
CHAPTER 2

WHAT IS PERIMETRY?

INTRODUCTION

PERIMETRY – A STANDARD TEST IN OPHTHALMOLOGY

Perimetry is a standard method used in ophthalmology and optometry to assess a patient's visual field. It provides a measure of the patient's visual function throughout their field of vision. The devices used to perform this evaluation are called perimeters. Perimetry is performed for several reasons: 1) detection of pathologies; 2) evaluation of disease status; 3) follow-up of pathologies over time to determine progression or disease stability; 4) determination of efficacy of treatment and 5) visual ability testing.

Any pathology along the visual pathway usually results in a loss of visual function. Perimetry can identify deviations from normal, and consequently the associated pathologies. Perimetry is most commonly used to diag-

nose glaucoma, but it is also often used to assess visual loss resulting from retinal diseases, as well as optic nerve, chiasmal or post-chiasmal damage due to trauma, stroke, compression and tumors.

Additionally, perimetry is used regularly for visual ability testing. Its most common use is to test a person's visual ability to drive. Furthermore, it is used to provide a quantitative measure of visual function in order to determine eligibility for a pension for visual impairment, and also to assess the benefits of ptosis surgery.

In sum, perimetry is a universally available diagnostic method to assess a patient's visual field or visual function.

THE NORMAL VISUAL FIELD

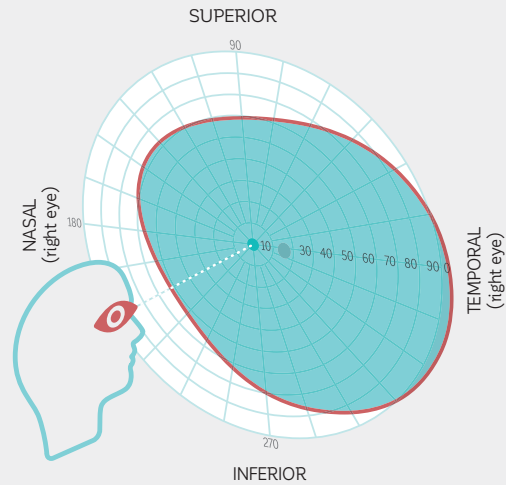
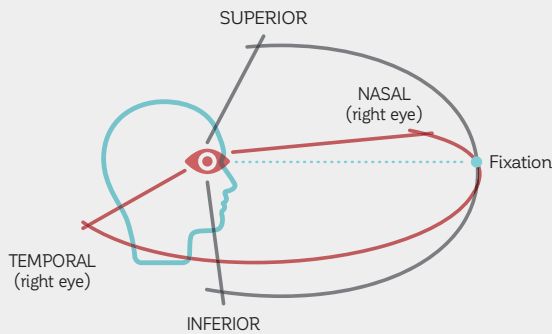
SPATIAL EXTENT OF THE VISUAL FIELD

The visual field of a person is defined as the area in which a person can see at a given moment relative to the direction of fixation, without head or eye movement (i.e., it defines the boundaries of the area beyond which

nothing can be seen). The extent of the visual field is an essential part of one's visual function, because a constricted visual field has a significant negative impact on activities of daily living, and as a result on quality of life.

SPATIAL EXTENT OF A NORMAL VISUAL FIELD

A) MONOCULAR VISUAL FIELD



B) BINOCULAR VISUAL FIELD

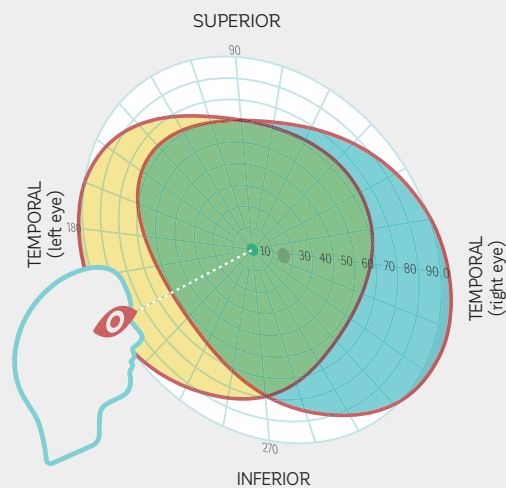
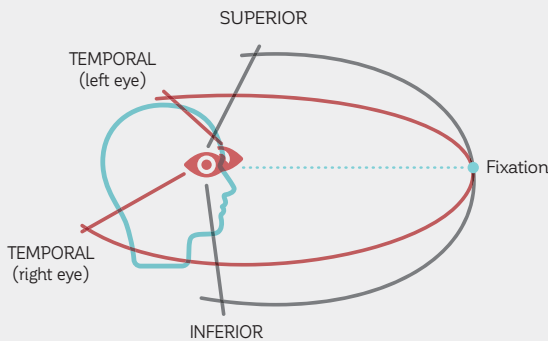


FIGURE 2-1 The monocular visual field of one eye is limited by the eye socket, nose, brow and cheekbones (A). The binocular visual field of two eyes overlaps in the central area (B).

The visual field of one eye is called the monocular visual field (**FIG 2-1A**). Its spatial extent in people with normal vision is limited by the facial anatomy of the person, with the eye socket, nose, brow and cheekbones, which outlines the limits of the visual field. On average, the monocular visual field extends from 60° nasally to approximately 90° or more temporally, and from approximately 60° superiorly to 70° inferiorly.

In people with normal vision, the visual field is binocular (**FIG 2-1B**). This means that it contains input from both eyes, with integration and mapping of information from the two eyes, allowing for stereo acuity and depth perception. Visual information in the central 60 degrees of the visual field is processed by both eyes.

SENSITIVITY TO LIGHT IN THE VISUAL FIELD

The area in which a person can see (extent of the visual field) does not suffice to describe a person's vision. It is also important to have a measure of sensitivity to light. But what is a person's sensitivity to light? One can imagine a room in which 100 people are present. The room is dim, with an adjustable light bulb at its lowest

level hanging from the ceiling. In that room, only a few people can see. As the light intensity of the bulb is increased, an increasing number of people will be able to see in the room. The people who could see even the very dim light bulb have a very high sensitivity to light, while the others have a lower sensitivity to light (**FIG 2-2**).

