Ophthalmic Diagnostics

Technology, Techniques, and Clinical Applications

Taraprasad Das
PremNandhini Satgunam

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To

My patients who encouraged me to interpret the test reports in their clinical context.

TD

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Several teachers came together to make this book a reality. I dedicate this book to all these teachers, and to the future teachers.

PN

Foreword 1

The ocular system is highly intricate, complex and involves not only the globe of the eye itself, but also its neural connections with the brain and surrounding muscular tissue. In order to perceive visual information of the highest quality, all ocular components are required to function harmoniously together. Consequently, examination approaches of the eye are required to meet an equivalent level of sophistication. Several sub-specialties have developed within ophthalmology; however, alongside some highly specific examination tools, key underlying examination techniques form the basis for standardized assessments of visual function and delivery of eye care. Thus, to provide an accurate diagnosis, clinicians must be well-versed in the fundamental techniques of ocular examination and be aware of any significant new and upcoming technologies within the field. While technological advancements allow for more detailed imaging and assessment of the eye as well as the opportunity to gain a deeper understanding of the underlying pathophysiology of disease states, these also present unique challenges as these additional tools must be integrated into standard practice.

This book, *Ophthalmic Diagnostics: Technology, Techniques, and Clinical Applications* by Taraprasad Das and PremNandhini Satgunam, contains 35 unique chapters, each contributed by expert authors, covering both basic and clinical aspects of ophthalmic diagnosis, as well as novel and recent investigational techniques. Cumulatively, the contents bring together a valuable collection of skills and techniques for accurately diagnosing pathologic conditions. This is a useful reference tool for all professionals involved in the eye care sector: medical, nursing, optometry, orthoptics, and vision science.

In modern clinical practice, virtually all parts of the eye can be examined from a functional, pathologic, or biometric perspective. These are highly interrelated and synergized; a suite of testing procedures and multimodal imaging techniques is often required to understand the patient thoroughly. Visual acuity has long been the standard parameter to measure visual function and indicate the presence of ocular pathology; however, visual acuity scores alone often have limited real-world applicability. Contrast sensitivity, visual fields, stereopsis, color vision, and ocular alignment also need to be considered for a broader assessment of the visual function of patients in the real world. Additionally, visual acuity will be significantly influenced by the

optical state of the eye, and this requires accurate measures of refraction to be obtained. Aside from its clinical use, information from refraction can be translated into functional benefits for the patient by prescribing and dispensing corrective spectacles. While technological advancements tend toward eliminating examiner bias through automated objective measures, examination via retinoscopy remains an invaluable skill, particularly for assessments in remote environments and in children and patients with intellectual disabilities.

To identify pathologies, slit lamp biomicroscopy is the core technique used to observe structures in the anterior segment of the eye. This has founded other viewing techniques, such as gonioscopy and fundoscopy. Since the advent of film and flash photography in the nineteenth century, numerous imaging modalities are now available to document pathologic conditions from the surface of the eye to the retina and optic nerve. Optical coherence tomography (OCT) is the fundamental modern-day imaging device which offers insights into almost every layer and tissue plane of the eye for both practitioners in the clinic and surgeons in the operating room. Further advancements in OCT capabilities have allowed finer segmentation on a cellular level as well as non-invasive visualization of the array of blood vessel networks located between the retina and the choroid. Earlier compromises between imaging speed, resolution, and invasiveness are significantly less apparent, contributing to a more detailed investigation with less patient burden.

On a global scale, cataract formation has been the most significant contributor to blindness, particularly in developed countries. In ophthalmic practice, cataract assessment is routine and a fundamental surgical indication for ophthalmologists. Biometry with current technologies and optimized lens formulas can now account for complex optics to provide accurate and convenient measurements, minimizing errors across a broad range of eyes. However, ultrasound techniques remain a reliable technique in the clinic to overcome the challenges of dense cataract and ocular media opacity, which hinder standard optical-based measures.

While the identification of ocular diseases and improvement of visual function is often the main intent of conducting ocular examinations, deeper insights can be gained as ocular pathology, alignment, and function can be the manifestations of systemic diseases, including diabetes, trauma, inflammatory and autoimmune conditions, as well as neurological defects. Testing pupillary responses is a core medical skill that assesses the optic nerve and higher neurological function. Electrophysiology has been able to differentiate, diagnose, and understand several rare inherited retinal degenerations using the principles of neuronal activity.

Naturally, the culmination of technological advancements opens the door to future novel applications. Tele-ophthalmology is evolving to become a vital solution for delivering ophthalmic and optometric healthcare to remote

areas. The development of smartphone-based ophthalmic imaging is one of the key drivers allowing this to be implemented more efficiently with minimal economic burden; however, it requires a lot of support from healthcare systems.

A wide spectrum of eye care professionals in early and established careers will find this book a most valuable resource in the clinical care of patients.

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Foreword 2

The field of eye care—optometrists, ophthalmologists, students, and residents alike—will benefit from this outstanding book, which provides a comprehensive, detailed description of the current state of ophthalmic diagnostics. The book is extraordinarily well organized, enabling the eye care practitioners to access the information they need for a specific patient. Likewise, the new student can start at the beginning and move through to the most current technology that makes our jobs as eye doctors easier.

Superbly curated by Drs. Taraprasad Das and PremNandhini Satgunam, the authors, have obviously worked hard on their state-of-the-art contributions. The effort and care taken by the many contributing authors is evident on every page. All are to be congratulated for the important contribution to the ophthalmic literature.

First, the book's chapters cover the traditional components of the eye examination, starting with the basics of assessing vision and refractive error. The reader will be able to extend the information on how to measure a patient's most fundamental visual function, blur, into the art of prescribing eyeglasses and optical dispensing.

