Optimizing Real-World Visual Performance

Why Contrast Sensitivity Testing & Nutritional Counseling are Essential in Primary Eye Care

By Mark W Roark, OD, FAAO

Eye care practitioners (ECPs) assess the vision of each patient as part of a comprehensive ocular exam. Visual acuity has been the traditional way of determining visual performance—a measure reflecting the ability to resolve fine details at a specific distance. This measurement is well-established as a valuable reference; if performance declines, the reason behind the change must be determined so that important ocular pathology is not missed.

Visual acuity tests are also key in determining refractive error. Significant improvements in best-corrected acuity serve to guide recommendations and updates to the spectacle prescription.

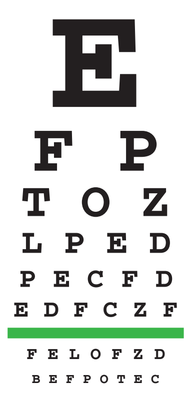
However, visual acuity charts have limitations for a number of reasons. Fortunately, advanced technology is making it possible to assess contrast sensitivity—an important measure of visual performance gauging the ability to discern subtle differences in the brightness of adjacent areas of objects so that edges are more easily seen. Once armed with this data, current research is showing that nutritional intervention can yield measurable improvements in visual performance, often leading to better vision outcomes for patients.

LIMITATIONS OF VISUAL ACUITY (VA) CHARTS

The Snellen chart has been used since the 1860s,[1] yet no universally accepted version exists to this day. Some charts have variations in letter shapes or non-uniform spacing between letters and lines. These variations may give additional cues or influence the findings through crowding effects.[2] It is also known that certain letters are more complex and, thus, more difficult to resolve by the eye even though they subtend the same visual angle.[3] In addition, larger increments in letter sizes from one line to another can mean a patient with acuity of 20/150 may be recorded as having 20/200 simply because the 20/100 line could not be read and there are no intermediate lines. (*see Figure 1*).

Many of these drawbacks have been addressed through the logarithim of the minimum angle of resolution notation used with some VA charts. Visual acuities can be measured using the logMAR whereby a score of 0 logMAR is equal to 1, which represents 20/20 since each stroke of this letter subtends 1 arc minute.[4] With a proper chart design, such as the ETDRS Chart (*see Figure 2*), each progressive line represents a 0.1 logMAR change in size with consistent spacing within and between lines to enable more uniform measurement.

Figure 1



The Sloan series of 10 optotypes developed in 1952 is believed to be equally legible (especially when the letter “C” is counted as correct when called as “O”[5]) and preferred

Assessing Contrast Sensitivity to Gain Actionable Insights

The number of ECPs who routinely measure and monitor contrast sensitivity in primary eye care is small. Remarkable advances in technology and new research indicate the need for change.

M&S Technologies has developed an electronic, calibrated system to accurately assess contrast sensitivity. This adds valuable insight so that patients with poor visual performance can be identified, including those with normal visual acuity.

This information is key, given that new research has revealed that patients with early and intermediate AMD and even those with healthy eyes and good vision can obtain measurable improvements in visual performance with nutritional intervention. These results were demonstrated with use of a unique formula containing all three macular carotenoids: 10mg of lutein, 2mg of zeaxanthin, and 10mg of meso-zeaxanthin available through MacuHealth®.

for more accurate testing as well. However, while these charts are standard in research, they are not uniformly used within the eye care community in the United States.

Even when visual acuity is accurately measured, central visual function has not been fully assessed.[6] High-contrast optotypes like those used during VA testing are not commonly encountered in the everyday visual world. And though other measures of visual performance such as visual field testing are available, the most efficient way to assess real-world central vision is to perform contrast sensitivity (CS) testing.[7]

CONTRAST SENSITIVITY TESTING FOR ASSESSING VISUAL PERFORMANCE

An integral part of optimal visual performance is the ability to discern subtle differences in the brightness of adjacent areas in an object, face or scene. Low surrounding luminance is present in many settings, with the average reflectance of objects in a typical visual environment measuring approximately 18%.[8]

The better the ability to distinguish the borders of an object, the greater the appreciation of fine details in the visual world and the better the quality of vision. The inverse of CS is known as the Contrast Sensitivity Threshold (CST) and describes the minimum contrast required by an individual to discriminate an object from its background. Unlike visual acuity measurements that maintain nearly 100% contrast as smaller letters are introduced, tests of contrast sensitivity often use targets of a given size that become fainter until an image is no longer able to be perceived.