SENSITIVITY TO LIGHT

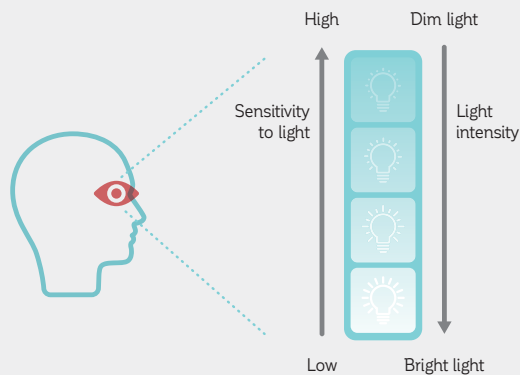
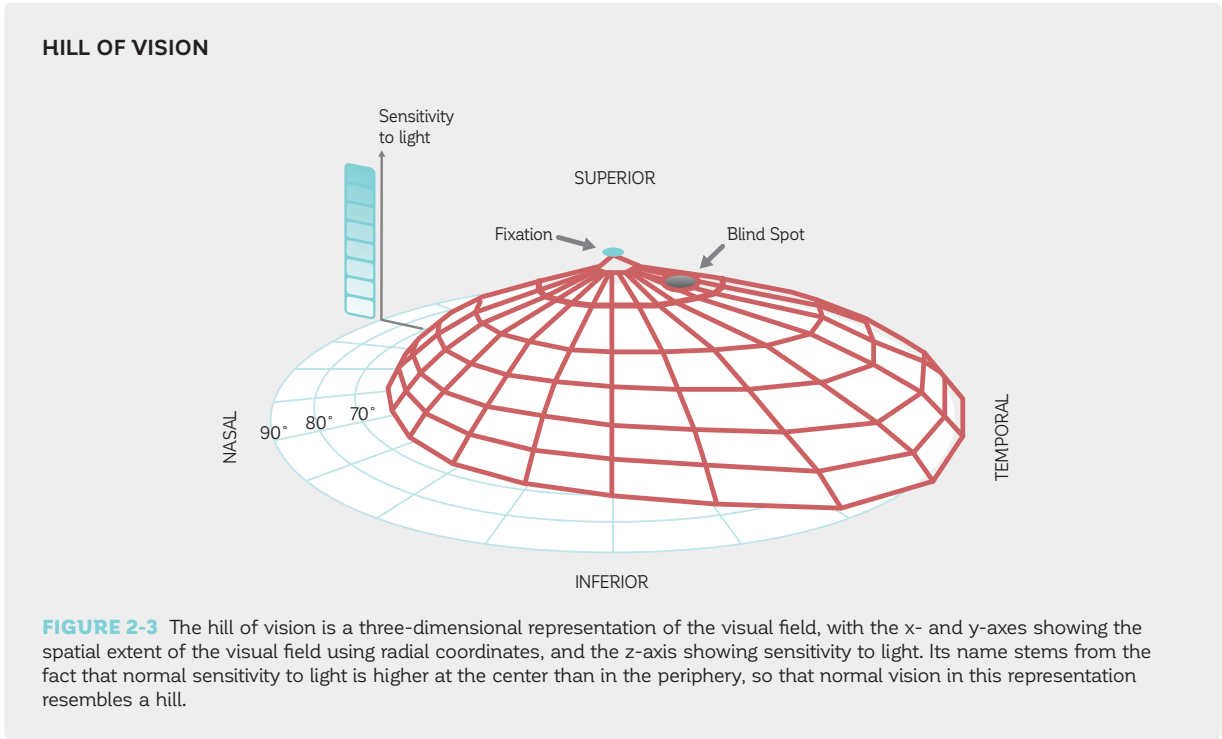


FIGURE 2-2 This figure illustrates the inverse relationship between light intensity and sensitivity to light. A person who can perceive a very dim light has a very high sensitivity to light, while a person who can only perceive very bright lights has low sensitivity to light.

THE HILL OF VISION – A VISUALIZATION OF VISUAL FUNCTION

Sensitivity to light is not uniform across the spatial extent of the visual field and depends on location within the visual field. For normal eyes and in typical daytime illumination, sensitivity is highest in the central area of the visual field and decreases gradually towards the periphery. To visualize this, sensitivities across the visual field can be drawn as a three-dimensional graph, with

the x- and y-axes representing the visual field locations and the z-axis representing the sensitivity to light. Since this representation resembles a hill, it is commonly referred to as the hill of vision, which is a visualization of a person’s visual function. Areas within the hill of vision represent areas of seeing, and areas outside the hill of vision represent areas of non-seeing (**FIG 2-3**).



MEASURING SENSITIVITY TO LIGHT ACROSS THE VISUAL FIELD

PERIMETRY ALLOWS QUANTIFICATION OF ABNORMAL SENSITIVITY TO LIGHT

Deviations from the normal hill of vision provide valuable clues regarding visual field loss and the underlying pathologies. The pattern and shape of visual loss can be identified by investigating deviations from the normal hill of vision. Differences in the visual field between the two eyes can also be identified by inspecting deviations from the normal hill of vision. These deviations from normal

can be either constrictions of the boundaries of the visual field, or depressions of sensitivity. Such depressions can be present throughout the visual field (widespread lowering of sensitivity), or localized in specific areas of the visual field (scotomas). It is thus desirable to quantify a patient's hill of vision with high accuracy and to identify its deviation from a normal hill of vision (**FIG 2-4**).

PERIMETRY ALLOWS DETECTION OF ABNORMAL SENSITIVITY TO LIGHT

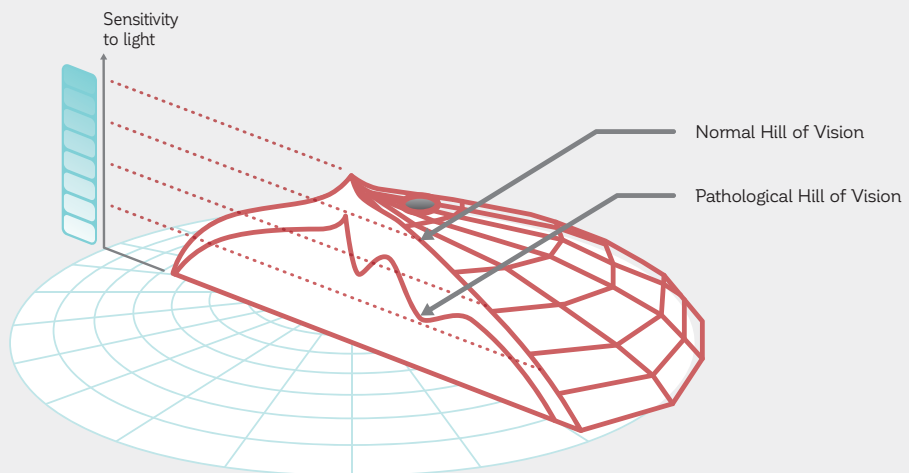


FIGURE 2-4 Pathologies affecting sensitivity to light result in an altered hill of vision for the patient. The deviation from the normal hill of vision provides valuable information regarding the nature and severity of the pathology.