The reader can then learn (or refresh their memory) on quantifying the binocular vision system, pupillary reactions, visual field, and colour vision.

And then the true, novel value of this textbook emerges. Chapters on the most current technology that enhances our ability to perform eye examinations are included. They cover smartphone-based imaging, cataract grading and imaging, microperimetry, and adaptive optics. The chapter on optical coherence tomography will be particularly valuable to the new student or resident.

As dean of The Ohio State University College of Optometry in Columbus, Ohio, United States, I calculated the number of eye examinations one cohort of optometry students will perform during their careers. If I conservatively figure the average optometrist practices for 30 years and sees 10 patients per day, 240 working days each year, a cohort of 70 graduating optometrists will be entrusted with 5,040,000 pairs of eyes!

I anticipate this book will be consulted early in students' and residents' careers and often when they enter eye care practice and continue to examine those five million patients. In the end, their patients will be the real beneficiaries of these authors' hard work.

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Preface

With the advent of technology, "time flies" at speed, sometimes even faster than light.

Just within the lifetime of three generations, we have seen how clunky telephones that were once only found in the houses of the elite are now sleek devices that are owned by almost everyone. Every single profession has been touched and turned around, sometimes even upside down, by these changing waves of technology.

Health care, including eye care, is no exception to this. Many instruments have become obsolete and outdated, and some have disappeared into oblivion. Yet, some are indispensable and have stood the test of time, showing that old is indeed gold.

The world has become smarter, often due to the "smart gadgets" in most people's hands in the form of phones. With this mini-computer called the smartphone, one can do wonders. Many Apps have been developed for various tests that were once expensive and found exclusively within the sanctorum of big institutes. These technologies have broken barriers, blurred borders, and provided even private practitioners in rural settings with advanced diagnostic tools. While some of these smart devices and Apps may not stand the test of time, some are robust and would evolve into better, faster, and more importantly, more accurate versions. Although the choices available are sometimes overwhelmingly many, a little research can often identify the correct smart tools and instruments to suit one's needs.

Given the drastic changes and many choices in diagnostic tools available today, a compilation of information on new and old diagnostic tools must be created. Such a compilation can help clinical practitioners to remain updated and avoid becoming outdated in their clinical practice. Within the clinical practice of eye care, which includes optometry, ophthalmology, and opticianry, the most rapid changes occur in the area of diagnostics. It is an area where tools, devices, instruments, and newer techniques keep evolving to improve eye care practices.

Therefore, consolidating all this information into a comprehensive book is a real need. In fact, as a ready, go-to handbook, it will be of immense help to any student, clinician, or researcher in eye care. This is the prime motivation for putting this book together.

Although some commercial product names are mentioned in this book, the editors (and authors) are not endorsing or promoting any product. Since some of the descriptions of the techniques are drawn from the individual author's

scope of practice, we are hopeful that the diverse and global cast of authors will provide a plethora of viewpoints that will be valuable to anyone involved in eye care anywhere in the world.

We are immensely grateful to these contributing authors, who took the time to share their wisdom and clinical pearls with us. Additionally, we also thank the science editor, Anusha Krishnan, PhD, and the content editor, Ms. Neerja Padmanabhan, from Springer Nature, for their help.

The book title reads *Technology, Techniques, and Clinical Application*. The aspirational goals of this book are to briefly explain the scientific principles of various diagnostic tools and techniques, provide an easy-to-follow protocol to execute specific techniques, and explain the clinical applications of these techniques. In essence, this book attempts to fill the "why" gaps in "what we do" in ophthalmic diagnosis wherever possible. We have also included information on newer tools, innovations, and techniques. In addition, the sequence of chapters in this book follows the sequence of clinical tests that are normally followed during an eye examination. However, very specialized or sophisticated techniques have not been included. Instead, this book focuses on generalized and commonly used techniques. We have also included a section on tele-eye health, as the SARS CoV 2 pandemic has taught us that this form of service delivery is not only possible but could also encourage eye care-seeking behaviour in rural areas; in addition, we feel that tele-eye health can and will change the future of eye care delivery. As we write this, we feel that all of us in the eye care sector must rise to face the challenges of the future, where eye care can be accessed with a click of a button or a swipe of a finger. We need to be ready.

This book is written with the desire to keep pace with the changing times. Although we are aware that many of the techniques documented in this book may become outdated shortly, we believe that this book will still be useful to eye care practitioners everywhere. Although every chapter provides a historical perspective on the techniques and instruments discussed in it, the question of whether this book describes the history of the eventual past or educates us on the practice of the future is something only time can tell.

However, one must start somewhere to ride the wave of development for better eye care.

We hope that the readers of this book enjoy this ride!

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Visual Acuity: High Contrast and Low Contrast

1

Rebecca Sumalini 🆔
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1.1 Introduction

There are many components of vision. These include visual acuity, contrast sensitivity, visual fields, 3D vision, motion perception, etc. Of all these components, the most important component is visual acuity, the ability of the eye to resolve and perceive small targets. There are various methods and ways to measure this resolution capacity of the eye. All these methods use black letters on a white background. Ironically, none of the real-world scenes and scenarios appear in black and white. The visual function that is more relevant to the real-world scenario is contrast sensitivity. Contrast sensitivity is the ability of the eye to detect the dimmest target and largely depends on the background (for example, a white bead placed on a white tabletop has poorer contrast than a gray bead on a white tabletop). This ability of the eye to distinguish the contrast of the target against the background is also related to the size of the object. If this ability is mapped for different target sizes, we arrive at the contrast sensitivity function (CSF). Interestingly, high-contrast visual acuity (or visual acuity) is only a single-point measurement within the CSF (see Sect. 2.3.2). Yet, we mostly draw conclusions and correlate patients' complaints and functional vision difficulties (e.g., identifying faces, pouring water into a cup) with the visual acuity value. Unfortunately, measures of contrast sensitivity have been mainly restricted to low-vision practice or research. However, for those patients whose symptoms are not explained through the "regular" visual acuity, measuring contrast sensitivity or low-contrast visual acuity may be insightful.

