depth of field does not always include the screen. A possible explanation is that the
display of sinusoidal gratings combined with a reduced or absent room illumination does not provide adequate stimulation for accommodation. Fortunately higher spatial frequencies, which are most affected by optical blur, provide a greater stimulation to accommodation than lower spatial frequencies. Nevertheless an improperly focused accommodative system in front of or behind the test screen can affect sensitivity to higher spatial frequencies of the CSF, depth aid notwithstanding. Therefore, when testing the CSF it is obviously important to have the observer properly corrected for the test distance.

In addition to blurring effect relative to the CSF, it is noted by Allen (1967) that an increasing amount of light scatter, notably in the crystalline lens, occurs significantly over the age of 40. How much this may affect the CSF is not clear.

The second category of optical factors deals with the relative magnification of an observer's corrected optical system. Magnification of an image shifts the CSF peak toward higher spatial frequencies (Bradley and Freeman, 1981). It is difficult to precisely compare the CSF of a corrected myope and the CSF of a corrected hyperope. An interesting study by Bradley and Freeman (1981) of anisometropic amblyopic subjects pondered the interocular differences created in subjects with a difference in aniseikonic imagery. The conclusion was that in addition to some neural deficits of the amblyopic eye, the CSF differences between the two eyes may be due to magnification differences. This is yet another question that arises when comparing CSF test norms between subjects.

A third category pertaining to the ocular system is pupil
size. A pupil that is too small will degrade the CSF. A pupil size of 2 mm or less agrees with the optical attenuation predicted for a diffraction limited system. A pupil larger than 2.5 mm avoids diffraction but optical aberrations may degrade the CSF. With increasing pupil size there is a general increase in contrast sensitivity at all but the lowest spatial frequencies. Bodis-Wollner (1980) states that with a dilated pupil, the effective power of the eye increases for a detection of low spatial frequencies.

Aging

As cited above, an increase in the scattering of light in the refractive ocular structures occurs with age along with a decreasing pupil size. These may only be partial contributors to a reduction in the CSF with age, but the type of CSF losses, either high or low, seems to be in dispute. Deerfeldt et al (1979) found high spatial frequency loss (greater than 4 CPD) more common in subjects over 60 years, in contrast to Sekular and Hutman's (1980) estimate of a three-fold drop in lower spatial frequencies in the elderly. Arundale (1978) reported young (8 to 15 years) observers were less sensitive to low frequencies while old (35 to 66 years) were less sensitive to high spatial frequencies. In contrast Sekular et al (1981) reported older (mean 74.2 years) observers were less sensitive to low frequencies and needed more contrast to detect faces. Even in the case of Arden plates, which have been utilized thoroughly in the clinical setting (Harris, 1981, Sekular, 1981), critics (Singh, 1981) have cited high false negative rates due to optical...
variables and macular disease. These studies on aging are typical of the confusion in the literature due to lack of uniformity and standardization.

Testing Methodology

The type of testing methodology used is significant as each method gives different CSF thresholds. When utilizing static gratings, the thresholds found with the von Bekesy method versus the method of seeing to nonseeing (or the inverse method of nonseeing to seeing) will differ significantly. This can make it difficult to compare anomalous results from one investigation to the next.

The method of nonseeing to seeing seems to be the method of choice in the clinical CSF testing. When using the method of nonseeing to seeing, the overall testing sensitivity will be higher in comparison to other testing methods. Most observers using this testing methodology will note that they see the grating well in advance of their responses. The sudden realization of recognizing the target is a normal psychophysical phenomenon that can alter an observer’s subsequent responses. The astute observer who notes this when first being tested may try to anticipate subsequent test exposures and thus raise the sensitivity values. In the case of the Arden gratings, the observer may begin to note by how much the grating is pulled out of the pocket which in turn could alter the subsequent sensitivity reading. Since subsequent gratings have normal sensitivity at different positions of the grating, the observer
may become disturbed due to not seeing the grating of a different frequency at comparable levels of the previous grating.