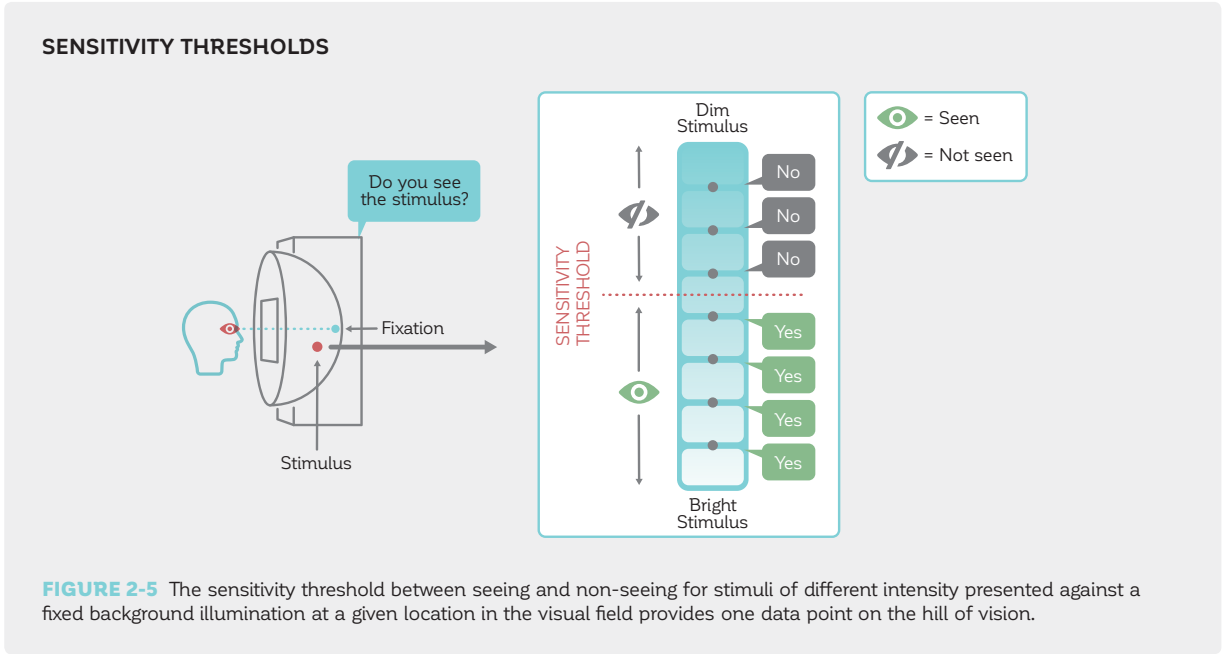
THE PERIMETRIC TEST

Perimetry accurately quantifies a patient’s sensitivity to light throughout the visual field in a systematic, highly standardized manner. To assess the visual field, a hemispheric cupola is typically used to project small light stimuli across the entire area of the visual field. These stimuli, and the uniform background onto which the stimuli are projected, are highly standardized in terms of shape, size, color, light intensity and duration, to ensure high reproducibility. The most commonly used test conditions project a round, white stimulus on a background, which is also white, but dimmer than the stimulus. The luminance (i.e., the reflected light intensity) of the stimulus can be altered from very low to very high. More detailed information on key examination parameters is provided in Chapter 4.

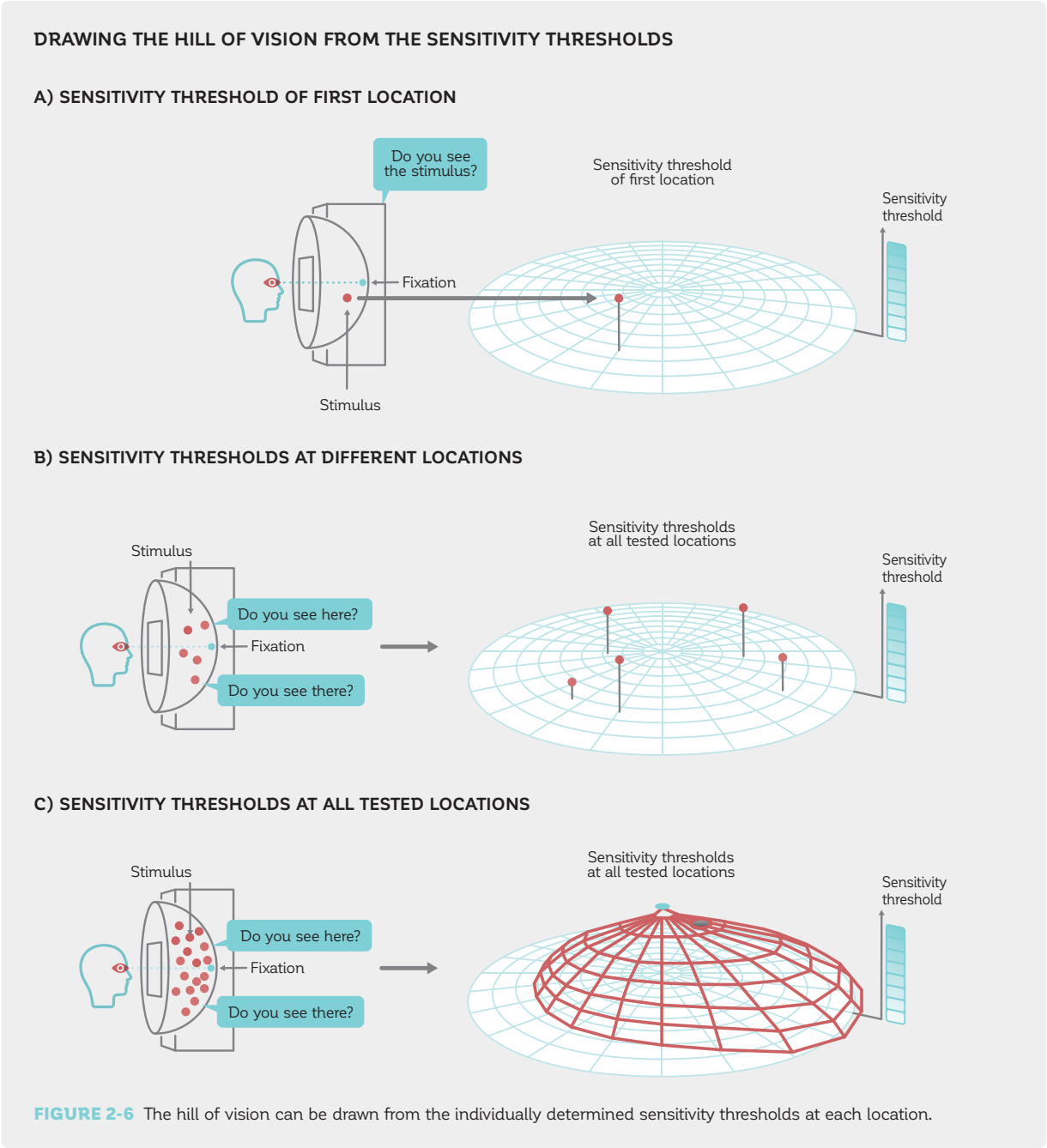
To perform a perimetric test, patients are asked to sit in front of the cupola with their head stabilized, to fixate onto a target in the center, and to indicate seeing a