Figure 2

Photopic contrast sensitivity is measured when the background luminance is bright and calibrated to a standard of 80-100 candelas per square meter (cd/m^2), which is the measure of light emitted per unit area.[9-11]

Mesopic contrast sensitivity utilizes a dim background luminance of 2.5-3.2 cd/m^2.[11] The luminance of the background and target must be controlled properly so that the actual CS is known and ANSI standards are met.

Historical Note

Contrast sensitivity was studied and described extensively in the mid-1800s by Gustav Fechner, a German physicist and philosopher. These findings led to additional discoveries and the modern era of contrast sensitivity research starting in the last half of the 20th century.[12]

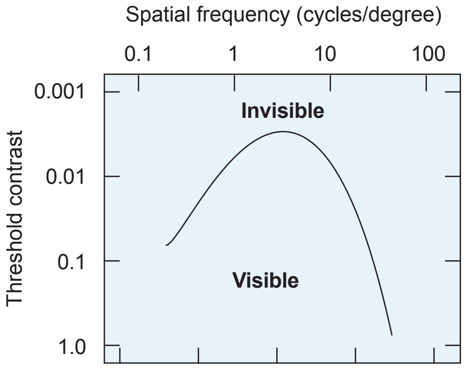
CONTRAST SENSITIVITY FUNCTION: GRAPHING SPATIAL FREQUENCIES

By measuring threshold levels across several target sizes, the Contrast Sensitivity Function (CSF) of an individual can be graphed to outline the exact border between the visible and invisible (*see Figure 3*). A similar concept is used with auditory testing in which the ability to detect faint sound levels is tested across various frequencies.[13]

The y-axis on the graph indicates the minimum level of contrast the patient can detect at a specific target size, with a higher CS score or lower CST representing better sensitivity. The x-axis indicates the spatial frequency of the sine wave grating being presented, with low spatial frequencies representing thick gratings and high spatial frequencies representing fine gratings. Spatial frequencies are expressed in units of cycles per degree (cpd).

The human visual system incorporates various optical and neural channels that affect contrast discernment uniquely at different spatial frequencies[14,15]

Figure 3



and is most sensitive in the intermediate range. This represents spatial frequencies from approximately 2 to 5 cycles per degree using sine wave gratings[16] and indicates that more contrast is required to identify spatial frequencies representing larger or smaller targets. This characteristic differs from high contrast visual acuity results in which larger targets subtend a larger visual angle and are easier to resolve than smaller targets.

When considering the borders of the CSF curve, visual acuity measurements address the lower right portion where high contrast targets are presented at high spatial frequencies. The upper, central portion of the curve (*see Figure 4*) corresponds to detection thresholds for intermediate spatial frequencies obtained by measuring contrast sensitivity. This portion of the visual arena cannot be predicted from high-contrast visual acuities and must be measured directly.

In the clinical setting, CS testing has been used to assess visual function, shown to decrease with a wide range of diseases. These include cataracts, corneal edema, dry eye disease and optic nerve dysfunctions including glaucoma, macular disease and certain neurological conditions such as Parkinson's disease.[12,13] CS can also be diminished with certain prescription medications[17] as well as with amblyopia and refractive errors.[18,19]

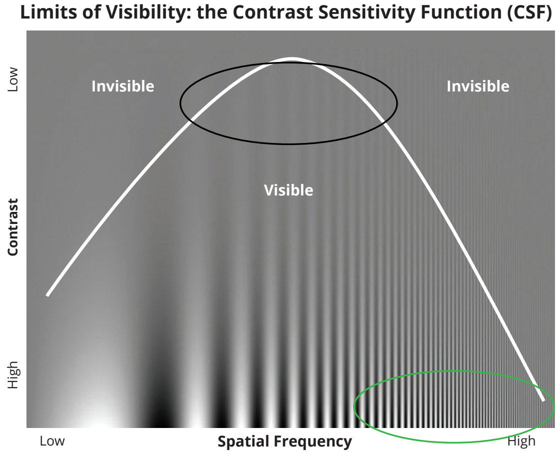
THE VALUE OF LOGARITHMIC SCALES

Contrast sensitivity values shown on graphs are often displayed with logarithmic scales. These scales are especially practical for displaying a large range in the quantity of data. This is logical since the same linear change represents a much smaller proportion of the total as the quantity increases. Several entities such as sound wave frequency, earthquake severity, and optical filter density commonly employ logarithmic scales for this reason.