This chapter gives an equal importance to visual acuity, contrast sensitivity, and low-contrast visual acuity. The importance of these measurements, with commonly used and commercially available tests, is discussed. Some special scenarios in which the conventional measurements are difficult are also discussed, with available alternate options.

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1.2 History

1.2.1 Visual Acuity Tools

The origin of standardized visual acuity testing dates back to 1862 by the Dutch ophthalmologist Hermann Snellen; this test is widely known

as the Snellen chart [1]. The most commonly used notation for visual acuity is the Snellen fraction (e.g., 20/20 or 6/6), a format easily understood by all clinicians and researchers. The numerator is the test distance, and the denominator is the distance from which the letter should be visible. Therefore, visual acuity of 20/200 indicates what is visible from 200 feet to a normally sighted individual, is only visible from a closer distance of 20 feet to someone with visual impairment. The Snellen acuity chart, despite its wide use, has several limitations. These include an unequal number of letters in each acuity line, unequal size progression of optotypes between acuity lines, unequal spacing between the letters, and reliability concerns. To address these shortcomings, the log-MAR chart was developed in 1976 by Ian Bailey and Jan Lovie-Kitchin [2]. The chart had a uniform number of letters, uniformly spaced progression, and proportionate spacing between the letters.

In 1982, the National Eye Institute used the Sloan letter set (i.e., non-serif letters) and log-MAR principles as described by Bailey and Lovie [2] and produced the current "gold-standard" ETDRS chart (Early Treatment of Diabetic Retinopathy Study) (Fig. 1.1, left) [3]. In addition to English letters, several other optotypes have been developed for individuals unfamiliar with English optotypes, such as letters of different languages (e.g., Chinese [4], Arabic [5], Hindi [6]), LEA symbols ((named after the inventor Lea Hyvarinen) [7]) (Fig. 1.1, middle), tumbling E [8], and Landolt C charts [9]. The recent computer-based visual acuity measurement tool, COMPlog (Fig. 1.1, right) [10] has several advantages such as ease of use, easy maintenance, and the ability to shuffle between and within optotypes whenever required.

Based on the preferential-looking principle, grating acuity tests are the tests of choice for pre-verbal/non-verbal individuals. Robert Fantz first described the principle in 1965 [11]. The currently used Teller acuity cards-II (Fig. 1.2, left) is a modified prototype of the same after several iterations. A handful of grating acuity tests are available (such as Keeler acuity cards and LEA gratings paddle), including the app-based grating acuity test, such as the Peekaboo Vision application (Fig. 1.2, right) [12].

Near visual acuity is a valuable measurement given that most of our day-to-day activities involve several near tasks such as reading, writing, and household chores (including cooking), to name a few. Jaeger cards were first developed by the Austrian ophthalmologist Eduard Jaeger in 1854 for checking near visual acuity [13]. The text size of the reading text progresses from 0.37 to 2.5 mm [14]. These cards have been discontinued because of a lack of standardization [15]. In 1980, Ian Bailey and Jan Lovie-Kitchin developed the Bailey–Lovie word reading charts (Fig. 1.3); these consisted of random words with a logarithmic progression of lines.
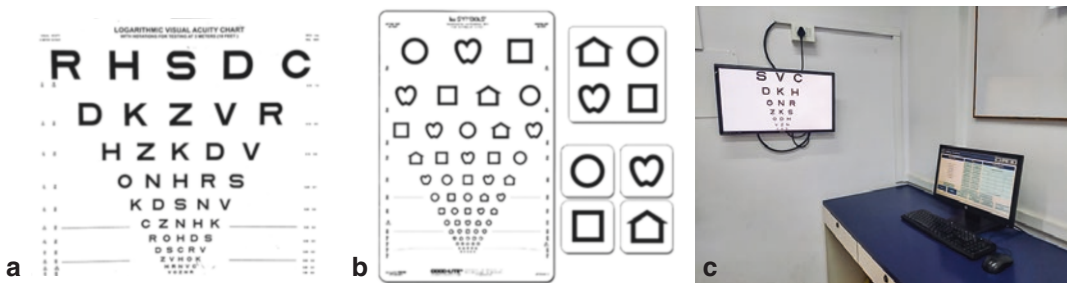
Fig. 1.1 Recognition acuity tests: (left) ETDRS chart, (middle) LEA symbols, and (right) COMPlog electronic chart. *ETDRS* early treatment of diabetic retinopathy study, *COMPlog* computerized logarithmic test

Fig. 1.2 (left) Grating acuity assessment using teller acuity cards-II (without testing stage) and (right) the Peekaboo Vision application

Fig. 1.3 The Bailey–Lovie word reading chart
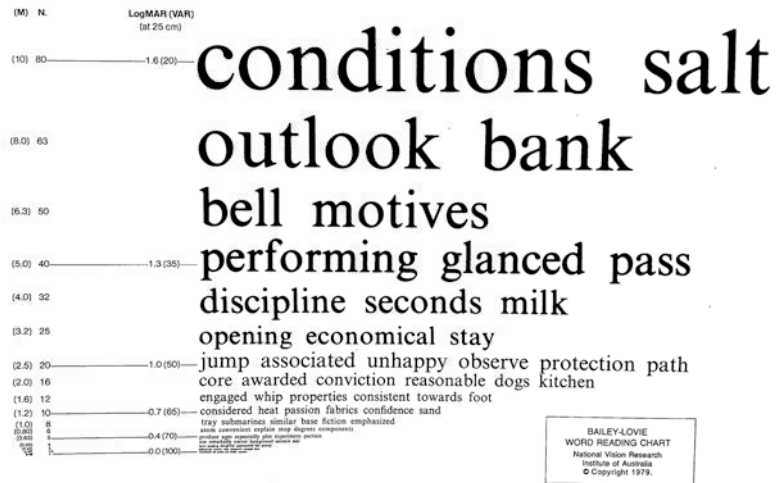
1.2.2 Contrast Sensitivity Tools