stimulus anywhere in their visual field by pressing a response button. Conceptually and to simplify things, one can imagine that at the first location the luminance of the stimulus is increased from the “off” position to the dimmest level of an adjustable light bulb. If the patient cannot see the stimulus when it is off or very dim, another stimulus is shown later, at a higher level of light intensity. Once the stimulus reaches a certain light intensity, the patient can see it and presses the button. It should be noted that the stimulus is always turned off before the next stimulus is presented.

This minimum light intensity that can be seen defines the patient’s sensitivity to light (i.e., the threshold between non-seeing and seeing) (FIG 2-5). Due to this evaluation method, in perimetry the word threshold is often used, instead of sensitivity to light. For ease of understanding, “sensitivity threshold” is the term used throughout this book.



The sensitivity threshold at the first test location provides the first data point to characterize the hill of vision (FIG 2-6A). To determine the patient’s hill of vision, the aforementioned procedure is then repeated at many locations across the visual field (FIG 2-6B). By connecting the sensitivity thresholds at all tested locations, a patient’s hill of vision can be drawn (FIG 2-6C).



While the process used to determine sensitivity thresholds is easy to understand, it would be much too time-consuming to test each location of the hill of vision in this manner. Therefore, more efficient strategies are used in

perimetry and they will be discussed in depth in Chapters 4, 5 and 6. Additionally, the order of stimulus presentation is randomized throughout the visual field, to avoid patients becoming accustomed to a certain presentation pattern.

DISPLAY OF SENSITIVITY THRESHOLDS

THE DECIBEL SCALE USED IN PERIMETRY

In clinical practice, visual field information needs to be easy to interpret and should directly correspond to the clinical situation. For that purpose, perimetry employs the decibel scale, with its unit of measurement being the decibel (dB). The decibel range depends on perimeter type and typically ranges from 0 dB to approximately 32 dB in the fovea. A sensitivity threshold of 0 dB means that a patient is not able to see the most intense

perimetric stimulus that the device can display, whereas values close to 32 dB represent normal foveal vision for a 20-year-old person. While the decibel scale is intuitive to understand and use in clinical practice, the underlying considerations and formulas are less intuitive and of limited relevance for clinical practice. For those interested, they are explained in [BOX 2A](#).

BOX 2A

THE RATIONALE FOR THE USE OF THE DECIBEL SCALE

The intensity of the light that is reflected on the perimetric surface is called luminance and can be measured objectively with a light meter. It is expressed in candelas per meter squared (cd/m^2) or in the older unit, the apostilb (asb), with $1 \text{ cd}/\text{m}^2$ corresponding to 3.14 asb. The measurement indicates light flux per unit area.

In theory, sensitivity thresholds could be expressed in luminance units. While this would be correct, it would be impractical in clinical practice for the following reasons:

- 1. Large number of discrete luminance levels**

The human eye can adjust to a large range of luminance levels over at least 3-4 orders of magnitude (e.g., from almost 0 asb to 10,000 asb in normal daytime lighting conditions). This would make certain threshold values very large and impractical to display.

- 2. The relationship between visual function and luminance is not linear**

Visual function is not linear with regard to the light intensity levels. For example, while an increase of 90 asb is likely to be noticed when luminance is increased from 10 to 100 asb, this same absolute increase in luminance (90 asb) would hardly be noticeable when luminance is increased from 1,000 to 1,090 asb.

- 3. Inverse relationship between luminance and sensitivity to light**

There is an inverse relationship between stimulus luminance and a patient's sensitivity to light. A patient with high sensitivity to light only needs a stimulus with low luminance to be able to see it, while a patient with low sensitivity to light needs a stimulus with high luminance. For clinical

use, a scale defining visual field loss as low and good vision as high would be more intuitive than the inverse luminance scale.

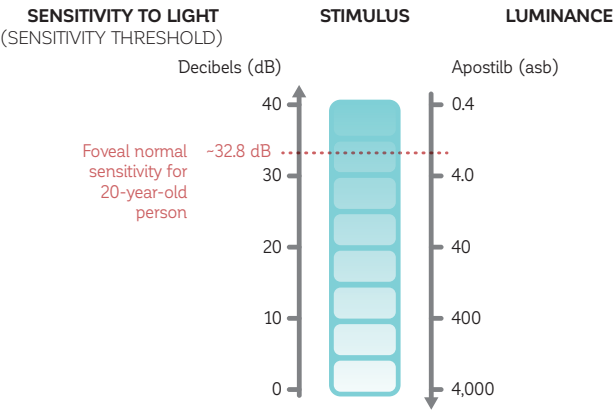
4. Lack of definition of complete visual field loss

Since luminance and sensitivity to light are inversely related, complete visual field loss would be a very high luminance number. This number would be limited by the maximum stimulus the perimeter is able to display, potentially resulting in large differences between different perimeter models.

THE DEFINITION OF SENSITIVITY TO LIGHT USING THE DECIBEL SCALE

The decibel scale addresses all of these issues and uses luminance levels solely as input variables. The relationship between the decibel scale and the luminance scale in apostilbs is shown below.