The eye can detect light over a wide spectrum of intensities, so logarithmic scales are employed when expressing measures of CS as well. The log value represents the exponent, and each sequential whole number on the y-axis corresponds to a quantity 10 times greater than the preceding number when using base 10. So a logCS of 2 on the y-axis identifies a CS of 100 (10 x 10), and a logCS of 1 indicates a CS of 10 (10 x 1). CS thresholds in physical or electronic letter charts are normally designated in increments corresponding to 0.1 or 0.15 logCS steps throughout. These can easily be converted to the actual CS values if desired.

Figure 4

Limits of Visibility: the Contrast Sensitivity Function (CSF)



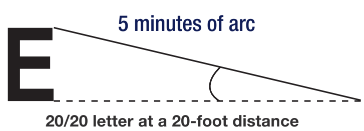
SINE WAVE GRATINGS VERSUS LETTERS

It should be noted that the results using letters will differ somewhat when compared with those found using sine waves.[20] Letters are more complex and technically composed of a variety of spatial frequencies,[16] though it is accepted practice to designate and label them according to the primary spatial frequency they represent.

Since a 20/20 letter subtends five minutes of arc at 20 feet (*see Figure 5*), each stroke of the letter subtends one minute of arc, and the adjacent space also subtends one minute. A complete cycle thus subtends 2 arc minutes, which corresponds to 30 complete cycles in one degree. Therefore, 20/20 can be considered to represent 30 cycles per degree (cpd); a 20/100 letter is five times larger, so equivalent to 6 cpd.

In the intermediate spatial frequencies, normal letter CS will be reduced compared with gratings in most spatial frequencies

Figure 5



and may peak in the 1.2 cpd (20/500) rather than at approximately 4 cpd (20/150) as typical of gratings.[21,22]

Using CS Insights To Enhance Patient Vision

CS reduction is non-specific, although it may be used to assist in the diagnosis and management of diseases like glaucoma[13] and cataracts.[23] With the many advances in instruments available to identify and manage disease, efficient testing of CS in a primary eye care setting will often add valuable insight in assessing the visual impact of these diseases on the patient.[16]

Figure 6

One remarkable advance in our knowledge is that CS can be improved even in patients with normal visual acuity and healthy ocular structure by enhancing macular pigments with a specific nutritional product. The CREST Normal Trial, published June 2016 in *Investigative Ophthalmology and Visual Science*, looked at subjects with healthy eyes and normal visual acuity. This Level 1 study showed statistically significant improvements in CS after 12 months only in the group taking MacuHealth®, a high-quality and unique product containing 10mg of lutein, 10mg of meso-zeaxanthin and 2 mg of zeaxanthin[22] (*see Figure 6*). It is, thus, reasonable to recommend this supplement for healthy patients who have average or poor contrast sensitivity despite using the best refractive correction available. This means that a comprehensive exam should include a routine measurement of CS even in patients without signs of ocular pathology.

TESTING STRATEGY AND TARGET SIZE CONSIDERATIONS

It can be quite time-consuming to measure CS at several targets sizes; fortunately, this is not necessary. Research has shown that, for purposes of real-world evaluation, the intermediate spatial frequency of 6 cpd is the most critical in performing various everyday tasks such as recognizing common objects and faces.[24] It is noteworthy that this spatial frequency is the same one used as the primary outcome measure, shown to improve with supplementation in the CREST trials.[22]

As previously noted, CS is a non-specific visual performance evaluation and can be reduced for several different reasons. With problems that reduce CS at high spatial frequencies, visual acuity will also be reduced. Other conditions that reduce contrast will cause a broad reduction in CS or alter it primarily at intermediate size targets.[6,12] An efficient approach to understanding a patient's visual world can therefore be obtained by measuring traditional visual acuity along with CST at a single intermediate target size of 6 cpd.

METHODS FOR MEASURING CONTRAST SENSITIVITY

But how should CS at this intermediate level be tested? One option is to use sine wave gratings with one of several available tests. The actual level of contrast being presented is calculated using the areas of highest and lowest luminance in the grating:

(High-Low)/(High+Low)[11]

In the Visitech® CS or FACT CS tests, gratings of various spatial frequencies are presented within circles on the chart. Using a forced choice method, the patient identifies the orientation of the lines as vertical, right or left. However, the number of targets at a given contrast is limited, and studies have found poor repeatability when using these charts.[25,26]

M&S Technologies has developed an electronic version of sine wave gratings that allows for multiple and random presentations of the stimulus with four orientations of the lines and a smaller increment of threshold determination. This chart would be preferred when utilizing gratings for contrast sensitivity testing.