Contrast sensitivity testing was first demonstrated in 1978 using Arden gratings and consisted of varying spatial frequencies and contrast levels. Based on similar principles, the functional acuity contrast test, first described by Arthur Ginsburg, consists of sine wave gratings of varying spatial frequencies and contrast levels [16]. The most popularly known contrast sensitivity test, the Pelli–Robson contrast sensitivity chart, was developed by DG Pelli, JG Robson, and AJ Wilkins; they published the design of this chart in 1988 [17]. In the Pelli–Robson contrast sensitivity chart (Fig. 1.4), English letters in triplets with fixed spatial frequency (i.e., constant size) vary in contrast levels. The optotype size subtends 2.8° at 1 m (~20/672) (appropriate for patients with visual impairment), which is equivalent to 20/224 at 3 m (~2.67 CPD [cycles per degree]) (recommended testing distance). The logCS was comparable at these two testing distances [18]. This chart measures contrast sensitivity from 0.00 to 2.25 logCS range. The higher the logCS, the better the contrast sensitivity. The chart has good repeatability of ±0.15 log units in young and older adults [19].

In addition, there are several commercially available contrast sensitivity tools using various targets such as pictures (hiding Heidi contrast

Fig. 1.4 The Pelli–Robson contrast sensitivity chart placed in a lightbox
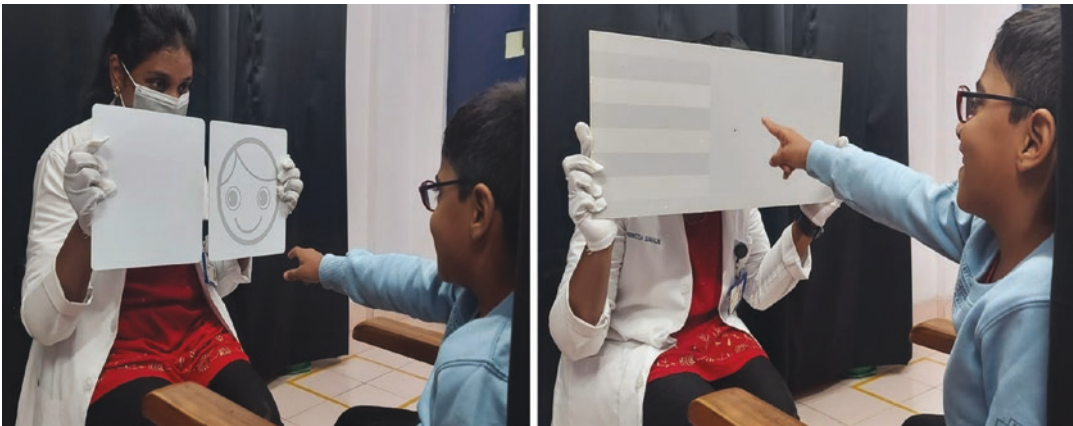

Fig. 1.5 Contrast sensitivity assessment using (left) the hiding Heidi low-contrast face test and (right) Ohio contrast cards

sensitivity test) (Fig. 1.5, left), gratings (Cambridge low-contrast gratings, Ohio contrast cards [20] (Fig. 1.5, right), letters (Mars letter contrast sensitivity test) [21], and circles (spot checks) [22].

1.3 Underlying Concept

1.3.1 Distance Visual Acuity

Visual acuity is the resolution capacity of an eye. The resolution capacity is the smallest gap an eye can detect between two objects. This gap would subtend an angle at the nodal point of the eye. Therefore, the smallest angle resolved by the eye is its visual acuity (Fig. 1.6). Any angle or separation smaller than this would result in a single blurred object instead of two distinct objects. The smallest visual angle a human eye could resolve is about 1′ (1 min of arc) (see Box 1.1) [23].

As seen in Fig. 1.6, two black lines with a white separation will require a minimum of 3 photoreceptors to resolve it. One photoreceptor detects one dark line, another photoreceptor detects the white space, and a third adjacent photoreceptor detects the other dark line. If we consider one dark line and the white space as one cycle, then two dark lines separated by a white space will have 1.5 cycles. Therefore, to resolve 1.5 cycles, three photoreceptors (i.e.,) double the cycles are required. This limit of how many minimum photoreceptors are required to resolve an
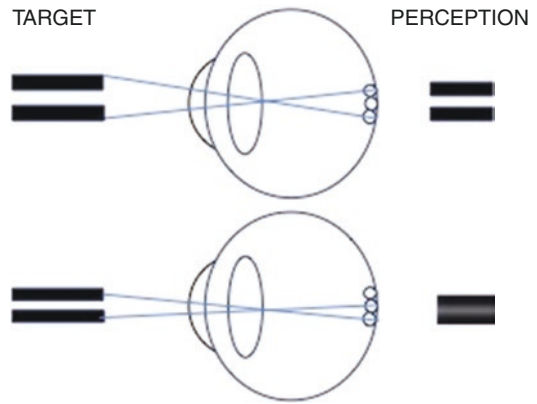

Fig. 1.6 An illustration of the minimum angle of resolution (MAR) to discern a black-and-white grating. A minimum of three photoreceptors are required to see the grating target (top panel). If the grating subtends a smaller angle than the MAR, then a blurred blob of the grating is seen, which makes it indiscernible (lower panel)

object is called the Nyquist limit. This is a borrowed concept from signal processing in electronics. If we consider the eye a device to capture and process light signals, the minimum number of photoreceptors required will be twice the spatial frequency (cycles per degree or CPD). Hence, to resolve 10 cycles, 20 photoreceptors are needed. Given this, and with the anatomical limi-

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Box 1.1 An Example Computation of Minimum Angle of Resolution (MAR)
Let us consider a visual acuity chart calibrated for 6 meters.
  The height of the 6/6 or 20/20 optotype is 0.875 cm or ~0.00875 m
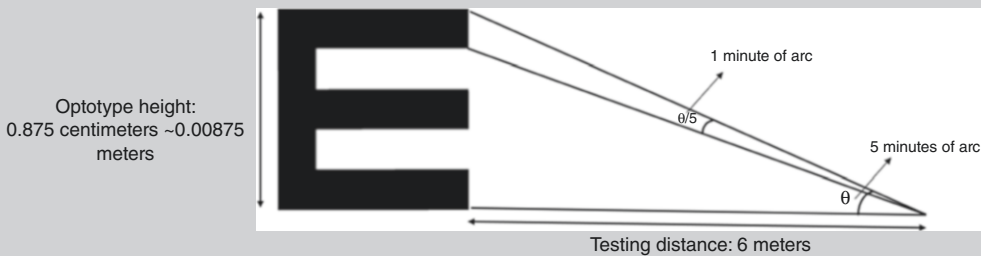
Tan θ = length of the opposite/length of the adjacent
$\theta = \tan^{-1}(0.00875/6) = \tan^{-1}(0.00145) = 0.083°$
(degrees to minutes of arc, $1° = 60′$)
Therefore, $0.083° \times 60′ = 4.98′–5′$
Minimum angle of resolution *(angle subtended by one stroke)* = $\theta/5 = 5/5 = 1′$

tation of how many photoreceptors can be packed into the fovea, along with neural and optical limitations, the maximum resolution capacity of the eye is usually around 30 CPD. This spatial frequency corresponds to a visual acuity of 20/20 (or 6/6). The math for this is shown in the calculation in Box 1.2 with a 20/40 optotype as an example. It must be noted that acuity better than 20/20 (or 6/6) is also possible depending on an individual's neural and optical factors. In the periphery, the packing of the photoreceptors is not dense, and the morphology of the cones in the periphery is wider than those in the foveal region. Also, more rods are interspersed in the periphery. All these contribute to poorer visual acuity in the periphery [24].

1.3.2 Near Visual Acuity

The resolution capacity of the eye remains the same for both distant and near objects. The only difference between distance and near vision is that the crystalline lens needs to accommodate for near vision. This is because light rays from a near source are divergent, unlike those from distant objects, for which parallel light rays reach the eye. Hence, to negate the diverging light rays, the lens increases the plus power by becoming more biconvex, a process called accommodation. In younger individuals, a good distance acuity should also be reflected as good near acuity. If not, accommodative issues should be considered or ruled out. In individuals closer to their

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Box 1.2: An Example Computation for Converting the Snellen Fraction to Cycles Per Degree and Cycles Per Degree to Snellen Fraction

Snellen fraction to cycles per degree

Let us consider a 6/12 or 20/40 optotype. In this, each stroke subtends 2 minutes of arc and therefore 1 cycle (black and white region) = 4 min of arc

Testing distance: 6 meters or 20 feet
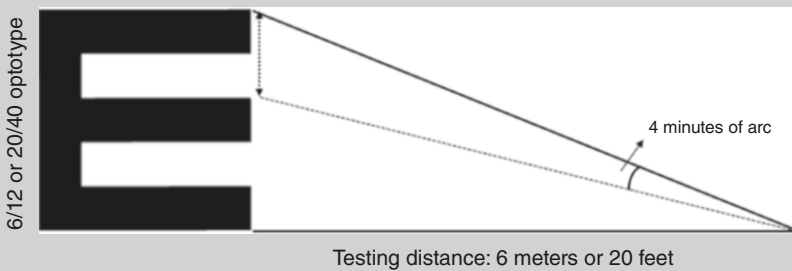
as $1° = 60'$ (minutes of arc)

$(1 \text{ cycle}/4') \times (60'/1°) = 15$ cycles per degree (CPD)

Therefore 20/40 = ~15 CPD

Cycles per degree to Snellen fraction

Let us consider the resolution acuity of 15 CPD. Since 15 cycles are in $1°$, therefore one cycle's angle of subtense is

$(1 \text{ cycle}/15 \text{ cycles/degree}) \times (60'/1°) = 4'$

In 1 cycle, we have $4'$ since there are 2 strokes in one cycle,

Minimum angle of resolution of one stroke = $4'/2 = 2'$

Therefore, the Snellen denominator = $2' = x/20$; $x = 40$

Hence, 15 CPD ~20/40

fourth decade of life (40 years), decreased accommodative amplitude may cause a reduction in near acuity (presbyopia). An appropriate near addition will restore the near visual acuity in such patients. However, in some instances, children may also have accommodative disorders, with or without good near visual acuity. These children may also require near addition [25, 26].

In other instances, where an accommodative disorder is not present, central opacity could be responsible for the reduction in near acuity. This is because of the pupillary miosis at near vision, and the effect of a central opacity, especially those closer to the nodal point (e.g., posterior polar cataract), could be more profound. Sometimes, binocular vision disorders like convergence insufficiency could cause a disturbance in reading. In some instances, pupillary miosis can cause an increased depth of focus, and that could result in better near visual acuity, with minimal or no near addition, even in the presbyopic age-group (e.g., use of pilocarpine in older adults for glaucoma could result in good near visual acuity).

1.3.3 Contrast

Contrast sensitivity is closely related to real-world visual functioning. Individuals with reduced contrast sensitivity at middle-to-low spatial frequencies were found to have difficulty in day-to-day tasks such as face recognition, identifying road signs and objects placed in common places, e.g., on an office desk, etc. [27]. In a large retrospective study of 1000 patients visiting a low-vision clinic, close to 50% of them with better than 20/60 presenting distance visual acuity, reported difficulty in face recognition [28]. In another large prospective study (n = 1113) on individuals with different ocular conditions, such as age-related macular degeneration, cataract, glaucoma, and retinitis pigmentosa, the contrast sensitivity tests provided valuable information in addition to visual acuity tests in the early detection of the disease [29].

Contrast sensitivity and low-contrast acuity are two different terms; therefore, care should be taken not to use them interchangeably. As discussed earlier, only the CSF gives a complete picture of the individual's contrast sensitivity across varying spatial frequencies; currently, CSF can be measured using tests such as the Functional Acuity Contrast Test (FACT) [30] and quick CSF [31].

1.3.3.1 Low-Contrast Visual Acuity

Similar to high-contrast visual acuity (HCVA), low-contrast visual acuity (LCVA) also tests the resolution of the eye but at contrast levels lower than the HCVA. The HCVA (or simply visual acuity) charts have a contrast level closer to 100%. Contrast levels usually tested for LCVA typically include 10% contrast, as in the Bailey–Lovie low-contrast visual acuity charts. At this level of contrast (i.e., at 10%), the expected reduction in visual acuity is by 2 lines earlier than that in HCVA [32]. The level of visual acuity reduction for different levels of contrast can be understood from the CSF (see Sect. 2.3.2). The factors that affect HCVA also affect LCVA. The blur circles formed due to refractive error impede the low-contrast acuity much more than the high-contrast acuity [33].

1.3.3.2 Contrast Sensitivity Function and Contrast Sensitivity

The CSF measures sensitivity to different contrast levels at different spatial frequencies. It is an inverted U-shaped function. The area under this function is where our visibility for different object sizes and contrasts lies. Every object or contrast outside this curve will be invisible to our eyes. Making those objects visible would require magnification or contrast enhancement, or both.

HCVA is a horizontal measurement in the CSF along the *x*-axis at 100% contrast value. LCVA is a horizontal measurement in the CSF along the *x*-axis at a 10% contrast value. The contrast is held constant in both these measures, and the spatial frequency is changed. Contrast sensitivity measure, on the other hand, is a vertical measurement where the spatial frequency (*x*-axis) is held constant, and only contrast is changed

Fig. 1.7 An illustration of the contrast sensitivity function (CSF). On the *x*-axis are the different spatial frequencies denoted in cpd (cycles per degree) and Snellen fractions. Contrast values vary along the *y*-axis. *CS* contrast sensitivity, *LCVA* low-contrast visual acuity, *HCVA* high-contrast visual acuity
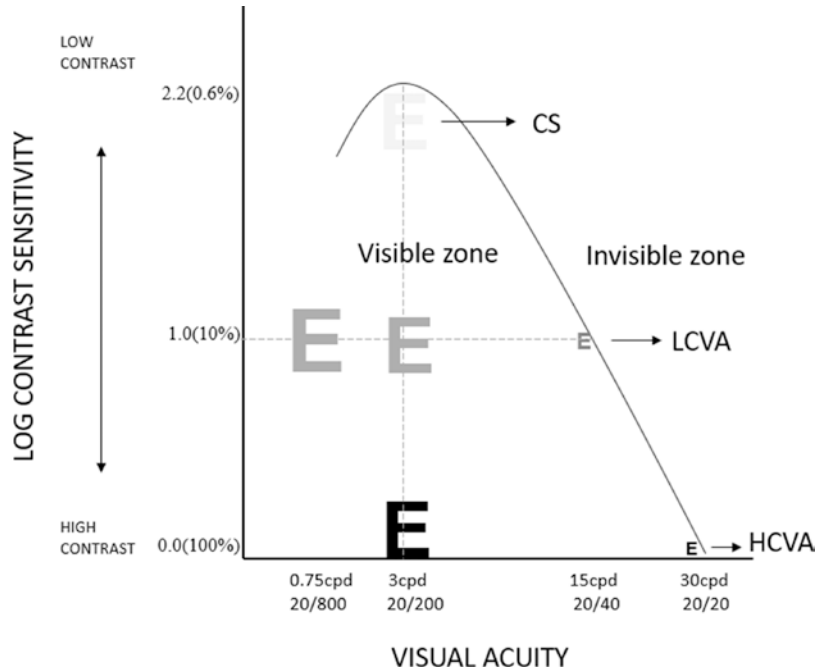
along the *y*-axis. At the lowest contrast (~1% contrast), the human eye can only see a target size of about 20/200 (or 6/60). This is the peak of the CSF (Fig. 1.7).

The high spatial frequency cut-off in CSF is the HCVA or visual acuity limit of the patient. This cut-off is determined by the photoreceptor density that also determines the resolution. The roll-off at the low spatial frequency end of the CSF is due to lateral inhibition of the receptive fields. A receptive field is the extent to which a stimulus can trigger neuronal firing within the neuron. Beyond this, the firing would decrease or cease. The ganglion receptive fields have a center-surround configuration. The center could get stimulated for an ON response, while the peripheral gets stimulated for an OFF response (ON-center, OFF-surround) or vice versa. A target big enough to fall within the center would stimulate a receptive field. However, if the target is too big (as in the low spatial frequencies), it falls on both the center and surround, cancelling the stimulation (lateral inhibition). This is why very low-spatial frequencies are also not visible.

Generally, when a reference to "contrast sensitivity" is made, it refers to the maximum peak in the CSF function. The height of this function is

usually between 2 and 4 cpd; this corresponds to an acuity value of 20/200 (6/60) for 3 cpd. This value indicates the lowest contrast that can be detected. The maximum sensitivity (or lowest threshold) of the human eye is about 1% for a target at 20/200 (6/60) size.

1.4 Technique

Visual acuity is the first test most clinicians would do after obtaining a thorough patient history. This test should be treated as sacrosanct, and enough time should be given to take a proper measure without rushing and adapting shortcuts (e.g., only showing single letters in an electronic chart). Ideally, thresholding should be done to find the potential visual acuity of a person. There have to be 5 letters shown for each acuity level (i.e., in LogMAR style charts). This would ensure that crowding is uniformly maintained in the different levels of acuity.

Thresholding means that 50% of the time, the person is right in their response. The conventional stopping criteria for visual acuity is 3 or more mistakes in a line with 5 letters. Every letter read is valuable information to record, especially

in determining improvement with an intervention in randomized clinical trials. It will be important to note such minor details (e.g., 20/20^{+1} or 20/20^{-2}). Depending on the history, one could decide on which line to start to measure visual acuity. If no complaints are mentioned, one could directly show the 20/32 or 20/25 line and ask the patient to read from there. If difficulty in vision is reported, one could start from 20/200 level and ask the patient to read the first letter. If read correctly, the patient can be asked to read only the first letter in each line, essentially going down the chart, till they miss a letter, at which time, the patient should be asked to read the line above fully. This would save time and help reach the visual acuity threshold quickly.

Observe how fast the letters are read; if these are missed systematically on the left/right side, it could indicate a visual field defect. Similarly, people with age-related macular degeneration may have to fixate eccentrically to read. While patients with tunnel vision, like in retinitis pigmentosa or glaucoma, should be oriented to the location of the chart to be able to read and should also be given sufficient time to read. Patients unfamiliar with English letters can be shown alternate optotypes such as region-specific optotypes, symbols, pictures, tumbling E, and Landolt C.

1.4.1 Measuring Acuity in Individuals with Vision Impairment

In the case of patients whose visual acuity cannot be recorded at standard testing distances such as 3, 4, and 6 m due to visual impairment, closer testing distances should be considered. Recording acuity by finger counting and hand movement should be avoided as much as possible, as they are not standardized or repeatable measures. When shorter testing distances are used, it is important to perform appropriate conversions (see Box 1.3).

Best corrected distance visual acuity is an important visual function (in addition to the peripheral visual field); it is considered for categorizing vision impairment and providing social

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Box 1.3 Examples of Visual Acuity Conversions for Different Distances in the Metric and Non-metric Systems

Example 1: If a patient reads a 6/60 optotype calibrated for 6 m at a 1-m testing distance, then the acuity will be 1/60, equivalent to 6/360 (obtained by multiplying the numerator and the denominator by 6).

Example 2: If a patient cannot read a 20/796 optotype on a COMPlog system calibrated for 20 feet. The patient can be asked to move closer (to 10 feet); therefore, a 20/796 optotype at 10 feet will be 10/796, equivalent to 20/1592 (obtained by multiplying the numerator and denominator by 2).

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benefits based on nation-specific acts and regulations. The different categories of vision impairment as per the International Classification of Diseases-11 (ICD-11) [34] are summarized in Table 1.1. There could be a wider variability in the test–retest of visual function parameters in individuals with vision impairment due to factors such as adaptation to illumination levels, disease progression, and psychosocial states. Therefore, the patient should be given adequate time to respond during testing [35].

Charts such as the Berkeley Rudimentary Vision Test (BRVT) (Fig. 1.8) can be used to quantify visual acuity in individuals with severe to profound visual impairment. The acuity range measured using the BRVT is 1.40–2.60 logMAR (i.e., 20/500–20/8000) in a single tumbling E

Table 1.1 Categories of vision impairment as per the International Classification of Diseases-11 (ICD-11) [34]

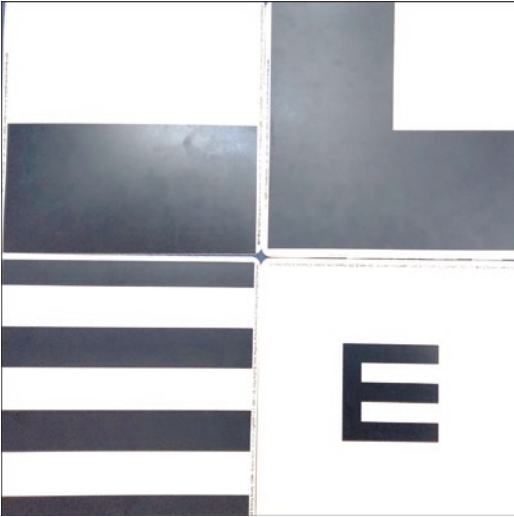| Category of vision impairment	Distance visual acuity range
Mild vision impairment	Worse than 6/12–6/18
Moderate vision impairment	Worse than 6/18–6/60
Severe vision impairment	Worse than 6/60–3/60
Blindness	Worse than 3/60
Near vision impairment: worse than N_6 or 8M at 40 cm	

Fig. 1.8 The Berkeley Rudimentary Vision Test (BRVT)

chart. For the grating acuity, the range is 2.30–2.90 logMAR (i.e., 20/4000–20/16,000), and for the white-field projection (including hemifield and quad-field), the logMin = 3.2 for testing spatial localization; for a basic visual function test called the black-white discrimination (BWD), the logMin = 3.5 [36]. Note logMin (not log-MAR) values given are arbitrary values as per the specifications of the test card. If the patient's visual acuity is unrecordable with any of the measures discussed above, projection of rays (in all 4 quadrants) and perception of light should be documented.

1.4.2 Measuring Visual Acuity in Children

Visual acuity testing is vital for detecting amblyopia. Therefore, it is important to avoid single-line and single-optotype testing. Test results with full chart vs. single line and single optotype can be variable, with the acuity estimates of the latter two techniques over-estimating visual acuity in amblyopia compared to the entire chart [37].

Visual acuity measurement in children can prove to be tricky. The optotypes should be shuffled while checking monocular acuity, and rechecking the same acuity line may lead to issues as children are likely to memorize the letters. In case of unavailability of an extra acuity chart, the letters could be asked to be read randomly or in reverse order. This problem is prevented in electronic visual acuity charts.

The choice of visual acuity tools in children cannot always be limited to chronologically age-appropriate tests. In such cases, alternate testing tools/techniques should be explored. For example, if a 10-year-old girl diagnosed with Down syndrome cannot respond verbally to letter optotypes, she can be asked to copy the letters (alternate technique), or testing with symbols/picture optotypes can be considered (alternate testing tools). Grating/resolution acuity tests are popularly used among infants, young children, children, and individuals with special needs, although acuities obtained using resolution and recognition acuity tests may not be comparable [38].

In using grating acuity tests (e.g., Teller acuity cards-II), it is important to mask the clinician to the location of the grating to avoid clinician bias. Firstly, the child's verbal/non-verbal response (finger pointing or based on eye movement) should be recorded by the clinician, and then the location of the grating should be checked on the card to judge whether it is a correct or incorrect response. For thresholding purposes, 2 of 3 correct criteria are suggested. When using grating paddles such as LEA grating paddles (Fig. 1.9), it is important to move both the paddles (plain and the grating) equally to avoid movement-initiated eye movement.

The chart used should also be documented, and if possible, the same chart should be used in the follow-up visit as well, as the acuities obtained with various tests may not be comparable [39, 40]. Good documentation is essential for an appropriate clinical interpretation of the acuity measure (e.g., progression with intervention). When documenting grating acuity, the cycles per centimeter (CPCM) should be converted to CPD (Box 1.4).
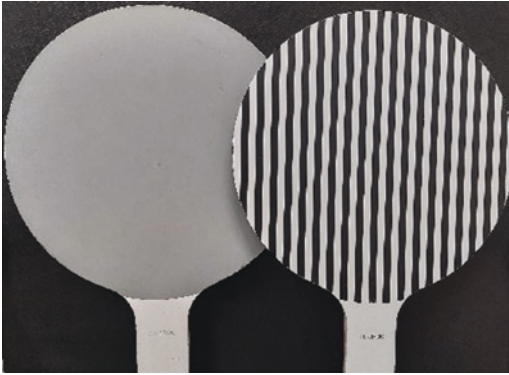
Fig. 1.9 LEA grating paddles

Box 1.4: An Example Computation to Convert Cycles Per Centimeter to Cycles Per Degree

(at 57 cm, 1 cm = 1° of visual angle; therefore, at 57 cm, CPCM~CPD)

For e.g., 10 CPCM at 38 cm = (38/57) × 10 = 6.66 CPD

(*CPCM* cycles per centimeter, *CPD* cycles per degree)

CPD = (testing distance/57) × CPCM

1.4.3 Measuring Near Visual Acuity

In near visual acuity measurement (ideal to record in "M" or "N" notation), it is important to mention the testing distance, chart, and illumination used for recording the acuity. While testing individuals with visual impairment, testing distance helps to determine the magnification required for near assistive devices. In addition to room illumination, extra illumination, when used, should be documented as well, as patients with impaired contrast sensitivity may have better near acuity with extra illumination. For individuals unfamiliar with words, alternate tools such as isolated letter charts, numbers (Fig. 1.10), symbols, tumbling E, and Landolt C should be considered for measurement purposes.

1.4.4 Contrast Acuity and Contrast Sensitivity

The assessment of LCVA is similar to that for HCVA, with the same thresholding criteria (3 of 5 optotypes). Assessment of LCVA at 2.5% was reported to help detect certain ocular conditions such as optic neuritis [41] and multiple sclerosis [42] and for a few occupational requirements, such as those for pilots [43]. However, in the clinic, the LCVA is conventionally assessed at 10% contrast, and HCVA is assessed at 95–100%, as most of the functional visual tasks are within this range of contrast. Reduction of acuity at 10% contrast sensitivity is important as it would mean a tenfold loss of contrast sensitivity than the normal measure of approximately 1%, which causes disabling effects in regular activities [44]. A decline of 2 or more lines in LCVA (recorded at 10% contrast sensitivity) compared to the high-contrast visual acuity is considered a clinically meaningful difference and can have functional implications [32]. This is commonly observed in individuals with vision impairment, who are then advised to use appropriate contrast-enhancing measures such as using appropriate illumination and maintaining good target and background contrast in regularly accessed stations (such as office desks, kitchen counters, etc.). In ocular conditions, such as albinism, aniridia, and a few retinal dystrophies, filters and tints are recommended to reduce glare and enhance contrast.

First, measuring binocular contrast sensitivity is suggested to quickly understand the patient's visual concerns in regular clinical practice. Care should be taken to shuffle the optotypes or show different ones to avoid the bias likely to occur due to memorizing them.

Card-based acuity and contrast charts can undergo wear and tear due to extensive usage in the clinics and should be regularly replaced. Using the charts with utmost care is important to avoid incorrect readings. Gloves should be used