RELATIONSHIP BETWEEN SENSITIVITY TO LIGHT AND LUMINANCE



The decibel scale is used to express sensitivity to light. This figure shows the relationship between sensitivity to light and luminance. The maximum stimulus brightness, which is used as a default in recent Octopus perimeter models, is 4,000 asb. It is a logarithmic scale and is inversely related to the linear luminance scale in apostilbs (asb). Note that the maximum stimulus brightness might be different in different perimeter models.

The sensitivity to light in decibels is defined using the formula below

$$dB = 10 * \log (L_{max}/L)$$

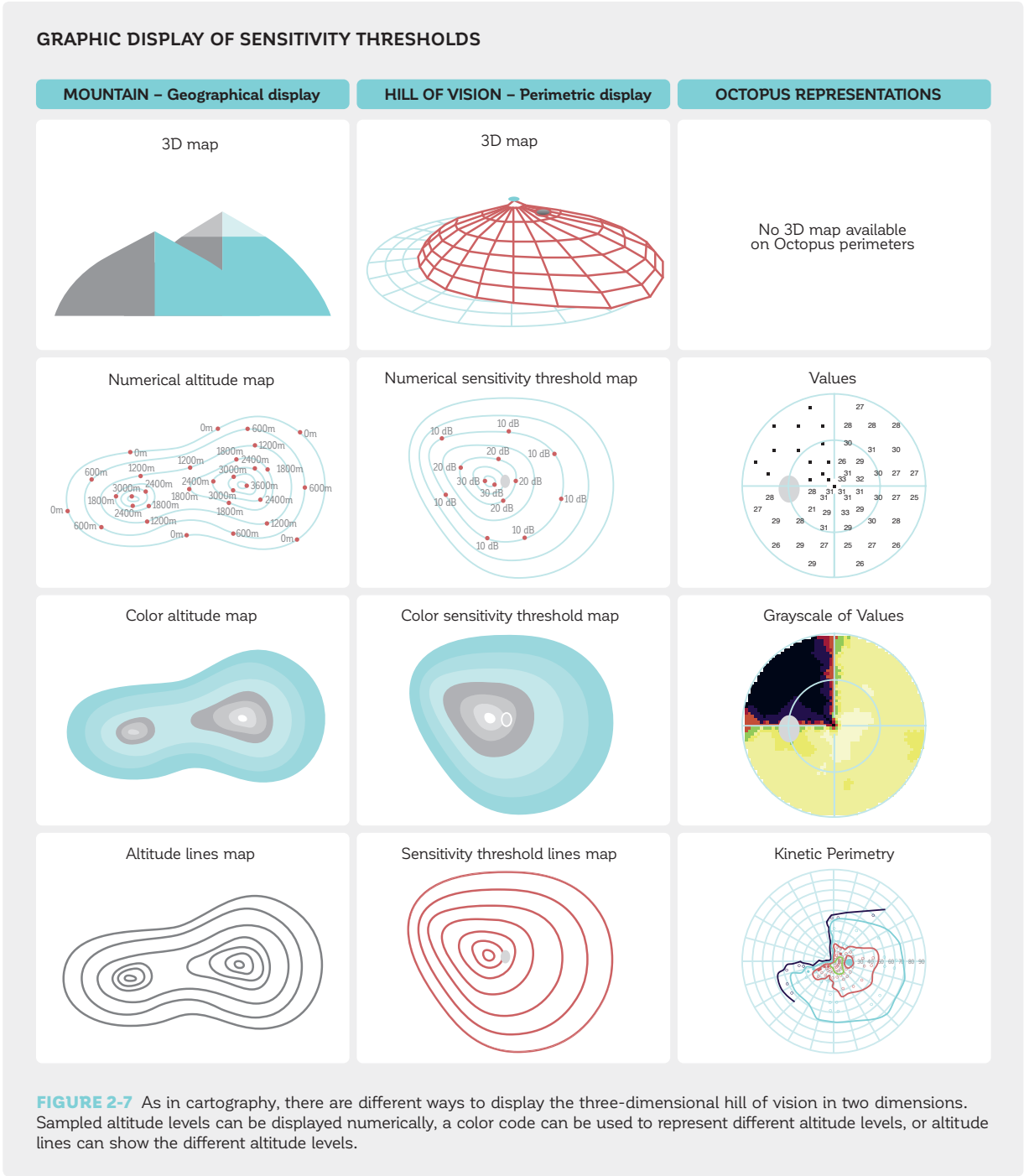
where dB is the sensitivity threshold, L_{max} is the maximum luminance the perimeter can display, and L is the luminance of the stimulus at the threshold (both expressed in apostilbs).

The logarithmic scale is used to address the large range of luminance values and to relate this range more linearly to visual function. To address the inverse relationship between luminance and sensitivity to light, the inverse of luminance ($1/L$) is used in the formula; and to make sure that near complete visual field loss equals 0 dB, which is intuitive, the maximum stimulus luminance L_{max} is added to the equation.

Since 0 dB refers to the maximum intensity that the perimeter can produce, its interpretation in terms of stimulus luminance may be different for various visual field devices. This should be kept in mind when switching between different perimeter models. Chapter 12 will focus on how to deal with differences between perimeters in clinical practice.

GRAPHIC DISPLAY OF SENSITIVITY THRESHOLDS

The three-dimensional hill of vision contains large amounts of information. It may therefore be challenging to appropriately display all aspects of a patient’s visual function from the three-dimensional representation. Cartographers face similar challenges when displaying three-dimensional mountains or hills, and have used



two-dimensional maps as a solution. Similar display strategies are used to display the hill of vision in two dimensions.

As in geographical maps (FIG 2-7), the various sensitivity thresholds can be displayed numerically (i.e., by sampling certain altitudes to give a feel for the overall shape of the hill or mountain). Color codes for different altitude levels are also often presented on geographical maps. Last but not least, lines of the same altitude level can provide a good representation of a hill on a map. For perimetry, these lines of equal altitude are referred to as isopters (lines of equal sensitivity).