Letter charts, however, are preferred by many clinicians and felt to be easier to use than gratings since they are part of our everyday experience and easily understood by patients.[21] Calculation of the measured contrast with letters uses the maximum and minimum luminance presented:

(High-Low)/High[16]

To make CS testing easier to incorporate into the office routine, a chart with large letters of a single size—known as the Pelli-Robson chart (*see Figure 7*)—was introduced in 1988.[27] It has become the standard reference for measuring CS with letters.[28] The chart consists of eight rows of six Sloan letters observed at 1 meter or 3 meters, with a decrease in contrast with each letter triplet in 0.15 logCS steps. Testing continues until two of three letters of the same contrast cannot be identified correctly, thus allowing for threshold measurements in the range of approximately 0.5% to 100%.[27]

Figure 7

This test offers a method of quantifying CS at a single spatial frequency in the intermediate to low range. It does, however, have some limitations. Not only can the chart fade over time, but it requires uniform room illumination for accurate results, and the letters can be memorized since there are only two versions of the chart available.[29]

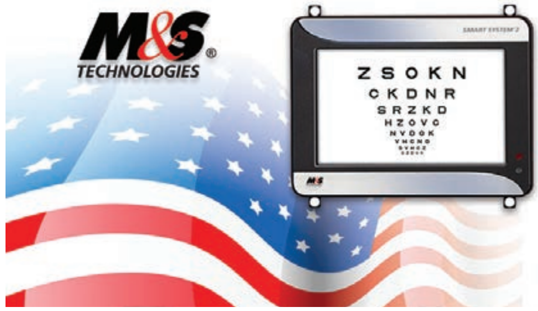
Other charts such as the Bailey-Lovie® come in high-contrast and low-contrast versions where all the letters shown have reduced contrast and the patient's best visual acuity is recorded at this lower contrast level. In these tests, healthy patients who are shown a 10% contrast chart will often have a reduction in best visual acuity of two lines compared with the high-contrast version.[16]

ELECTRONIC LETTER CHARTS

Many ECPs now use an electronic system with an LCD monitor to measure visual acuities and perform other tests of visual function in the office. It is ideal to have one system for both visual acuity and contrast sensitivity testing to enhance efficiency and improve cost-effectiveness. The M&S Smart System II using the Harris Contrast Test provides an alternative to physical charts (*see Figure 8*).

Importantly, this system uses validated techniques for measuring CS[30] through ANSI-compliant computerized systems with user-friendly software protocols developed by M&S Technologies. It allows the use of isolated, random Sloan letters of various sizes to measure CS efficiently. In a comparison study, letter CS with this system was consistent with results found with the Pelli-Robson chart.[9]

Figure 8



How to Measure Contrast Sensitivity

1. Measure CS monocularly with best distance prescription and non-dilated pupils
2. Turn the room lights *off*
3. Isolate a 20/100 (6 cpd) Sloan letter on a properly calibrated electronic chart
4. Project a 20% contrast letter for demonstration
5. Next, project a 5% contrast letter and ask the patient to identify it
6. Decrease (or increase) the contrast level by one step as needed
7. Proceed slowly, allowing time for the letters to come into view
8. Record the lowest CST where the patient can correctly identify 2 of 3 random letters
9. Document for OD or OS (Example OD: CST@ 6cpd 2.5%)

OFFICE PROTOCOL FOR CS MEASUREMENTS

An easy protocol for testing CS starts with occluding one eye with best-corrected distance vision in place and with the room lights off so the room is dark or very dim. An isolated 20/100 (6 cpd) Sloan letter[12] is presented with a starting CST of 20% to assure that the patient understands the test. Then the contrast is changed by one to two steps, from 5% until the patient cannot correctly identify the letter. It is important to pause for a few seconds as the threshold is approached to allow time for the letter to come into view. The lowest contrast where the patient gives a correct response on two of three letters is recorded as the Contrast Sensitivity Threshold.

For the patient free of ocular disease, it is acceptable to test only one eye when results are in the expected range since the other eye should give a similar response; however, the same eye tested should be documented and rechecked later when the test is repeated. There have been some minimal differences reported when comparing dominant to non-dominant eyes,[10] and if the patient has cataracts or other ocular disease, the eyes will often be different. In this case, record each eye individually using the same method.

Importantly, a dim testing environment will help avoid glare and help standardize the testing environment per the FDA protocol.[11] The gray scales for the letter contrasts in the M&S System are also calibrated in this dim environment to assure accurate threshold measurements.[31]

GUIDELINES FOR ACTION

Once a calibrated CST has been measured, it is essential to know whether the results fall within an expected range. Since many things can reduce CS, the clinician will need to determine what factors are affecting the results. While this may be difficult in certain cases, documentation of the current level of CS will, at a minimum, enable documentation of change over time.

What is Normal?

When looking at intermediate spatial frequencies for Pelli-Robson letter CS in healthy eyes with normal visual acuity, monocular expectations range from 1.5- 2.5% for younger patients, to 2.1- 3.2% for patients 60 and above.[8,9,32-34] This is consistent with the baseline-letter CS of the 78 healthy subjects in the CREST Normal Trial groups with monocular CST of 2.0% to 2.1% at 6 cpd.[22]

In a study using the M&S System with the Harris Contrast Test, the results of binocular testing in 53 healthy individuals showed an average CST of 2.3% at 6 cpd.[30] Binocular testing would be expected to give a lower threshold compared to the recommended monocular tests.[35]

As with several visual performance measures, the effect of age on photopic CS appears to be minimal until the mid-60s.[36] Smaller pupil size has been linked to a decrease in CS, so this is a factor that may affect the CS of older individuals.[35]

Figure 9 illustrates an action diagram based on the outcome of CS testing, while taking into account the patient's age. Patients in the average range, and especially those in the poor range, should be made aware of the potential for improvement in visual function through nutritional intervention.

When Does Visual Impairment Occur?

Some level of visual impairment is present when the Pelli-Robson CST is higher than 3.2%,[32] and studies have shown an increased risk of driving accidents when thresholds are above 5.6%.[8] In fact, drivers involved in crashes were six times more likely to have severe CS impairment than accident-free drivers[23] although visual acuity alone could not predict driving performance.[37]

Severe impairment is present once the threshold reaches 10%. Since this represents a ten-fold reduction in CS compared to the optimum level of approximately 1%, there will likely be a pronounced impact on visual function.[8] Loss of CS but not visual acuity from ocular diseases such as cataracts has a close correlation to mobility performance, and slower reading speed can occur as well.[8,38-40]

The action diagram below (*see Figure 10*) gives suggested guidelines for cataract management based on CST levels incorporating the above studies and clinical experience. This will also be driven by objective assessments and patient symptoms, but the ability to carefully monitor for CS changes offers a more complete picture of the need for intervention. For example, with the presence of central cortical cataracts, which are particularly bothersome due to the forward scatter of light that occurs, CS was shown to be more effective in assessing visual performance than either visual acuity or glare disability testing.[41] Patients in the average range can generally be followed, but those with poor CS are likely good candidates for cataract removal. Each case must be assessed individually to

Figure 9

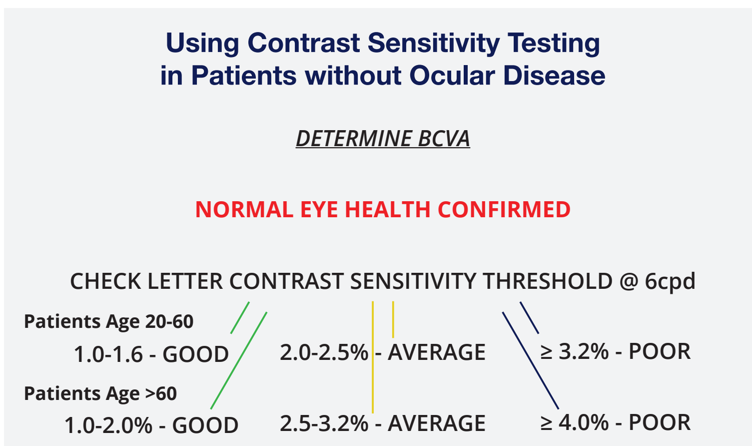
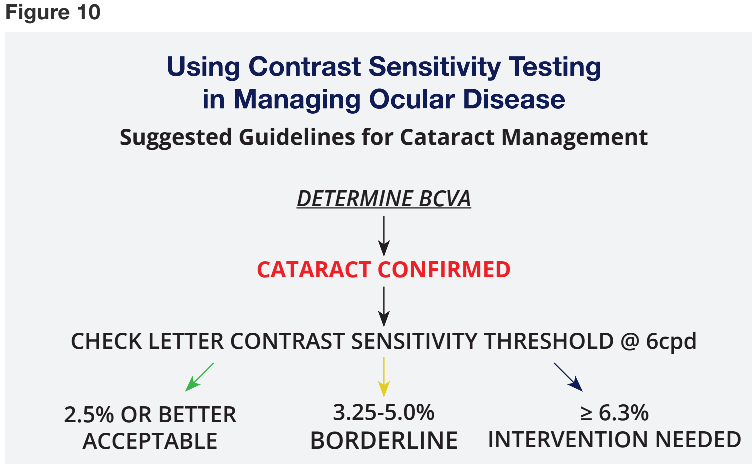


Figure 10



determine the appropriate time for intervention.

Nutritional intervention should be recommended for patients with early or intermediate AMD since studies have shown improvement in letter CS, especially with products containing meso-zeaxanthin (MZ).[42] CREST AMD also showed significant visual performance improvements in patients taking a modified AREDS2 formula with less zinc.[43] Additional analysis revealed better CS improvement when MZ was included in the formula.[43]

VISUAL IMPACT OF CHANGES IN CONTRAST SENSITIVITY

Along with the ability to accurately measure and monitor CS levels, it is important to know how changes in CS impact the patient's visual performance. For example, how significant is a one- or two-line improvement in threshold contrast sensitivity levels for visual function in the real world? One way to gain insight is to compare changes in CS to those in visual acuity while using a consistent logarithmic scale for both (*see Table 1*). By starting at peak performance levels based on research and clinical experience, the two measures align nicely as to onset of visual impairment defined by accepted standards.[32]

By using this model, a similar impact on visual performance could be considered to have occurred when improving CS by two lines, from 2.5% to 1.6%, for example, as when improving VA level by two lines; in this case, from 20/32 to 20/20. Few clinicians would argue that this change in visual acuity is insignificant, and it is likely that a similar logarithmic improvement in CS has a significant effect as well. With improvements in visual acuity, the lower right portion of the CSF curve is moved to the right, and with improvements in CS at 6 cpd, it is shifted upward (*see Figure 4*). Both of these expansions increase the area of the "visible" and reduce the size of the "invisible" zones.

Though a patient with excellent CS is likely to have excellent visual acuity, it is essential to stress that CS cannot be predicted from these measurements. Patients with a BCVA of 20/20 or better can often have a CST range anywhere from 1.0% to 6.3%. This shows the necessity of measuring CS, regardless of visual acuity levels (*see Figure 11*).

CASE STUDY: Using CS Testing in the Office

A 50-year-old male presented for a comprehensive eye exam complaining of glare and blur in both daytime and nighttime vision. He reported a history of LASIK done about a decade prior, but noted decreasing visual clarity gradually over the last two years.

Refraction showed good best-corrected visual acuity of 20/25+ OD and 20/20 OS, but CS testing at 20/100 revealed a CST of 8.0% OD and 6.3% OS. Slit-lamp exam revealed 2+ fine anterior cortical opacities in the crystalline lens in each eye, but no other ocular pathology was present.

Despite excellent VA, referral for cataract surgery was made due to significant symptoms and impaired CS. The patient returned after successful surgery with monofocal implants in each eye. He reported excellent vision, which then corrected to 20/15 in each eye with CSTs of 2.0% OD and 2.5% OS. This case illustrates that CS cannot be predicted from VA measurements, but correlates much better with real-world visual performance.

Table 1

Understanding the Visual Impact of Changes in Contrast Sensitivity

Roark Model for Assessing Visual Impact of Letter Contrast Sensitivity Threshold Changes @ 6 CPD Compared to Visual Aquity Changes

Constant CPD with Decreasing Contrast Sensitivity ↓ Poor Visual Performance →

Letter CST @ 6 cpd 0.1 LogCS Steps	VA @ 100% Contrast 0.1 LogMAR Steps
1.0%	20/12.5
1.25%	20/16
1.6%	20/20
2.0%	20/25
2.5%	20/32
3.2%	20/40
4.0%	20/50
5.0%	20/63

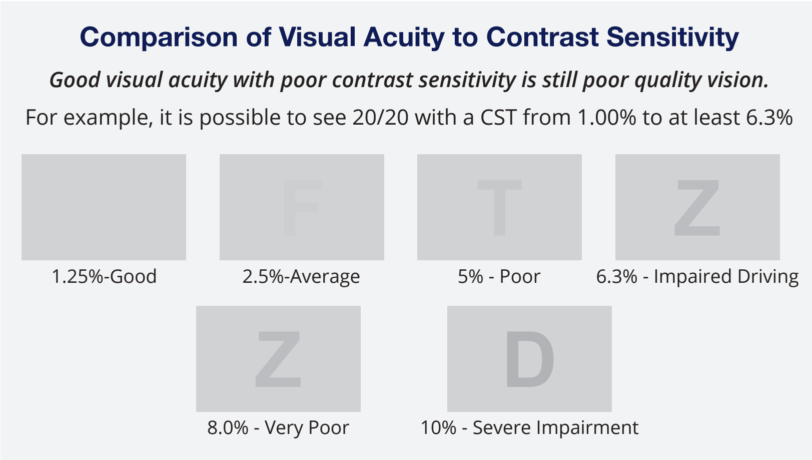
Constant Contrast with Decreasing Letter Resultion ↓ ← Poor Visual Performance

*Assuming Limiting Letter CST of 1% and Peak BVA of 2012

BEST PRACTICE FOR ASSESSING VISUAL PERFORMANCE

Patients trust their ECPs to provide a thorough and complete visual assessment that is based on the latest research and technology available. This requires the evaluation of real-world visual performance through both visual acuity measurements and contrast sensitivity testing using the strategies mentioned here. The valuable insights gained will enable appropriate and essential intervention by the clinician to optimize the visual outcome of each patient and increase the chances for vision success in ways only recently uncovered.

Figure 11



Dr. Roark is an optometrist at Allisonville Eye Care Center Inc., Fishers, Ind. You may contact the author at markroark.od@gmail.com

1. Collenbrander A. The historical evolution of visual acuity measurement. Visual Impairment Research 2008;10(2-3):57-66.
2. Yehezkel O, Sterkin A, Levet M, et al. Crowding is proportional to visual acuity in young and aging eyes. Journal of Vision 2015;15(8).
3. Mathew JA, Shah SA, Simon JW. Varying difficulty of snellen letters and common errors in amblyopic and fellow eyes. Arch Ophthalmol 2011;129(2):184–187.
4. Holladay JT. proper method for calculating average visual acuity. journal of refractive surgery 1997;13:388-91.
5. Elliott DB, Whitaker D, Bonette L, et al. Differences in the legibility of letters at contrast threshold using the Pelli-Robson Chart. Ophthal Physiol Opt 1990;10(4):323-6.
6. National Research Council (US) Committee on Vision. Emergent Techniques for Assessment of Visual Performance. Available at: https://www.ncbi.nlm.nih.gov/books/NBK219042/ (last accessed Nov. 1, 2017).
7. Owsley C. Contrast Sensitivity. Ophthalmol Clin North Am 2003;16(2):171-7
8. Lennie P, Van Hemel SB. Visual impairments determining eligibility for social security benefits. Visual Impairments Determining Eligibility for Social Security Benefits, National Academy Press, 2002, pp. 83-5.
9. Chandrakumar M, Colpa L, Reginald YA, et al. measuring contrast sensitivity using the M&S Smart System II versus the Pelli-Robson Chart. Ophthalmology 2013;120(10):2160-1.e1
10. Khanani, Arshad M, Brown SM, Xu KT, et al. normal values for a clinical test of letter-recognition contrast thresholds. J Cataract Refract Surg 2014;30:2377-82.
11. Macrae S, Holladay JT, Glasser A, et al. Special Report: American Academy of Ophthalmology Task Force Consensus Statement for Extended Depth of Focus Intraocular Lenses. Ophthalmology 2017;124(1):139-41.
12. Pelli DG, Bex P. Measuring Contrast Sensitivity. Vision Research 2013;90:10-14.
13. Liu JL, McAnany JJ, Wilensky JT, et al. M&S Smart System contrast sensitivity measurements compared with standard visual function measurements in primary open-angle glaucoma patients. Journal of Glaucoma 2017;26(6):528-33.
14. Sabour-Pickett S, Beatty S, Connolly E, et al. Supplementation with three different macular carotenoid formulations in patients with early age-related macular degeneration. Retina 2014;34(9):1757-66.
15. Campbell, FW, Robson JG. Application of Fourier Analysis to the Visibility of Gratings. The Journal of Physiology 1968;197(3):551-66.
16. Woods RL, Wood JM. the role of contrast sensitivity charts and contrast letter charts in clinical practice. Clinical and Experimental Optometry 1995;78(2):43-57.
17. Santaella RM, Fraunfelder F. Ocular adverse effects associated with systemic medications. Drugs 2007;67(1):75-93.
18. Bradley A, Hook J, Haeseker, J. A comparison of clinical acuity and contrast sensitivity charts: Effect of uncorrected myopia. Ophthalmic and Physiological Optics 1991;11:218-26.
19. Mathew JA, Shah SA, Simon JW. Varying difficulty of snellen letters and common errors in amblyopic and fellow eyes. Arch Ophthalmol 2011;129(2):184-7.
20. McAnany JJ, Alexander KR. Contrast sensitivity for letter optotypes vs. gratings under conditions biased toward parvocellular and magnocellular pathways. Vision Research 2006;46(10):1574-84.
21. Prestwich C, Kim J, Harris P. (2015) Comparison of the measurement of contrast sensitivity threshold using sine wave gratings and Sloan letters on a LCD-based testing screen. Southern College of Optometry, Poster session.
22. Nolan JM, Power R, Stringham J, et al. Enrichment of macular pigment enhances contrast sensitivity in subjects free of retinal disease: Central Retinal Enrichment Supplementation Trials report 1." Investigative Ophthalmology & Visual Science 2016;57(7):3429-39.
23. Owsley C, Stalvey BT, Wells J, et al. Visual risk factors for crash involvement in older drivers with cataract. Arch Ophthalmol.2001;119(6):881-7.
24. Owsley C, Sloane ME. Contrast sensitivity, acuity, and the perception of 'real-world' targets. British Journal of Ophthalmology 1987;71:791-6.
25. Reeves BC, Wood JM, Hill AR. Vistech VCTS 6500 charts—within- and between-session reliability. Optom Vis Sci 1991;68:728-37.
26. Pesudovs, K, Hazel CA, Doran RML, et al. The usefulness of Vistech and FACT contrast sensitivity charts for cataract and refractive surgery outcomes research. The British Journal of Ophthalmology 2004;88(1):11-16.
27. Pelli, DG, Robson JG, Wilkins AJ. The design of a new letter chart for measuring contrast sensitivity. Clinical Vision Sciences 1988;2(3):187-99.
28. Chandrakumar M, Reginald YA, Colpa L, et al. Comparing M&S Smart System letter contrast test with Pelli-Robson chart. Journal of Ophthalmology 2013;120(10).
29. Kavitha T, Crossland MD, Rubin GS. Clinical assessment of two new contrast sensitivity charts. The British Journal of Ophthalmology 2007;91(6):749-52.
30. Henderson S, et al. (2015) Validation Study of New LCD Based Contrast Sensitivity Testing Method, Southern College of Optometry. Poster session.
31. Letter Contrast Sensitivity. M&S Technologies. Available atL https://www.macuhealth.com/contrast-sensitivity-testing/ (last accessed September 9, 2017).
32. Leat SJ, Legge G, Bullimore MA, et al. What is low vision? A re-evaluation of definitions. Optometry and Vision Science 1999;76(4):198-211.
33. MÃ¤ntyjÃ¤rvi M, Laitinen T. Normal Values for the Pelli-Robson Contrast Sensitivity Test. Journal of Cataract & Refractive Surgery 2001;27(2):261-6.
34. Elliott DB, Sanderson K, Conkey A. The reliability of the Pelli-Robson contrast sensitivity chart. Ophthalmic and Physiological Optics 1990;10:21-4.
35. Karatepe AS, Köse S, E rilmez S., et al. factors affecting contrast sensitivity in healthy individuals: A pilot study. TÃ¼rk Oftalmoloji Dergisi 2017;47(2):80-4.
36. Enoch, JM, Werner JS, Haegerstrom-Portnoy G, et al. Forever young: visual functions not affected or minimally affected by aging: A review. The Journals of Gerontology Series A: Biological Sciences and Medical Sciences 1999;54(8). B336-51
37. Wood JM, Owens DA. Standard measures of visual acuity do not predict drivers' recognition performance under day or night conditions. Optometry and Vision Science 2005;82(8):698-705.
38. Marron JA, Bailey IL. Visual Factors and Orientation-Mobility Performance. Am J Optom Physiol Opt 1982;59(5):413-26.
39. Elliott DB, Hurst MA, Weatherill J, et al. Comparing clinical tests of visual function in cataract with the patient's perceived visual disability. Eye 1990;4(Pt 5):712-17.
40. Owsley C, McGwin G. Vision and Driving. Vision Res 2010;50(23):2348-61.
41. Elliott, David B, Hurst MA, Weatherill J, et al. Comparing clinical tests of visual loss in cataract patients using a quantification of forward light scatter. Eye 1991;5:601-6.
42. Akuffo KO, Nolan JM, Howard AN, et al. Sustained supplementation and monitored response with differing carotenoid formulations in early age-related macular degeneration." Eye 2015;29(7):902-12.
43. Akuffo, KO. (2016) Macular carotenoid supplementation and visual function in early age-related macular degeneration, Waterford Institute of Technology. (Doctoral thesis).