Contrast Sensitivity, Glare, and Quality of Vision

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Background

An understanding of what constitutes good or normal vision is fundamental to the eye care practitioner whose goal is to provide the best vision care to his/her patients. Traditionally, performance on the Snellen chart has been used to measure how well a patient sees, with 20/20 vision being the gold standard for what is considered normal. But life is not lived in a refraction lane and an individual’s visual demands extend beyond the boundaries of the phoroptor. A “perfect” 20/20 vision measured in the doctor’s office may be far from perfect in the real world. Even in the same individual, what is generally considered to be good vision may deteriorate into not-good-enough vision under specific work or environmental conditions.

Perhaps in no other area has the inadequacy of Snellen acuity as the sole determinant of visual performance been recognized as in the evaluation of cataracts. Cataracts are the most common cause of blindness and visual disability worldwide. Cataract surgery is the most frequently performed operation in the United States, with an estimated 2.5 million procedures done annually. Advances in surgical techniques and visual rehabilitation of patients undergoing cataract surgery have greatly increased the pool of mild-to-moderate cataract patients who are potential candidates for this operation. As might be expected, this has led to concerns on the parts of medical and consumer watchdog groups—as well as the federal government, who is largely responsible for picking up the tab for cataract surgery under the Medicare program—regarding the possibility of unnecessary surgery. While Snellen acuity has been the traditional criterion employed for determining when cataract surgery is indicated (with 20/50 or less best corrected acuity being the usual cut-off point for recommending surgery), many practitioners have been forced to deal with patients with better than 20/50 vision, but with significant visual disabilities associated with their cataracts, whom they suspect successful surgery would benefit. Because of this, any number of practical and ethical questions could arise: Who should decide when cataract surgery is indicated: the cataract surgeon, the cataract patient, or the government? When is cataract surgery really necessary? Is 20/50 Snellen acuity a reasonable cut-off point to define visual disability? And, if so, why are some individuals with 20/50 (or even worse) visual acuity satisfied with their vision, while others with better vision are not? Are there more reliable ways to measure functional visual acuity and to determine visual disability than using standard Snellen acuity?

While non-traditional, non-Snellen modalities to assess visual function have existed for some time, their use has been largely confined to the area of vision research. Thoughtful practitioners began adapting these modalities for use in clinical practice. Contrast sensitivity and glare testing were employed as adjuncts to standard Snellen acuity in assessing the need for cataract surgery. Quality of vision (as determined by contrast sensitivity and glare testing) became as important a criterion as quantity of vision (as measured by Snellen acuity) in deciding whether cataract extraction was indicated.

Not surprisingly, accusations were then made that these non-traditional arbiters of visual function were
being abused by over-eager cataract surgeons to justify operations when the Snellen acuity appeared adequate, with reports of 20/20 vision cataracts being performed in some cases.

The situation became a public health issue when in 1989 the American Academy of Ophthalmology convened a panel of medical and research experts to determine how to reliably test for acceptable vision and determine visual disability. The result was an Ophthalmic Procedures Assessment, which addressed the role and value of tests other than the standard Snellen acuity—specifically contrast sensitivity and glare testing—in assessing visual function in anterior segment diseases, particularly in cataracts. The report concluded that “…while it is premature to establish definitive guidelines for supplemental tests to visual acuity in assessing the overall visual disability from immature cataracts, contrast sensitivity or low-contrast visual acuity, measured before and after adding a glare source, is probably sufficiently specific and sensitive.” It went on to suggest that “…glare tests may be of help in adding to the objective assessment of the impact on visual disability of anterior segment disease.”

Resulting clinical interest in the use of contrast sensitivity and glare testing to assess quality of vision has led to the increasing use of these tests in other ocular—and systemic—diseases to determine how various disorders might affect visual function. It has also served to make the eye care practitioner more aware that quantity of vision may not necessarily equate with quality of vision, and to help explain the patient who consistently tests 20/20 in the practitioner’s office but remains dissatisfied with his/her vision.