A similar situation occurs with the presentation time using the CRT with a computer. By having the same presentation time from the subthreshold preset, an astute observer can anticipate the time it takes from the preview of the grating to the threshold point. This can obviously affect subsequent sensitivity values. Since the presentation rate is operated by computer, a randomized subthreshold starting point can be preprogrammed to avoid anticipation effects that can occur with constant subthreshold starting points. Perhaps the best way of getting a more consistent observer response is to provide a good set of preset instructions telling the observer what he may experience. But then again, this may create a different set of responses due to the differing manner in which the tester explains the test. In addition, the instruction set could be taped allowing the same set of instructions to be given to all observers in the exact same manner. Obviously this shows the need for a given set of clinical instruction protocol regarding the administration of CSF testing.

Other methodologies such as the von Bekesy take the mean between the observer's first recognition of the grating and the response when he no longer sees the grating. This seemingly implies a compromise CSF between the CSF found in the limits of seeing to nonseeing and its inverse of nonseeing to seeing. The von Bekesy method results in a mean CSF value with a large standard deviation which can greatly overlap with anomalous standard deviations when using the same method. Also, because
the observer is exposed to the grating for a longer period of time, adaptational effects, as mentioned previously, may affect the CSF results. Consequently, this hasn't been the method of choice partly due to these factors.

The method of seeing to nonseeing has the above-mentioned problems of adaptation and may have too low a sensitivity level for legitimate comparison of anomalous results taken via the same methodology.

The above-mentioned methodologies refer to static gratings. By using other modes such as counterphasing gratings, the low spatial frequencies of the CSF disappear (Bodis-Wollner 1980). This is a form of temporal modulation that can be visualized by each white bar changing place with a dark bar several times per second. Temporal modulation up to a certain temporal frequency introduces an increased threshold at low spatial frequencies and this may be another mode for evaluating defects in low spatial frequencies.

What is obviously needed in the literature and in the clinical testing of the CSF, is proper description of the testing methodology. The type of methodology, randomization of subthreshold starting points and standardized pretesting instructions are all important in obtaining a more consistent evaluation of the CSF.

Fixation

When an observer constantly fixates on the CSF testing target display, a bleaching effect may be increasingly reported.
during the testing of later frequencies. Arden (1979A) suggests, when using the Arden plates, to have the observer scan the top portion of the pocket which may help in reducing this effect. Just how this affects the contrast levels of given spatial frequency gratings is not in the literature at present.

CSF defined in terms of eccentricity from the fovea has been reported (Hochsteiner and Shapely, 1976). Using flashed grating patterns, the CSF 12 degrees from the fovea shows a shift in the peak to about 2 CPD versus a normal peak location of 5 CPD. While the overall sensitivity is lower in the periphery, the contrast sensitivity curve for a given eccentricity undergoes the same changes with luminance as the central retina. Hilz and Cavonius (1974) found, that when measuring the CSF from 1 to 32 degrees temporally, the manner in which sensitivity falls off was different for high and low spatial frequencies. With 20 CPD or greater, the fall-off in sensitivity was linearly related to eccentricity. With low spatial frequencies, sensitivity was relatively constant up to a certain eccentricity, after which the fall-off in sensitivity was the same as for all high spatial frequencies.

There are no doubt other internal factors that have not been presented here. Internal subjective factors are more difficult to control, but by being more aware of these factors, internal variables of the CSF can be kept to a minimum, making test results more valid. External testing variables are much easier to control but can create major changes if not considered properly.
External Testing Factors

Physical Testing Display

A wide variation in the production of gratings has been reported in the literature. CSF has been measured by interference fringes, projection techniques via oscilloscopes, CRT displays and preprinted plates. Clinical use has been mainly limited to that of preprinted plates and CRT displays. Generally, the literature describes the physical test display production used. It is important when reading the literature to know what type of methodology was used as this has obvious effects on the outcome of testing results.

Display Size

Display size of the target is an important factor to be noted as it is one of the components used in the derivation of spatial frequency (see appendix). Display size is also an important factor because width or length differences affect the CSF. Campbell and Robson (1968) demonstrated that increasing the field size from 2 to 10 degrees created enhancement of spatial frequencies of less than 3 CPD. For high spatial frequencies, the field size showed no effect. The limitation for the field size is the number of cycles presented at a spatial frequency. With less than 4 cycles in any grating, the CSF threshold rises considerably according to Hoekstra et al (1974). This could explain contrast sensitivity losses at low spatial frequencies in observers with visual field defects. Decrease in the grating
length (vertical extent of the gratings) also has an effect on the lower spatial frequencies of the CSF (Koening, 1979). This may be relevant to understanding CSF losses in observers with vertical restrictions in the visual field.