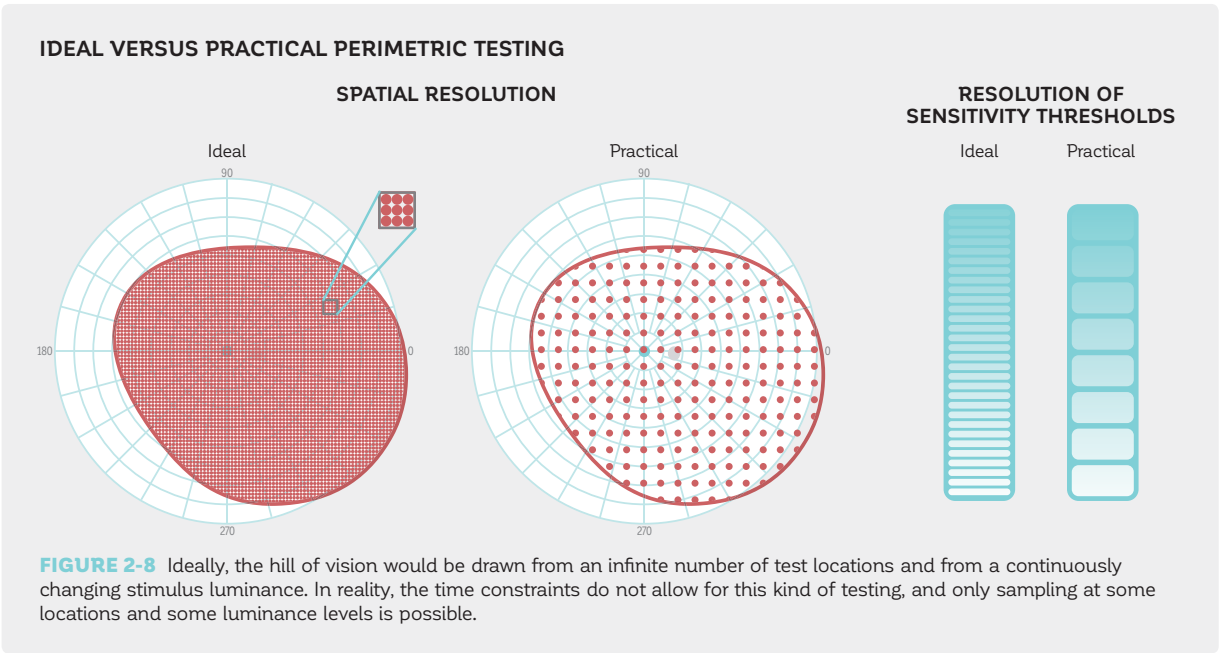
It should be noted that whichever display form is used, there is always some information lost. All three versions are used to display perimetric results, as each emphasizes different clinical information. For more details of the various representations, see Chapters 7, 8, and 11.

CHALLENGES IN VISUAL FIELD TESTING AND INTERPRETATION

PERIMETRIC TESTING HAS LOW RESOLUTION

So far, this book has presented perimetry as a very accurate way of continuously showing the stimuli of increasing intensity for the patient. It has also been assumed that thresholding is performed at all locations across the visual field.

From a practical point of view, however, it is nearly impossible to test each location within the visual field (spatial resolution) using each possible light intensity (luminance resolution). This would take too long to be useful in a clinical setting. Therefore, referring back to



the example of the light bulb in a room, the dimmer only has a set number of discrete levels, such as high, medium and low, and there are only a few bulbs to illuminate the room (FIG 2-8).

For perimetry, this means that stimuli are presented at a fixed number of key locations and that only a limited num-

ber of light intensity levels are presented. This approach introduces inaccuracies in the perimetric test. In order to still be able to receive the information necessary for good clinical decision-making, a number of elaborate processes are used in perimetry. This maximizes clinical information and offers a good trade-off between testing time and accuracy. These are described in Chapters 4, 5 and 6.

NORMAL SENSITIVITIES DEPEND ON AGE AND TEST LOCATION

As already illustrated in the section about the hill of vision, normal sensitivity thresholds depend on the test location and are higher at the center than in the periphery. In addition, the normal hill of vision is affected by age. Normal sensitivity to light in decibels decreases approximately linearly with increasing age, beginning at the age of 20.¹⁻³ Thus, the hill of vision of a 20-year-old is typically higher than the hill of vision of an 85-year-old person (FIG 2-9).

For these reasons, sensitivity thresholds are challenging to interpret directly in the clinic, because the representations of normal and abnormal values depend on testing- and patient-specific factors. For correct clinical assessment of sensitivity thresholds, a clinician would have to keep normal reference values in mind for all age groups and test locations, in order to correctly interpret the results. That would be a challenging task.