It is important for the eye doctor to realize that there is more to testing—and correcting—vision than using the Snellen chart. Discrepancies between the quantity and quality of vision may signal the possibility of underlying disease. And even in the normal eye, the quality of vision and the visual experience may be affected by non-ocular factors—specifically environmental conditions related to light exposure and modulation—that may be addressed by the judicious use of spectacle lens treatments to provide the patient with the best quantity and quality of vision possible under diverse circumstances. A meticulously performed refraction is the surest way for the practitioner to provide 20/20 vision to the ametropic patient when ocular health allows. The appropriate use of spectacle lens treatments enables the practitioner to go beyond 20/20 with his/her patient and provide the maximum quantity and quality in vision correction.

**Snellen Acuity**

*What Is Snellen Acuity?*

The Snellen chart has become something of an ophthalmic icon when it comes to measuring vision. And 20/20, in addition to being considered synonymous with perfect vision, has evolved into a term unto itself, an integral part of our vocabulary. But what is Snellen acuity? What does 20/20 actually mean?

Snellen acuity is all about spatial resolution—the spatial resolution capacity of the central retina, more accurately. Measuring visual acuity indirectly assesses the spatial resolution capacity of the central retina. The higher the spatial resolution, the better the vision. The theory behind letter acuity is directly related to spatial resolution capacity as measured with gratings. A grating consists of spatially repeating light and dark bars. One cycle of a grating consists of one light and one dark bar, and when each bar has a width of 30 minutes of minarc, the grating has a spatial frequency of 1 cycle per degree (cpd). The Snellen chart presents optotypes of gradually decreasing size and correspondingly increasing cpd. The smaller the optotype (or the narrower the equivalent grating or the higher the cpd), the better the acuity. In a 20/20 eye, the equivalent of a 30 cpd grating can be resolved. In a 20/200 eye, resolution decreases to 3 cpd (Figure 1).

In more practical terms, an individual with 20/20 visual acuity is able to recognize letters that are approximately 1/3-inch tall on a Snellen chart from a distance of 20 feet. When vision is less than 20/20, the denominator of the fraction indicates the equivalent distance at which a normally sighted observer can identify the letters. With 20/200 visual acuity, for example, the observer would have to be at 20 feet to identify the same letter that a 20/20 sighted observer could identify at 200 feet.

**Contrast Sensitivity**

*What Is Contrast Sensitivity?*

If Snellen acuity measures how well the eyes see in black and white, contrast sensitivity acuity measures how well the eye can discriminate the various shades of gray. Contrast is a measure of relative distribution of lighter and darker parts of a visual stimulus. It is defined by the Michaelson formula, which relates the magnitude of the difference in light intensity between the light and dark areas to the overall luminance of the stimulus: (Lmax-Lmin)/(Lmax+Lmin), where Lmax is the luminance of the light bars and Lmin is the luminance of the dark bars (Figure 2). With decreasing contrast, the luminance difference in the grating is reduced until, at some level, the luminance difference is too small to be perceived. This point represents the contrast threshold. Contrast thresholds are normally related to spatial frequency by the contrast sensitivity function (CSF) (Figure 3).

*How Is Contrast Sensitivity Function Measured?*

Contrast sensitivity function can be measured clinically using special charts (eg, Peli-Robson and Regan low-contrast acuity charts).

With the Peli-Robson chart, letter optotypes are presented at a fundamental spatial frequency of 0.5 cpd. The chart consists of two groups of three letters per row. The contrast of each letter group decreases from 90% at the top of the chart to 0.5% at the bottom. Subjects are required to read the letters from top to bottom until two of three letters are named incorrectly. The contrast of the letter test consists of two charts of letter optotypes. The contrasts of the letters are 96% and 11%. All of the letters on a single chart have the same contrast and decrease in size from top to bottom. Subjects read the letters from top to bottom and the smallest identifiable letter is recorded for each chart. Using a nomogram supplied with the charts, a line is drawn between these two acuity measures. Contrast deficits are indicated if the slope of the line is steeper than normal.