Sizes of the CSF targets have not been standardized, partially due to variations in the production of grating targets. Larger target screens are increasingly costly but are versatile at varying distances. Target size is a factor that is often omitted from the literature. Its effects, as noted above, can alter CSF thresholds.

Target Distance

Target distance indirectly affects the CSF due to factors cited previously, i.e., focusing posture and display size. The target distance and size of the screen are calculated to figure the angular subtense that comprise how many fixed cycles fall into one degree. Since the desired cycles per degree to be tested are calculated relative to the distance and target size before the test is administered, any subsequent change in distance after the test has begun would obviously require a recalculation due to the change in angular subtense. Target distance creates a varying stimulus parameter to the focusing posture of the eye which could potentially affect the CSF.

Presentation Rate

Presentation rate as mentioned in the methodology section can affect the CSF threshold. If the rate at which the target appears from subthreshold to threshold is too fast, the contrast
will change quickly, and the observer's reaction time will interfere with proper data interpretation. If the rate is too slow, observers may get impatient, leading to spurious and unreliable results. In addition to this, there may be differences in the presentation rates that occur between the astute or practiced observer versus the older or unpracticed observer.

Reflections and Shadows

It is obvious that reflections or shadows can alter the CSF results. CRT displays don't have this problem as typical testing is done in a dark-surround testing condition. Arden plates do have this factor to contend with and, therefore, steps should be taken to minimize shadows and reflections that may occur when administering this test.

It cannot be emphasized enough that standardization of the CSF protocol must be adhered to in order to make the CSF evaluation more valid and reliable. By initially providing a standardized set of testing parameters, variations can be clearly noted so that confounding cryptic factors can be assessed along with the primary investigation of the test. Standardization would eliminate much of the stigma that the CSF has received due to the many confounding variables. Standardization of the above results could make the CSF a more widely accepted procedure among clinicians in addition to being more widely read in the literature. The conditions for which the CSF has been utilized are presented next.
Evaluation of the CSF for Clinical Diagnosis

Presently contrast sensitivity studies are primarily utilized in research; as more investigations are conducted findings indicate that some abnormalities in the CSF can be indicative of pathology. Since the studies cited often are concerned with a limited number of patients, no definite profile for a specific disease has yet emerged. The confounding factors as already mentioned and the variety of test conditions also preclude the use of the CSF as a single basis for diagnosis. There are no population norms established as of this writing and age variations have not been fully analyzed. However, variations of the CSF may qualify as a screening device or as a means for verifying already suspected impairments. A summary of the papers in current literature, which are concerned with the visual problems most conducive to evaluation with contrast sensitivity measurements, will be presented here. The reader is cautioned, however, that the test conditions are not standardized and, therefore, the CSF cannot be used alone as a basis for diagnosis; it is merely an addition to standard optometric testing. The CSF gives additional insight into consequences of visual disorders which are often functionally evident to the patient but, impossible to quantify with standard methods.

Test parameters, e.g. mean luminance, test distance etc. have not been cited here for each study because these sometimes vary greatly, from study to study and sometimes are not given.
Neurological Disease

In neurological disease, patients may present with complaints of blurred vision, but have normal Snellen acuity. The Snellen number only establishes the endpoint on the contrast sensitivity function. Bodis-Wollner and Diamond (1976) measured the CSF of patients with cerebral lesions. These patients complained of blurred vision but exhibited normal or only minimally diminished acuity, normal central fields and no pupillary or oculomotor dysfunction. Of the 35 patients involved, most showed greater than 50% elevation of thresholds in comparison to predetermined norms. Three different types of losses described were: high frequency loss, uniform reduction over the entire range (level loss) and selective loss in the intermediate frequency interval (notch loss). No conclusions were drawn relating type of loss and position or nature of abnormality.