HILL OF VISION IS AGE- AND LOCATION-DEPENDENT

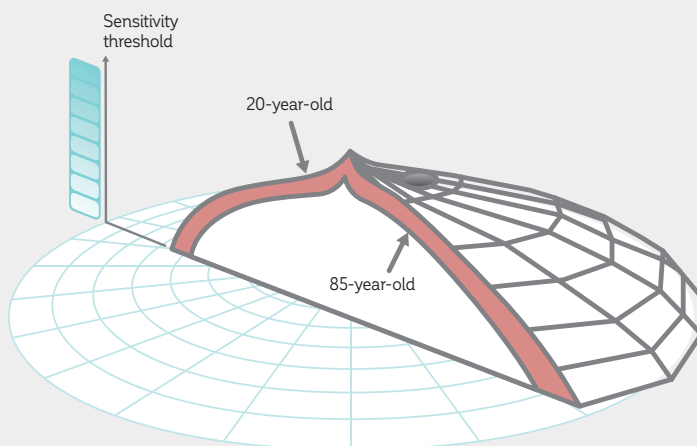
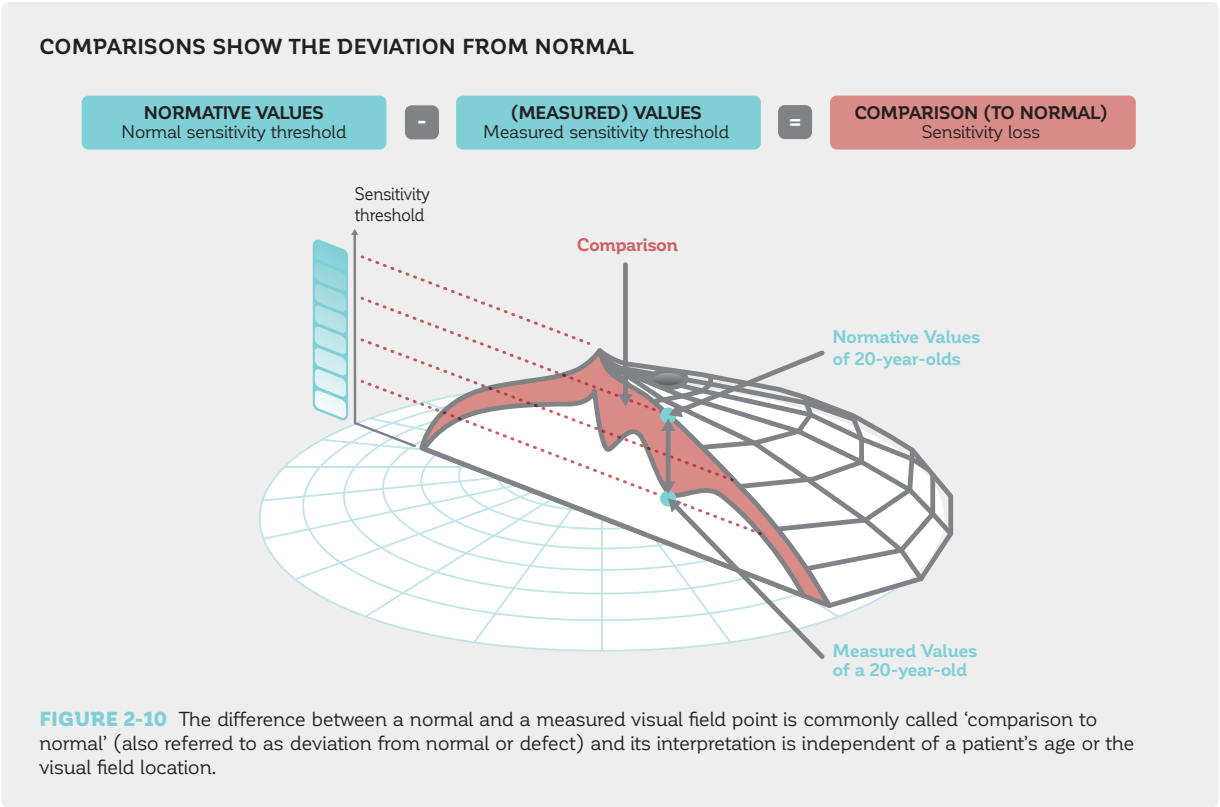


FIGURE 2-9 The normal hill of vision shows the highest sensitivity thresholds at the center, with decreasing sensitivity thresholds towards the periphery. Similarly, there is also a decrease in sensitivity thresholds with increasing age at all test locations.

Therefore, distinct normative databases have been developed for most modern perimeters and these databases are used to facilitate clinical visual field interpretation. Normative databases contain normal reference values for each age group and test location (BOX 2B). They are used to compare any measured sensitivity threshold to the respective normative value for someone of that age. The calculated comparison to normal is clinically meaningful, as it relates directly to sensitivity loss (FIG 2-10). Alternative expressions that are commonly used for comparisons to normal are deviation from normal or defect.



Due to their ease of use, most representations in the Octopus perimeters are based on comparisons to normal and not on the measured sensitivity thresholds. For more information, refer to Chapter 7.

BOX 2B**NORMATIVE DATABASES IN OCTOPUS PERIMETERS****DESIGN OF A NORMATIVE DATABASE**

By definition, the normative database of a perimeter consists of a pool of visual field data from people with normal vision in all age groups. The challenge associated with generating this pool is to ensure that these normal visual fields are truly normal and that there are sufficient visual fields to account for individual differences.

The standards to be fulfilled for a perimetric normative database are described exhaustively in the ISO norm «Ophthalmic instruments - Perimeters (ISO 12866:1999/Amd1:2008); Amendment A1, Appendix C». All normative databases of Octopus perimeters comply fully with these standards. The typical process to comply with the standards is to perform a clinical study that includes a thorough eye examination and repeated visual field testing.

DISTINCT NORMATIVE DATABASES FOR DIFFERENT DEVICES AND EXAMINATION PARAMETERS

Since particular perimeter models vary in design and might use different examination parameters, a stimulus of the same light intensity may be perceived differently on various perimeter models. Therefore, there are distinct normative databases for different perimeter types and settings.

PERIMETRY HAS OBJECTIVE AND SUBJECTIVE COMPONENTS

In the interest of simplicity, perimetry has been treated as a purely objective procedure, with exact measurements and distinct sensitivity thresholds at each test location. This is true for the equipment and the test conditions. However, there is a subjective element to perimetry, due to the subjectivity of the patients undergoing the test. As a result, there is always a certain amount of normal fluctuation both among different normal individuals, as well as between different measurements of the same individual over a short period of time. The accuracy of the test results is highly dependent on several factors, including the cooperation of the patients, their cognitive and physical abilities, and their decision criteria.⁴⁻⁶ If the

patient does not understand the test, does not pay attention or does not focus continuously on the central target, then the results of the test will be difficult to interpret. Additionally, some patients may be very conservative in their judgements, requiring a more intense stimulus for detection, while other patients may be liberal and accept a less intense stimulus for detection. The most important person to maximize the performance of the patients is the visual field examiner (e.g., a perimetrist or technician). Chapter 3 focuses on potential sources of unreliable and thereby highly fluctuating visual fields and provides practical guidance on how to minimize these factors.

NORMAL FLUCTUATION DEPENDS ON TEST LOCATIONS AND DISEASE SEVERITY

A further complication in visual field interpretation is the fact that normal fluctuation is not uniformly distributed across the visual field (**FIG 2-11**). Instead, normal fluctua-

tion is smaller at the center of the visual field than in the periphery and is also smaller in areas of good vision than in areas of poor vision.^{1,7}