*Why Is Contrast Sensitivity Important?*

The world is a visually complex place. Objects vary in many dimensions, including size, brightness, and contrast. Standard Snellen visual acuity measurements only provide information about high contrast resolution (ie, the smallest, high contrast object that can be seen). Contrast sensitivity testing helps provide important additional information about the visual world. This includes information about the visibility of objects that vary in size, contrast, and orientation.

**20/20: The Problem With Snellen Vision**

One of the problems with standardized Snellen acuity is precisely that it is standardized. In real-world viewing conditions, are not standardized. They vary and these variations can cause a normal 20/20 vision measured under conditions of high illumination in the absence of glare to deteriorate to a far less than 20/20 functional vision when illumination is reduced or glare conditions arise. Simply put, the Snellen chart is in black and white, while the real world exists in shades of gray. It is these shades of gray that need to be addressed in discussing quality-of-vision issues.
Contrast sensitivity losses can occur at high, low, and broad spatial frequencies. Various ocular and systemic diseases can affect contrast sensitivity functions in different ways and at different frequencies (Figures 4-6). It is especially important in patients presenting with normal Snellen acuity but with persistent visual complaints to consider evaluating contrast sensitivity to rule out possible contributing ocular—or even systemic—disease that might be affecting the quality of vision.

The value of contrast sensitivity testing in assessing visual impairment in cataract patients has already been discussed. However, the usefulness of contrast sensitivity, along with glare testing, in determining the need for cataract surgery with mild-to-moderate anatomical cataracts cannot be overemphasized. With most types of cataracts, a broad spatial frequency loss is encountered. High spatial frequency losses can be produced by optical or non-optical abnormalities (Figure 4). Conditions affecting the optical quality of the eye that may lead to high spatial frequency losses include refractive errors, mild cortical or nuclear cataracts, and various corneal disorders (eg, edema, irregularities, or opacities) (Figures 7 and 8). Among the non-optical abnormalities leading to high spatial frequency losses are mild amblyopia, macular disease, chronic open-angle glaucoma with moderate visual field loss, and retinitis pigmentosa (RP) in its early stages (Figures 9 and 10).

Contrast Sensitivity and Ocular Disease
Perhaps the most important determinant of contrast sensitivity is the health of the eye. A corollary of this is that abnormalities in contrast sensitivity may point to the possibility of underlying ocular disease and alert the clinician to the need for additional testing.

Figure 4. High spatial frequency loss and eye disease.

Figure 5. Low spatial frequency loss and eye disease.

Figure 6. Broad spatial frequency loss and eye disease.

Contrast Sensitivity and Normal Eyes
Recent research studied the effects of various spectacle lens tints at different levels of transmittance on contrast sensitivity acuity in normal subjects and in those with incipient senile cataracts. The impetus for the research was the realization that while spectacle lens tints are important in attenuating excessive light exposure and promoting visual comfort by decreasing illumination when necessary, the very decrease in illumination that is produced might adversely affect contrast sensitivity. The aim of the study was to determine: 1) if contrast sensitivity function was affected by spectacle lens tints and 2) whether there were differences in how various tints affected contrast sensitivity.

Results demonstrated that all spectacle lens tints produced an increase in contrast thresholds under glare conditions. There were definite differences in the amount of increase with the various tints, however, and these differences varied between the normal and particularly diabetic retinopathy—the eye care practitioner must be aware that visual complaints may sometimes point to a diagnosis of unsuspected diabetes and screen patients accordingly. This is especially important since diabetic retinopathy produces 12000-14000 cases of potentially preventable or treatable blindness each year.

In many of the previously mentioned conditions, Snellen acuity will be affected as well, indicating to the clinician that ocular health has been compromised. Occasionally, however, significant ocular disease may not be manifested by changes in Snellen acuity, and it is only after contrast sensitivity is found to be affected that more careful clinical evaluation reveals the presence of such sight-threatening disorders as optic neuritis, RP, or glaucoma.