Patients having the same VA measurements had markedly dissimilar contrast sensitivity functions, indicating the varying disruptive modes. The selective frequency losses found in post-chiasmal lesions are similar to the depression seen in the CSF after adaptation to a grating (Bodis-Wollner and Diamond, 1976). This evidence is suggestive of visual channels corresponding to the parallel spatial frequency selective channels suggested by Campbell and Gubish (1966). Bodis-Wollner and Diamond (1976) further suggest that since neurons are sensitive to different frequencies and have overlapping fields, lesions may allow visual fields to remain intact to perimetry presenting a single stimulus, but a complex stimulus with multi-channel frequencies,
to which affected neural elements are sensitive, may indicate the perceptual defect. The possibility of orientationally selective losses needs to be explored utilizing gratings with orientations other than the standard vertical direction.

In evaluating patients with compressive lesions in the anterior visual pathway, Kupersmith et al (1982) found 94% showed abnormal CSF by comparison to previously determined age-matched norms. Improvement in the CSF was documented after surgery although the function did not return to normal. Those with more than 20% improvement in the CSF had a corresponding improvement in color vision and in visual fields; those with less than a 20% improvement showed no recovery in color vision or in visual fields.

Specific studies on patients with retrobulbar neuritis (RBN) have been published by Arden and Gucukoglo (1978). In a test group of 57 patients, 36 had been diagnosed as having RBN, of these 29 were found to have an abnormal CSF and 7 showed a bilateral abnormality. 21 positively diagnosed multiple sclerosis (MS) patients were found to have an abnormal CSF in 18 of the affected eyes and in 12 of the unaffected eyes. This suggests that the CSF may be an adequately sensitive test of demyelination and may possibly be useful in early detection of MS. In two other studies the CSF has been heralded as useful in MS differentiation. Kayazuma et al (1976) found marked attenuation in all frequency ranges in M.S. and Arden (1979B) reported up to 40% of patients with MS demonstrated normal Snellen acuity and a decrease in contrast sensitivity.
Raymond, Regan and Murray (1981) claimed 44% abnormal sensitivity in patients diagnosed with MS but no history of ocular involvement; of these, 7 were found to have bilateral deficiencies, again indicating the CSF may facilitate early diagnosis of MS. The deficiencies occurred at intermediate and/or low spatial frequencies with high spatial frequencies normal. It had been postulated that test sensitivity in MS may be dependent on the grating orientation or on an adaptation (abnormally rapid or severe) to the grating. When Raymond et al (1981) tested this, the information obtained was opposite to that expected; adaptation did not produce as great an elevation of contrast threshold in MS patients as in the control subjects. The MS patients were found to adapt more slowly than normal. Little or no threshold elevation occurred in the phases following exposure to the adapting pattern of low relative contrast, however, the MS patients eventually reached the same threshold as normal but took approximately four times the normal adaptation period to do so.

Retinal Disease

Disease affecting the neural layer of the eye has been investigated and found to be associated with abnormalities in contrast thresholds. Grating tests depend on the integrity of the peripheral and central retina and small punctate lesions in the periphery may affect signal transmission. Wolkstein, Atkin and Bodis-Wollner (1980) report seven of nine subjects with retinitis pigmentosa suffered high frequency loss coincident with normal visual acuity. Some unexplained findings
reported by Wolkstein et al (1980) indicate that persons with central serous retinopathy had a level loss with the graph cut-off falling below that which corresponded to their Snellen acuity. In macular degeneration there was a level loss and a high frequency loss again not correlated with Snellen acuity, but this time the cut-off frequency, in three of the four subjects, was higher than would be expected by the measured acuity.

Sjostrand and Frisen (1979) report, in the early stages of macular disease, a reduction in high and mid frequencies; in advanced disease the decrease extends across a greater spectrum. Conversely, Arden (1979b) reports a greatly reduced sensitivity to low spatial frequencies. However, Sjostrand and Frisen reported their findings for normals differed from those previously reported. The peak occurred at a higher frequency, probably due to the use of a higher space-average luminance in the television-based display compared to the cathode ray tube formerly used.

In addition, Arden (1979b) reports that the normal eye, in those with unilateral senile macular degeneration and normal VA and ophthalmoscopic findings, shows a loss in contrast sensitivity, which may indicate the beginning of disease. The macular degeneration symptom is generally a reduction in acuity but this does not always equate with the loss in perception actually experienced. The perceived loss in the patient’s visual world may be greater than that shown by Snellen measurement. Even in macular degeneration patients with a minor reduction in VA, a pronounced loss in contrast sensitivity is found. The CSF may
give insight into the visual problem of macular disease. Vision is often aided with magnifiers, and may be enhanced with attention to adequate contrast.

Arden (1979B) also reports 60% of the diabetics having normal VA and no retinopathy, had a reduction in contrast sensitivity. 100% of those diabetics with visual acuity of less than 20/40 showed some loss in the CSF.

In a study done by Ghafour et al (1982) the normal patient curves agreed with those found by Arden and Jacobson (1978) except for plates 5 and 6 where a significant decrease was found for normal sensitivity. In addition, an increase was found for the higher frequencies of plates 6 and 7 in the diabetic. These differences may reflect age differences between the two studies. Investigation by Singh et al (1981) agreed with the Ghafour findings. Ghafour also addressed the question of comparison between background retinopathy and proliferative retinopathy. A significant difference was found on plates 3, 4, and 5 in those without retinopathy compared with those having background retinopathy. In proliferative retinopathy a difference in all plates but number 2 was found. Proliferative changes showed an increase on plate 5 and 7 compared to those with background retinopathy. The statistical variance for each plate was greater for the diabetic than that for the normal. Diabetic patients with visible signs of fundus changes showed an increased threshold at higher frequencies.

In the Moloney and Drury (1982) study 40% of 123 eyes in insulin dependent diabetes mellitus and normal visual acuity showed an abnormal Arden score. Color disturbances have been
recorded in the diabetic and Moloney and Drury reported that an abnormal Farnsworth-Munsell (100 hue test) was likely to correlate with an abnormal Arden score. Hue and contrast discrimination may have a common etiology (Moloney and Drury, 1982). However, they found no significant differences in those with or without retinopathy; the mean scores and the prevalence of abnormal scores did not correlate with age or duration of disease.

The CSF may not be useful in separating patients into those with serious and not serious classes of retinopathy because of the large standard deviation found in the Ghafour et al (1982) study, but, it may be useful assessing the functional status of the eye. Perhaps the abnormalities in the CSF may represent diabetic eye disease unrelated to vascular change.

Glaucoma

The use of the CSF in the screening for glaucoma is controversial. Arden and Jacobson (1978) indicated severe contrast losses in glaucomatous patients with normal or near normal acuity. Using the Arden plates the performance was poorest on plates 6 and 7. According to this study changing various factors, e.g. luminance ranging from 130-159 candelas with or without miosis, had no significant effect on the difference found between normal subjects and those diagnosed with glaucoma. However, Singh et al (1981) reported, when using plates 6 and 7 for glaucoma screening in the elderly, a false negative rate of 83% for plate 6 and 52% for plate 7. They
predicted a false positive rate of 17%. Sokol et al (1981) found no significant difference in age-matched subjects between normals, patients with glaucoma, and those with ocular hypertension. In addition a high false positive rate was determined in normals over age 50. In the Lundh and Lennerstrand (1980) study, using both Arden plates and a CRT, the examiners could not differentiate normal eyes from glaucomatous eyes.

Some modifications to the testing method may be advantageous in the detection of glaucoma. Lundh and Lennerstrand (1981) adapted the test situation to probe the paracentral area since this is where the early defects are found. A red fixation light was shown on the oscilloscope above or below the center of the screen. In all the glaucoma patients the CSF was found to be normal or only slightly reduced in the central area but in the paracentral area, two-thirds of the patients had decreased sensitivity well below the normal.

Wolkstein et al (1980), in a study of 18 patients with glaucoma and 20/20 acuity, found a reduction in the cut-off frequency and some patients had contrast sensitivity loss at low spatial frequencies, but these findings were not consistent for all subjects. Further testing utilizing a low frequency grating in conjunction with 'counterphase flicker' revealed sensitivity deficits in nearly all glaucoma patients and in some ocular hypertensives. Some ocular hypertensives will eventually show cupping and field loss while others will not. An invaluable test would be one which could predict those who would show such symptoms unless the IOP is controlled.

Wolkstein et al (1980) continued the study of those with
high intraocular pressure. Two different presentations were used in testing the contrast sensitivity; diffuse flicker, in which the screen appearance changed uniformly light to dark and counterphase flicker in which the grating pattern was alternated with the bars shifting right and left, i.e. the second grating was one-half cycle out of phase with the first. The temporal frequency was 8 hertz in each flicker pattern and the mean luminance in diffuse flicker was equal to that in the counterphase flicker. Results of each test alone did not appear significantly different between the groups, but the average of the two methods, termed DRC (dynamic response coefficient), was consistently lower in all the glaucomatous eyes and in half of the hypertensive eyes compared to normals. This modification may prove useful in recognizing glaucomatous damage before the losses of function occur.

Cataracts

Since cataracts are a normal consequence of the physiological aging of the lens, it may be useful to first cite some studies concerned with age-normed CSFs. The problem again in using these as a basis for standard functions is the limited number of subjects and the lack of standardized procedure. Arundale (1978) tested 36 patients aged 18 to 67. CSF curves for the 8-15 year olds and the 18-39 year olds peaked at 4 CPD. Those in the age 45-66 group peaked at 2 CPD. The younger group showed slightly lower sensitivity to low and mid spatial frequencies than did the middle group and the older group was
less sensitive than the middle group at mid and high spatial frequencies. In a larger study of 100 normal subjects, conducted by Skalka (1981) a significant increase in test scores was noted. Skalka's scores tended to be higher than those reported by Arden. The contrast had to be increased over that necessary for the younger for both coarse and fine gratings in order to be seen by the older subjects, i.e. threshold increased with age.

Skalka (1981) reports a wide variability in Arden grating scores obtained in patients of the same age and acuity with similar posterior subcapsular cataracts and was unable to derive norms for this condition. Only subjective symptoms seemed to correlate roughly with Arden scores; slitlamp exam, fundus exam and Snellen acuity did not. Hess and Woo (1978) indicate that the Snellen acuity may grossly overestimate the visual world of the cataract patient. In their study no one single description of the loss of visual function was formulated, but, generally, degradation of the high spatial frequencies was expected due to optical interference as indicated by Hess and Howell (1977), with the low spatial frequencies affected by neural elements. CSF in a cataractous patient may be utilized in a borderline case when contemplating surgery. If a significant amount of low frequency loss is found in addition to the high loss there is a possibility of neural impairment.

Reading Disabilities

It has been theorized for some time that visual problems may play a role in reading disabilities. Lovegrove et al (1982) tested two groups, one of students with average or above
average reading ability and the other of students reading below their grade level. It was determined that the two groups differed in spatial and temporal processing. At short durations of stimulus presentation the normal reading group and the disabled reading group had similar CSFs. The patterns began to differ when the stimulus was presented for longer durations. The normal students showed an average curve with the peak at 4 CPD, while disabled readers showed no peak but only a monotonic decrease in sensitivity. These findings were confirmed in a later study by Lovegrove et al (1980). The critical stimulus duration was the same as that of a reading fixation. This is where the sensitivity breaks down and, therefore, where the problem is maximized.

There are two components in visual persistence. The first may result from temporal integration and the second may be influenced by contrast and grating orientation. The latter component is measured by a long stimulus, which does not affect retinal persistence but does affect the cortical level (Lovegrove et al 1982). Lovegrove et al (1980) also investigated whether or not the difference between the two groups came directly from the differences in reading ability. Mayer (Lovegrove et al 1980) suggested that the increased sensitivity to oblique gratings occurs between the ages of 5 and 11 and is a partial result of learning to read. Lovegrove's investigation showed no difference in the "oblique effect" in the CSF between the two groups, this indirectly shows that the sensitivity differences are not a direct result of the reading ability differences. The measurement of contrast sensitivity
could become a screening tool in recognizing potential reading problems in the very young.

Ambyopia

Much of the knowledge of the CSF has been based on research done in the laboratory with amblyopia. Intersubject variables can be negated by taking the CSF on the amblyopic eye and comparing it to that of the normal eye. Hess and Howell (1977) postulated two different types of strabismic amblyopia. Type I involves only high frequency losses, which is similar to optical blurring. Type II was thought to be a superimposition of low frequency loss on the high frequency loss. They speculated that type II may be a simple extension of high frequency type I loss or a more severe or further progressed case of amblyopia. Their type I and type II classification might possibly differentiate between contrast sensitivity loss due to variables of optics and eccentric fixation from that of a neural loss which involves the low spatial frequencies. Thomas (1978) found losses in all frequencies in the strabismic amblyope. The CSF changes, according to the Thomas study, are as follows: (1) overall decrease in function sensitivity, (2) peak sensitivity shift toward decreased spatial frequency, and (3) reduction in the cut-off frequency for detection of pattern and flicker. Although, the CSF has not been utilized much clinically, Kayazawa et al (1976) have reported that the function improved in the amblyopic eye after occlusion of the other eye. The contrast sensitivity measure has potential as a monitoring device during amblyopia
therapy.

Corneal Changes

CSF may be capable of evaluating visual loss from corneal abnormalities and enable assessment of improvement. In an experiment by Hess and Garner (1977) anoxia-induced corneal edema (probably epithelium limited) produced a decrease in contrast sensitivity to high frequencies, with no effect found on the peak or the low frequencies. A study by Hess and Carney (1979) in experimentally-induced corneal edema (probably limited to stroma) indicated a depression in the sensitivity to both high and low bands. Hess and Carney (1979) in addition evaluated the CSF for experimentally induced corneal distortion and found that the contrast threshold was affected at high and medium frequencies, but the low frequencies were not affected; the visual effect was similar to a defocused or abnormal optical system. The contrast attenuation clearly differed for distortion and edema. Since it is difficult to cause edema without some irregular topography the altered corneal shape may have been a major contributing factor in the earlier study.

The effects of edema can be thought of as a dioptric defocus and the high frequency channel losses parallel the changes in corneal thickness. When a diffuser was used to simulate edema, low frequencies were affected even more. It is possible that effects from distortion were involved.

In the keratoconus patient, low spatial frequencies were unchanged with the mid and high frequencies affected (Hess and Carney, 1979). The high frequencies were progressively affected
with the progression of the disease. With advanced disease involving areas of opacification, low frequency loss was experienced, as with scattering. Vision, in cases of intraocular scattering, cannot be adequately evaluated solely with typical letter acuity measurement.

Contact Lens Wear

As mentioned previously, there are two independent components of the CSF. The first is the optical component, which is affected by optical imperfections, diffraction, and scatter that degrade the retinal image; the second is the neural component due to physiological losses and interactions which affect the processing in the retina and visual pathways. Any change in the lens-eye system is demonstrated in the optical component and not in the neural, and the CSF is an excellent indication of visual optical performance.

There are conflicting reports in the literature concerning the effect of contact lenses on contrast sensitivity. Applegate and Massof (1975) reported decreased contrast discrimination with soft contact lenses as compared to the measurement with spectacles and hard (PMMA) lenses. In several of the subjects in this study, there was no correlation with Snellen acuity. The increase in contrast threshold was probably secondary to uncorrected residual astigmatism. Mitra and Lamberts (1981) report a significant decrease in contrast sensitivity even in those with no residual astigmatism. This loss was seen on twelve myopes after two weeks of soft contact lens wear. The loss was
postulated to be at least partially due to effects of deposit formation.

Woo and Hess (1979) reported on three patients, two of whom had no visual complaints, and showed similar functions with both spectacles and soft lenses. The third patient complained of reduced vision upon insertion of the lens which was not indicated via letter acuity measurement, but, was evident as a significant decrease in contrast sensitivity at all frequencies—most notably the high frequencies. This finding suggested to the investigators an aberration effect which was not amenable to refractive correction.

A study by Bernstein and Brodrick (1981) concentrated on carefully chosen subjects with residual astigmatism less than 0.12 diopters. They wore a spectacle correction on one eye and a soft contact lens on the other eye continuously for eighteen hours. No significant difference in the CSF was found and it did not deteriorate over time. It may be that the CSF discrepancies are a function of any refractive error left uncorrected and this loss is not found via conventional visual acuity assessment.
CONCLUSION

Contrast sensitivity measurement (CSM) entails a new dimension in optometric testing. The number of variables affecting this measurement demand rigid test conditions. Since these conditions have not been standardized in the clinical settings reported here, the practitioner should establish a specific methodology controlling the aforementioned variables and standardize test methods. Then it is recommended that the tester run a series of CSFs on patients free of disease and establish a set of norms unique to the given clinical setting.