NORMAL FLUCTUATION IN PERIMETRY

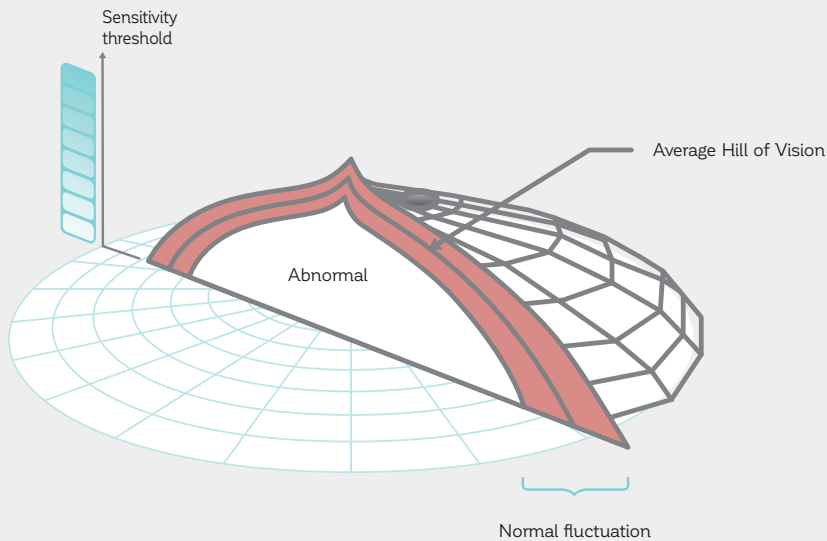


FIGURE 2-11 Since perimetry contains a subjective, patient-related component, there is always normal fluctuation. Its magnitude depends on both the test location and disease severity.

These two factors must be kept in mind when making clinical decisions based on visual field results. To objectively measure fluctuation around a sensitivity threshold, the frequency-of-seeing (FOS) curve may be used (BOX 2C).

THE FREQUENCY-OF-SEEING (FOS) CURVE

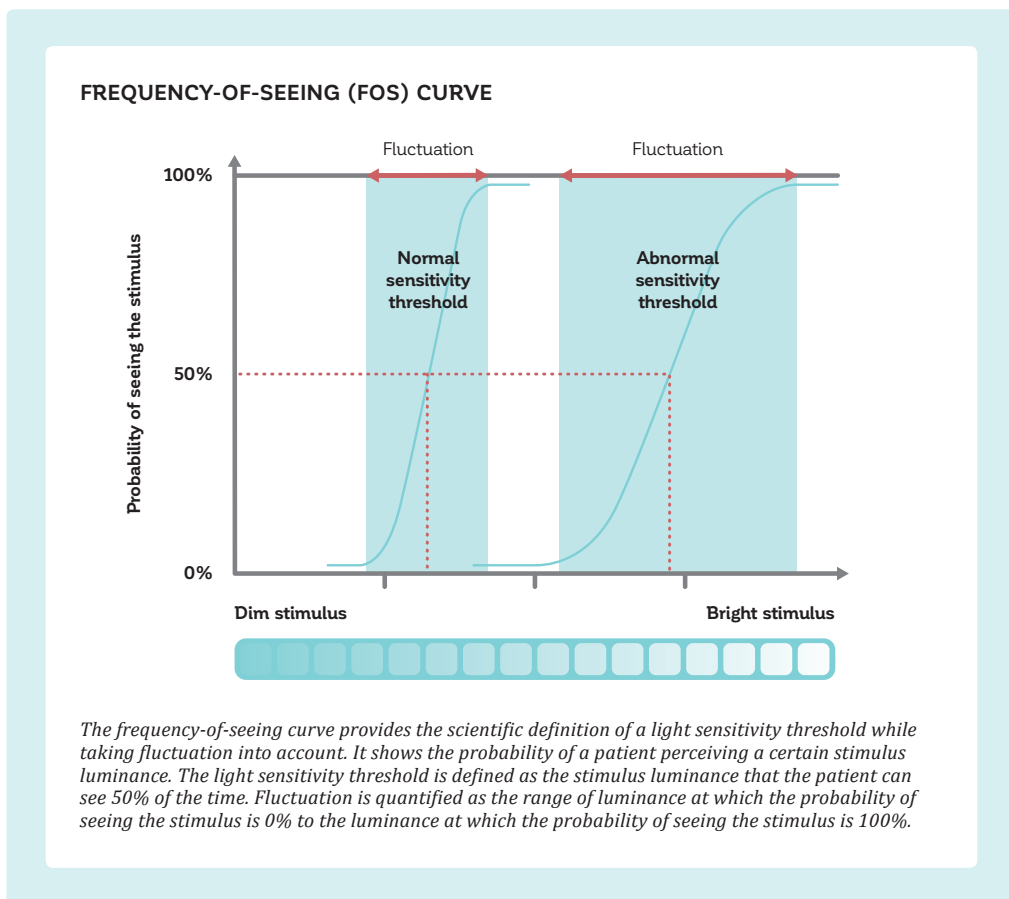
BOX 2C

Due to fluctuation, distinct sensitivity thresholds at a given test location cannot be measured precisely. In reality, the same patient always shows slightly varying responses in repetitive testing. In other words, the likelihood of seeing or not seeing a stimulus is probabilistic.

As the luminance (i.e., the light intensity of the stimulus) increases, there is a gradual increase from “unseen” to “seen” responses, so that the probability that a patient will perceive a stimulus changes gradually from 0% to 100%. Because of this, sensitivity thresholds are defined as the stimulus luminance that is perceived with a probability of 50%.

To get a measure of fluctuation, one can show a stimulus of a certain luminance to a patient many times at a given test location and determine how often the patient is able to see it. The probability of perceiving a stimulus can be mapped in a graph as a function of stimulus luminance. When doing this for many different luminance levels, one can generate a frequency-of-seeing (FOS) curve, which describes the probability that a patient will perceive a target as a function of stimulus luminance. This is a useful tool to illustrate the variability associated with the determination of thresholds.⁸ In areas of normal sensitivity, the FOS curve is typically steep, indicating that there is less variability. In other words, the patient has a high probability of seeing stimuli that are slightly more intense than the luminance at the threshold, and also a high probability of not seeing stimuli that are slightly less intense than those at the threshold. This is illustrated on the left side of the figure by the steep shape of the FOS curve.

In areas where defects are present, the FOS curve is typically shallow, indicating that there is greater variability. In other words, there is a gradual change in the probability of detecting stimuli that are higher and lower than the luminance at threshold. This is illustrated on the right side of the figure by the shallow shape of the FOS curve.



CLINICAL STANDARD FOR VISUAL FUNCTION TESTING

Even though perimetry has low resolution and contains subjective, patient-related components resulting in normal fluctuation, perimetric testing is useful to assess visual fields in clinical practice. It remains highly important because visual field function is most directly related to a patient's quality of life and ability to perform activities of

daily living, which are the most important factors for the patient. Additionally, slowly progressing diseases such as glaucoma can be followed accurately through all stages of the disease. Perimetry is therefore an indispensable tool for every glaucoma specialist.

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