Contrast Sensitivity and Normal Eyes
The real world is not black and white. It is the various shades of gray encountered in everyday life that make contrast sensitivity crucial in determining how well even a normally sighted individual truly sees. If the properly prescribed modern spectacle lens defines the black and white for the wearer, spectacle lens treatments—such as photochromics and anti-reflection coatings—may serve to fill in the gray in between. And, although contrast sensitivity testing may appear to be primarily a laboratory tool, the fact is that measuring contrast sensitivity acuity clinically is one way to go beyond the simple quantification of vision and gain important information about quality of vision.

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Results demonstrated that all spectacle lens tints tested (gray, brown, yellow, green, purple, and blue) produced an increase in contrast thresholds under glare conditions. There were definite differences in the amount of increase with the various tints, however, and these differences varied between the normal and
the cataractous eyes. In the latter, brown or yellow tints caused the least change in thresholds, while in the former, purple and gray tints were preferable. These differences are probably related to changes in clarity and transmission characteristics of the normal versus the cataractous lens.

Glare

What Is Glare?

Glare is the loss in visual performance or visibility, or the annoyance or discomfort, produced by a lumiance in the visual field greater than the lumiance to which the eyes are adapted. Luminance is defined in terms of the lumen: a unit of measurement of the amount of light incident on a surface. The higher the luminance, the brighter the surface.

Optimal lighting is in the range of 1000-1400 lumens. Examples of typical environmental luminances include:

- Indoor, artificial light: 400 lumens
- Sunny day, shady side of street: 1000-1400 lumens
- Sunny day, sunny side of street: 3500 lumens
- Concrete highway: 6000-8000 lumens
- Beach or ski slopes: 10000-12000 lumens

Glare may come directly from a light source (eg, facing toward the sun) or be reflected. There are four types of glare: Distracting glare, Discomforting glare, Disabling glare, and Blinding Glare.

Distracting Glare

Distracting glare results from light being reflected from the surface of an optical medium. Wherever the incident light moves from one optical medium to another (eg, from air to glass) some of the incident light is reflected. This results in reflections from the lens surface or in the presence of halos around bright lights at night. Distracting glare can represent an annoyance to the viewer and lead to eye fatigue.

Discomforting Glare

Discomforting glare results from incident light reflecting from smooth shiny surfaces such as water and snow, and becoming plane polarized. It can block vision to the extent that the wearer becomes visually compromised.

How Does Glare Differ From Contrast Sensitivity?

There exists considerable confusion about the difference between contrast sensitivity and glare. This is because glare is used in testing contrast sensitivity. Simply put, contrast sensitivity is about differentiating the various shades of gray. Glare, on the other hand, relates to how it becomes more difficult to differentiate those various shades of gray when illuminance is excessive. Contrast sensitivity tests measure the amount of contrast necessary to recognize a target. Glare sensitivity tests measure the change in visual function that results from a glare source in another part of the field of vision.

Disabling Glare

Disabling or veiling glare is when the level of light increases to 10000 lumens or more and it produces a glare that can actually interfere with or block vision. This type of glare causes objects to appear to have lower contrast than they would were there no glare. It occurs because the eye is not a perfect optical system due to inhomogeneities in the optical media that lead to light scattering which, in turn, reduces visual acuity and raises the differential light threshold. Disabling glare tends to become more problematic in the elderly, as the decreasing transparency of the crystalline lens that comes with age leads to incipient cataract formation.

Blinding Glare

Blinding glare results from incident light reflecting from smooth shiny surfaces such as water and snow, and becoming plane polarized. It can block vision to the extent that the wearer becomes visually compromised.

How Does Glare Affect the Abnormal Eye?