Although the CSM cannot be used to diagnose disease, at this point, its value lies in the recognition that Snellen acuity may overestimate the visual performance of the patient. Subjective complaints which do not correlate with the measured acuity may indicate visual defects only substantiated by CSM. Above all, it may be reassuring to the patient that the practitioner does recognize the complaint and has a means of quantifying it.

In the differential diagnosis, no established trends of CSF can be adhered to at this time due to the variable methods and conditions utilized in the reported investigations. The reader is urged to refer to appropriate sources for comparisons among test conditions. The position of contrast sensitivity tests in the inventory of visual function testing has yet to be firmly established.
Figure 2. Contrast sensitivity function visuogram depicting (1) graphing components, (2) normal and abnormal contrast sensitivity functions, (3) visual acuity relationship to contrast sensitivity function and, (4) estimated breakdown of contrast sensitivity categories.

(1) Grating components are logarithmically graphed on both abscissa and ordinate. Spatial frequency lies on the abscissa, while sensitivity or threshold (sensitivity = 1/ threshold) lies on the ordinate. CSF log graphing allows for simple addition or subtraction between two different contrast sensitivity functions. Log graphing also gives the normal CSF its characteristic inverted "U shaped" configuration.

(2) Four cases of differing contrast sensitivity functions are depicted. Plot A (squares) is a normal CSF under a typical set of test conditions. Generally, contrast thresholds are taken at five to eight selected spatial frequencies and a curve is derived from this. The dashed line at the end of the high spatial frequencies is projected to calculate a potential visual acuity. Plot B (triangles) depicts a 'high frequency' loss due to a spatial frequency anomaly. High frequency loss is typical of a refractive defect. Plot D (circles) depicts a 'level' loss due to a contrast anomaly. Level loss is typical of a neuroretinal defect. Plot C (diamonds) depicts a 'notch' loss which affects the mid spatial frequencies leaving low and high spatial frequencies relatively normal.

(3) The dark arrow in the higher spatial frequency area depicts an area where typical 20/20 Snellen acuity testing lies in relation to the typical contrast sensitivity function.

(4) Top of figure depicts a rough breakdown of commonly referred to low, medium and high spatial frequencies. The literature does not clearly define these specific categories and therefore there is room for variation, resulting in overlapping of these categories.
Appendix

Derivation of Contrast

Contrast of a grating pattern is the change in distribution of luminance across the stimulus display. Contrast is defined by:

\[
\text{Contrast} = \frac{L_{\text{max}} - L_{\text{min}}}{L_{\text{max}} + L_{\text{min}}}
\]

(Luminance modulation)

Where \(L_{\text{max}}\) is the peak luminance (measured at the brightest point in a light bar) and \(L_{\text{min}}\) is the minimum luminance (measured at the darkest point in a dark bar). Luminance is the average amount of light per unit area coming off the stimulus display. Two gratings can be equal in contrast but different in mean luminance. Mean luminance must remain some absolute value e.g. 75 or 100 candelas per meters squared. Mean luminance is kept constant so true contrast sensitivity rather than luminance sensitivity is measured.

Derivation of Spatial Frequency

Spatial frequency is defined as the number of cycles in a grating
pattern subtending one degree of visual angle at the eye. Since the viewing distance of an observer is directly related to the visual angle of an object, the spatial frequency in cycles per degree can vary with distance. The spatial frequency of a grating can be figured from the number of cycles seen on the display if the visual angle is known. Visual angle is figured by:

\[
\tan \text{ angle} = \frac{\text{Screen width of display}}{\text{Viewing distance from display}}
\]

By dividing the number of grating cycles in the display by the degrees the display subtends, you obtain cycles per degree. For example, going back to figure (1), the grating display is 5.8 cm wide and the distance at which you view it is 165 cm. The angle whose tangent is .035 (5.8/165 = .035) is 2 degrees of visual angle. Now dividing the number of cycles displayed, which are 3, by 2 degrees, gives a spatial frequency of 1.5 cycles/degree.