Glare sensitivity may be tested using contrast detection tasks or by acuity-based measures. The majority of glare tests in current use assess the effects of glare on contrast sensitivity by measuring contrast thresholds in the presence or absence of glare, since veiling luminance reduces image contrast. Acuity-based tests rely on the fact that acuity is affected by changing the contrast of the acuity targets. Targets used in glare testing may be point sources or extended-glare sources. Subjects generally are more comfortable with the latter.

Photophobia

What Is Photophobia?

Photophobia is a symptom, not a disease. Photophobia, as its name implies, is “a fear of light.” It is not the same as glare, although individuals who are photophobic tend to be more bothered by the effects of glare than those who are not. With glare, it is the amount of light or how it is presented that produces the problem. With photophobia, it is not necessarily the amount or the presentation that is the problem, it is simply the light itself.

Photophobia, or light sensitivity, is one of the most common complaints made to the eye doctor. It should be separated into two categories: pathological photophobia and non-pathological photophobia, where there is demonstrable ocular disease to account for the light sensitivity; and non-pathological photophobia, where there is no obvious ocular abnormality to explain the symptom.

Pathological Photophobia

A variety of eye diseases may lead to pathological photophobia. This type of photophobia can be truly disabling, even incapacitating at times, serving to compound the basic visual deficit caused by the underlying disease.

macular edema (Figures 13 and 14). An area of great interest relating to glare sensitivity at this time is in the post-operative refractive surgery patient. Both with older techniques (radial keratotomy and photorefractive keratoplasty or PRK) and newer laser techniques (LASIK and LASEK), a variety of qualitative vision issues may arise, even in the face of an excellent quantitative (20/20) result (Figure 15). These include problems with night vision, distortion, ghost images, monocular diplopia, and glare. Many of these are attributable to cataract haze and surface irregularities after surgery, producing increased incident light scatter with resultant Discomforting or even Disabling glare.
probably the most commonly recognized ocular condition associated with photophobia is albinism (Figures 16a and b). The characteristic white-blond hair, brows, and lashes; pale complexion; light blue (almost transparent) irides; hypopigmented fundus; nystagmus; and poor vision usually point to the diagnosis in individuals with this genetic disease.

Certain metabolic disorders where crystalline deposits accumulate in the cornea may also produce pathological photophobia (eg, cystinosis). Secondary crystalline or lipid deposition can occur in the cornea as a result of chronic inflammatory disease (Figure 17). Transient irregularities or defects in the corneal surface can induce temporary disease-based photophobia. These clinical manifestations are most commonly encountered in traumatic corneal abrasions. In individuals with severe keratoconjunctivitis sicca and associated corneal epithelial damage, photophobia is a frequent complaint (Figure 18).

Since the iris serves to control the amount of light entering the eye, any abnormality in the structure or integrity of the iris may lead to pathological photophobia. This can develop primarily (eg, in congenital aniridia or mesodermal dysgenesis [Figure 19]) or secondarily, after damage to the iris as a result of surgery, trauma, or inflammation. Pharmacological dilation of the pupil will also help temporarily; iris defects temporarily cause temporary photophobia.

Non-Pathological Photophobia

Most individuals who complain of photophobia, however, fall into the category of non-pathological photophobia. These are typically the same people who complain of having "sensitive eyes." Although this has traditionally been associated with fair-skinned, light-eyed individuals, there does not appear to be any proven racial or ethnic bias in this regard, with many people of African-American and Hispanic descent having symptomatic non-pathological photophobia. In these individuals, visual acuity is typically normal and there is no obvious ocular pathology to account for the light sensitivity described.
with its vibration plane perpendicular to the reflected light (Figure 24). Polarized lenses eliminate reflected glare, improving the quality of vision and relieving visual discomfort. This is especially important for individuals who work outdoors or enjoy water sports or skiing.

The relationship between light and sight remains a complicated one, but fortunately spectacle lens technology has evolved to the point where there is a spectacle lens treatment or combination of treatments to meet the visual requirements of most people under most circumstances. It is the responsibility of the eye care practitioner to assist the vision care consumer in choosing these treatments wisely.

References: