Conventional Perimetry

Part I: Introduction – Basic Terms

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Slightly modified translation of:
U. Schiefer, J. Pätzold, F. Dannheim: Konventionalle Perimetrie. Teil I: Einführung – Grundbegriffe. Der Ophthalmologe 2005, 102(6):627-646.
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Summary

Evaluation of the visual field is an important component of the ophthalmological examination. The application of psychophysical principles has been used to develop a non-invasive, topo-diagnostic test that is useful for investigating cases of visual loss of uncertain origin, or cases of suspected disease in the afferent visual pathways. Perimetry is also useful for formal certification of visual function to determine suitability for employment, degrees of disability, operation of motor vehicles, etc. Multiple, sequential examinations are also used to follow the temporal course of visual disorders and to monitor the effectiveness of their therapies. The material covered here deals with the conventional methods of visual field examination that have been developed and standardized over many years of clinical use in the everyday practice of ophthalmology. This first section covers the basic definitions and psychophysical terms of perimetry and includes a discussion of the clinical settings in which visual field testing is indispensible. Also, a system for the classification of visual field findings is given.

Keywords

Perimetry, Visual field, Visual field defect, Scotoma, Psychophysics

The purpose of this document

As mentioned, this section covers the basics of visual field examination and is targeted at readers from both within and outside the discipline of ophthalmology. This is not an exhaustive review of the literature. For a more detailed coverage of the material please refer to the texts and book chapters referenced at the end of this section [3,4,6,7,9,11-14,17-20].

History

The concept of visual field testing was documented during antiquity by Ptolemy (Claudius Ptolemaeus, 87 - 150 CE) as having been described in the 2nd century BCE. (A summary of the historical dates given here can be found in [9]). Campimetry (testing of the central portions of the visual field) was introduced by Porta in 1593 CE, and the first description of the physiologic blind spot was by Mariotte in 1666. The first determination of an acquired visual field defect was reported by Young in 1800. The systematic use of visual field testing as an essential component of the ophthalmic examination dates from the time of Albrecht von Graefe (1828 - 1870), and the technology and methods of modern perimetry developed most rapidly during the second half of the 20th century.

Terms and Definitions

Visual Field – Field of Gaze / Field of View– Campimetry – Perimetry

The term "***visual field***" refers to the sum total of visual perception for an eye fixed on a stationary object of regard with the head and body held fixed in position. The ***binocular visual field*** is the combined visual perception of both eyes under the same restrictions on movement. The standard unit of measurement in the visual field is the ***differential light sensitivity*** (DLS). This is defined as the threshold of perception of a test object, relative to its background (also called the surround). In practice the background brightness (luminance) is held constant, while a test object of varying size, brightness, and position is projected onto it. The test object can be introduced with movement while its size and brightness are kept constant (***kinetic perimetry***), or it can be kept at fixed positions while varying its size and/or brightness (***static perimetry***). The threshold is defined probabilistically as a 50% likelihood of perception at any given location in the visual field. The resulting data set is characterized by a central peak of sensitivity at the point of fixation with a monotonically falling of sensitivity in all directions away from the center. This has been referred to conceptually as a 3-dimensional "***hill of vision***" or as an "***island of vision***". Loci of equal sensitivity on the surface of this structure form contours of isosensitivity (***isopters***) that are closely analogous to the cartographic lines of elevation on a contour map or to the isobars or the isothermic contours seen on meteorological maps. When 2 or more isopters closely approach one another, they indicate a relatively steep rise or fall of the 3-dimensional surface, while widely separated isopters indicate a more gently sloping contour. At the extreme periphery of the visual field, the island of vision is said to sink into the "***sea of blindness***" [16], indicating a total absence of visual perception beyond the peripheral border of the visual field. A normal visual field requires clarity of the optical media, focused image formation on the retina, and healthy image processing elements in all portions of the afferent visual pathways from the photoreceptors through the bipolar and ganglion cells of the retina, through the ganglion cell axons of the optic nerves and tract to the lateral geniculate body, and then along the optic radiations to all of the neuronal elements of the primary visual cortex.

The visual field is to be strictly differentiated from the "***field of gaze***", in which the eye is permitted to have freedom of rotational movement while the head and body are kept in a constant position, and from the "***field of view***", in which the eye as well as the head can be moved. Since everyday visual experience includes these combined freedoms of movement, the field of view and the field of gaze are more accurate expressions of total visual performance than is the (rather artificial) visual field. However, with these greater degrees of freedom the specific diagnostic value of the data is diminished, because the performance of the ocular and somatic motor systems is being combined with the performance of the afferent sensory pathways. With movement permitted, the presence of a defect in the visual field can often be masked by compensatory eye, head and/or body movements, and may thus escape detection during an ophthalmic examination.

Campimetry (from Latin campus: field) refers to examination of the visual field projected on to a flat surface, e.g. on a wall, a transparent screen, or a video or flat-panel monitor. This method is best suited to examination of the central visual field, up to approximately 20 degrees of eccentricity, but is less useful in more peripheral locations due to geometric distortions.

Perimetry, however, is performed with a hemispherical surface onto which the visual field is projected. The eye to be examined is positioned at the geometric center of the hemisphere, such that all points on its inner surface are equidistant from the eye. The surface is uniformly illuminated and test objects are small spots of light that are projected on top of the adapting background (also called the ***surround***).

(Although they are not precisely the same, the terms "visual field examination" and "perimetry" will be used synonymously in this document).

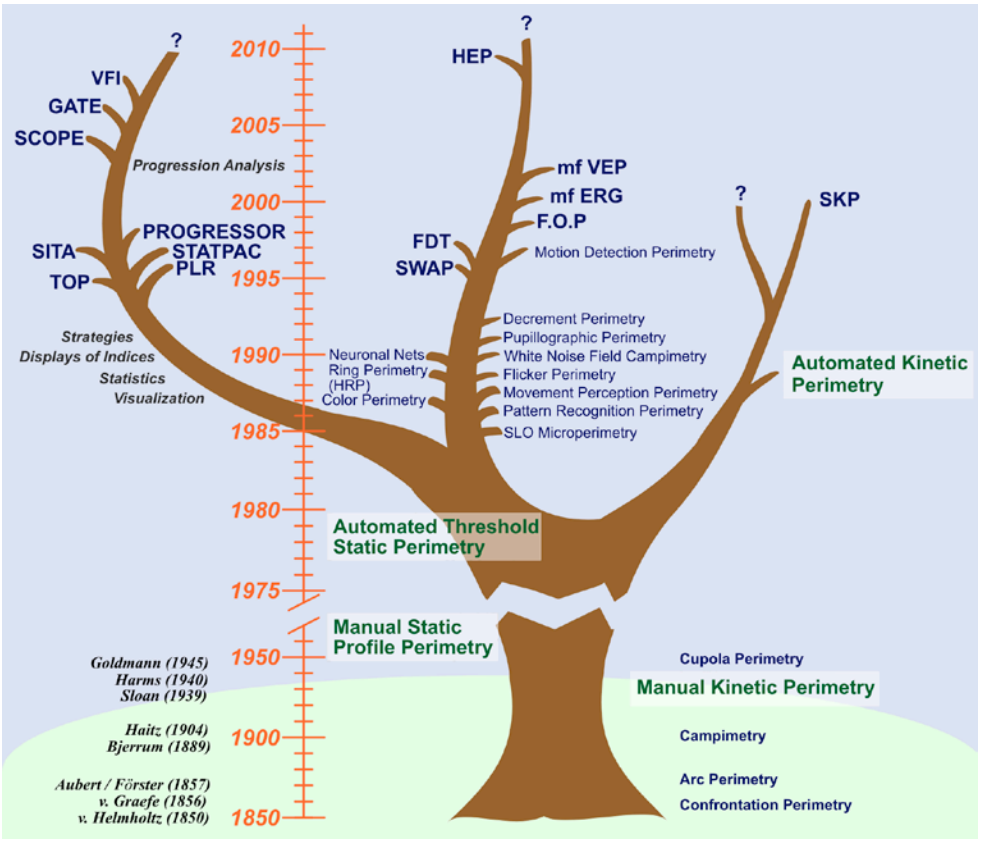

Figure 1
The "perimetric family tree" diagrams the evolution of clinical methods for visual field testing during the 20th Century.
FDT = Frequency Doubling Technology, FOP= Fundus oriented perimetry, GATE = German Adaptive Thresholding Estimation, HEP = Heidelberg Edge Perimeter, mfVEP = multi-focal Visually Evoked Potentials; mf-ERG = multi-focal Electroretinogram, PLR = pointwise linear regression, SCOPE = Scotoma oriented Perimetry, SITA = Swedish Interactive Thresholding Algorithm, SKP = semi-automated Kinetic Perimetry; SWAP = Short Wavelength Automated Perimetry; TOP = Tendency-Oriented Perimetry; VFI = Visual field index
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Kinetic Perimetry – Static Profile Perimetry – Automated Static Perimetry

Kinetic perimetry uses test objects that are fixed in size and brightness. They are moved from non-seeing areas into seeing portions of the visual field, the test subject being asked to signal when the object first becomes visible (Fig. 2a). This method is particularly realistic and relevant to clinical practice, since visible objects in everyday life come to notice either through their own movements or by gaze movements of the eye, causing their images to move across the retinal surface. The results of this method are plotted in the form of so-called isopters, which are lines of equal differential light sensitivity (DLS).

Static perimetry employs stationary test objects that vary in size and brightness, but never move. If the test object locations are arranged in a linear sequence, a vertical slice is made through the hill of vision, analogous to profile portrayals used in cartography (Fig. 2b). This largely manual technique is useful when examining the central and paracentral areas of the central visual field, e.g. when used to study cases of central serous retinopathy. Static profile perimetry of this sort has been done as a manual technique that is seldom used now and is included in this discussion largely for the sake of completeness. If the test objects are to be presented across an area of the field (usually as a rectilinear grid), a computer algorithm controls their display in a manner that is largely independent of the examiner's input - a method called ***static automated perimetry*** (Fig. 2c). A graphic representation of the hill of vision can be generated by interpolation of the DLS values, producing an image that is much like the appearance of the polygonal facets that make up the surface of a geodesic dome.

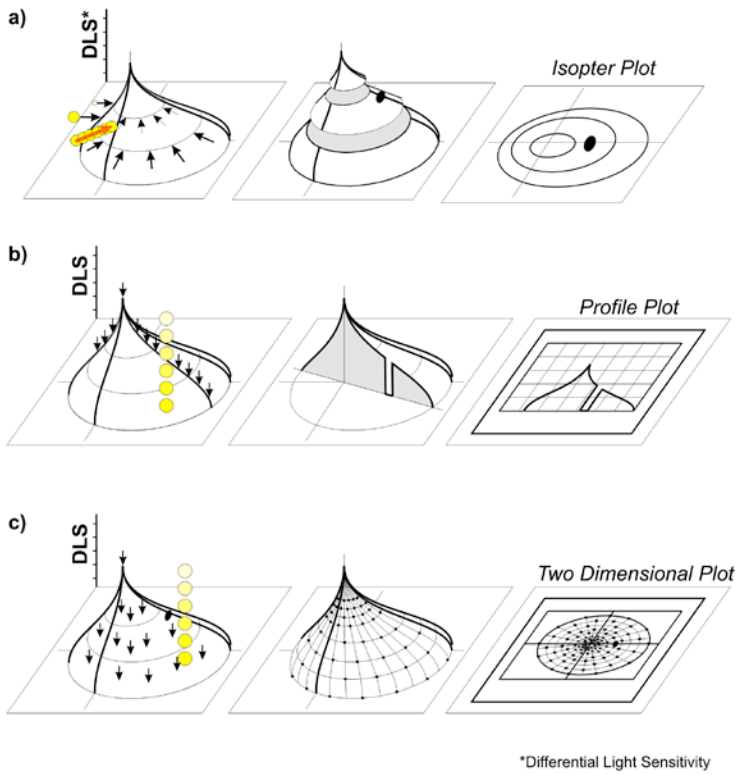

Figure 2 **a-c**
Conventional perimetric methods (modified after [13,14]:

a: kinetic perimetry

b: static profile perimetry

c: automated threshold static perimetry

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Basic Psychophysical Terms [2]

This somewhat lengthy section deals with the basics of photometry and is meant to explain its numerous and sometimes confusing terms. Many of these quantities are expressed in non-metric units but remain in use in the Anglo-American literature. Readers for whom this is of no interest can jump ahead to the section titled "Indications".

Luminous Energy - Luminous Flux - Luminous Intensity - Illuminance - Luminance

The power of visible light emitted by an object is called its ***luminous flux*** (Φ), whose unit of measure is the lumen (lm). ***Luminous intensity*** (*I*) is the luminous flux emitted in a particular direction:

$$I = \frac{\Phi}{\Omega}$$

in which Ω is the solid angle (expressed in *steradians*) within which the luminous flux is radiating. Luminous intensity is measured in units of the candela (cd). To determine how much

light falls upon an object, the luminous intensity (*I*) must be determined on a reflective area (A) of the object. This quantity is called ***Illuminance*** (*E*):

$$E = I / A$$

Thus, illuminance is the luminous intensity per unit area of an object and is expressed in units of lux (lm/m^2). Illuminance is measured using a luxmeter.

The subjectively perceived brightness of an object, for example a perimetric stimulus or the background of the perimeter bowl, are related to their luminance. Luminance is a physical term that expresses the amount of light emitted or reflected from a surface in a particular direction. It is measured in units of cd/m^2, although older and still often encountered unit are the apostilb (asb, $= 1/pi * cd/m^2$) and foot-lambert (fL, 3.42 cd/m^2). Luminance depends on the reflectance of the object and should therefore not be confused with illuminance which measures the amount of incident light falling upon a surface.

In Table 1 are examples of illuminance found in various conditions to give an idea of the range of values that one encounters in some familiar circumstances. Note that the human visual system has a dynamic range of 8-9 logarithmic units.

Table 1 [8,15]

Examples of Various Levels of Illuminance and Luminance		
	Illuminance (cd/m^2)	**Luminance (lx)**
Cloudy and moonless night, little or no visibility		**0.001**
Clear night at new moon, orientation possible	**0.003**	**0.01**
Full moon, reading possible		**0.24**
Street scene at dusk	**0.1 - 0.5**	**1**
Room with incandescent lighting		**20-100**
Good working light		**100 - 2000**
Video or LCD monitor	**150-300**	**-**
Cloudy winter day		**200 - 4000**
Overcast sky	**300-5000**	**10,000-30,000**
White surface under direct sun	**10,000**	**up to 100,000**
Fresh snow surface or white sand beach in full sunlight	**100,000**	

The dark adapted region of the eye (night vision, i.e. below a luminance level of 0.01 cd/m^2) is called ***scotopic***. The ***photopic*** region of light adaptation (day vision) is at and above luminance

levels of 1.0 cd/m2). The transitional, overlapping region between scotopic and photopic levels of luminance (i.e. 0.01-1.0 cd/m^2) is called the ***mesopic*** range of light adaptation (Table 2).

Table 2

Scotopic, mesopic and photopic levels of luminance	
Scotopic	< 0.01 cd/m^2
Mesopic	0.001 - 1.0 cd/m^2
Photopic	> 1.0 cd/m^2

The Weber and Fechner Laws – Contrast – Decibel Scale

In everyday experience we compare object sizes, speeds and weights through observation of apparent differences and can determine how much more big, fast or heavy one object is compared to another. A comparison of subjective ("psychophysical") sensory comparisons and physical measures of stimulus intensity finds them entirely different in their abilities, as can be illustrated by the following example. If one has a lighted candle and adds another to it, the illuminance is doubled, and the increase in brightness is easily perceived (even though two candles do not appear twice as bright as a single one). If one adds the same candle to a group of 1000 candles, the increase in brightness is no longer apparent; one must add 1000 additional candles to obtain the same subjective increase. The difference in luminance is call contrast. The natural law that underlies this phenomenon was first described by **Weber** in 1846: it expresses the contrast, or the luminance difference (ΔL), that can be seen as a function of the luminance of the background as a proportional constant:

$$\frac{\Delta L}{L} = const.$$

Fechner (1860) extended Weber's law to the description of equal sensory differences (ΔE):

$$\Delta E = c \times \frac{\Delta L}{L}$$

The laws governing visual perception of contrast are not functions of differences but of ratios. Contrast perception is not an expression of "how much", but rather of "how much more". (In fact, this is a generic property of all biological sensory systems). One can express ratios on a logarithmic scale, converting the values back to arithmetic differences. By expressing the quotients as logarithmic units, the huge range of luminance values (0.001 - 100,000) can be compressed into 8 logarithmic units.

This method expresses the increment of the stimulus luminance ΔL over the background luminance LU ($\Delta L = L - LU$) with respect to a reference luminance (L_{Ref}) according to the following formula:

$$\Delta L(in\ dB) = 10 \times \log \frac{L_{Ref}\left(in\ cd/m^2\right)}{\Delta L(in\ cd/m^2)}$$

The unit of a logarithmic scale is the Bel: it denotes 2 numbers or quantities that are proportional at a ratio of 10:1. The rather more useful decibel (dB = 0.1 Bel) denotes 2 numbers that are proportional at a ratio of $10^{0.1}$:1 ($10^{0.1}$ = 1.26); 3 dB correspond approximately to a factor of 2 (see Figure 3 below).

Because an exact conversion of the dB values between one perimeter design and another is difficult, each instrument should be used with its own unique (method-)specific, age-corrected, normative data.

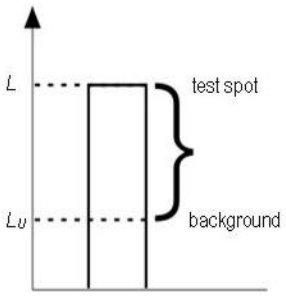
A default standard has been adopted by most instrument manufacturers by using the maximal stimulus intensity that each instrument is capable of producing as its reference luminance. Thus, 0 dB is the maximal stimulus luminance that an instrument can achieve. Higher dB values correspond to attenuated stimulus intensities (meaning increased levels of contrast sensitivity). In practice, the attenuation is produced by introducing neutral density filters into the light path of the stimulus projector. Higher dB values indicate greater attenuation, meaning lower levels of stimulus luminance. With this method negative dB values are not encountered, because luminance values greater than the maximum are not possible. The various perimeters differ from one another in the null points of their scales, since they have differing maximum luminance levels. This means that a result of 20 dB for one manufacturer's instrument is not comparable with the same dB value from another's. The choice of a reference value in the form of an instrument-specific maximum luminance is none the less arbitrary. Any value could be used except for 0 cd/m^2, since a null value cannot be used in a ratio. The conversion from one scale to another is easily made (thanks to the use of logarithmic scaling) by simple addition or subtraction of a constant (see Figure 3). Consequently, negative dB values are possible: These are encountered if the luminance level of stimuli is greater than the reference luminance, which is the case for some of the values for the dB_s scale (see Figure 3).

Comparison of the luminance scales of ΔL [dB] for various perimeters							
	Goldmann	TAP / Twinfield	Humphrey	Octopus101	dBs scale		
L_B [cd/m²]	10	10	10	1.28	10	asb	cd/m²
L_{Ref} [cd/m²]	316	316	3162	316	10		
				47	32	0.020	0.006
				46	31	0.025	0.008
				45	30	0.031	0.010
				44	29	0.040	0.013
				43	28	0.050	0.016
				42	27	0.063	0.020
				41	26	0.079	0.025
				40	25	0.099	0.032
				39	24	0.125	0.040
				38	23	0.157	0.050
				37	22	0.198	0.063
				36	21	0.250	0.089
		40		35	20	0.31	0.100
		39		34	19	0.40	0.126
		38		33	18	0.50	0.158
		37		32	17	0.63	0.200
		36		31	16	0.79	0.251
		35	40	30	15	1.00	0.318
		34	39	29	14	1.26	0.401
		33	38	28	13	1.58	0.504
		32	37	27	12	1.99	0.635
		31	36	26	11	2.51	0.800
		30	35	25	10	3.14	1.00
		29	34	24	9	3.98	1.27
		28	33	23	8	5.01	1.59
		27	32	22	7	6.31	2.00
		26	31	21	6	7.94	2.53
		25	30	20	5	10.0	3.18
	1a	24	29	19	4	12.6	4.01
	1b	23	28	18	3	15.8	5.04
	1c	22	27	17	2	19.9	6.35
	1d	21	26	16	1	25.1	7.99
	1e	20	25	15	0 (L_{Ref})	31.4	10.0
	2a	19	24	14	-1	39.8	12.7
	2b	18	23	13	-2	50.1	15.9
	2c	17	22	12	-3	63.1	20.1
	2d	16	21	11	-4	79.4	25.3
	2e	15	20	10	-5	100	31.8
	3a	14	19	9	-6	126	40.1
	3b	13	18	8	-7	158	50.5
	3c	12	17	7	-8	199	63.5
	3d	11	16	6	-9	251	79.9
	3e	10	15	5	-10	314	100
	4a	9	14	4	-11	398	127
	4b	8	13	3	-12	501	159
	4c	7	12	2	-13	630	201
	4d	6	11	1	-14	794	253
	4e (L_{Ref})	4	10	0 (L_{Ref})	-15	1000	318
		3	9		-16	1258	400
		2	8		-17	1584	504
		1	7		-18	1995	635
		0 (L_{Ref})	6		-19	2511	799
			5		-20	3140	1000
			4		-21	3981	1267
			3		-22	5011	1595
			2		-23	6309	2008
			1		-24	7943	2528
			0 (L_{Ref})		-25	10000	3183

Explanation

Computation of stimulus intensity:

ΔL (in dB) = 10 × log (L_{Ref} / ΔL)



Each indicated stimulus value (ΔL) is computed as the photometrically measured illuminance for the stimulus (L), reduced by the illuminance of the background (L_B).
This value therefore expresses the contrast value of the stimulus relative to the background illuminance on which it is projected:

$\Delta L = L - L_B$

Conversion by factor of $\pi = 3.14$ between asb units and cd/m² units

Note that the dB_S scale uses the most common background illuminance as reference illuminance.

Fig. 3. Comparison and conversion of different luminance scales.

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If one wishes to have test results of various perimeters be more easily comparable, it is best choose instruments that use the most common background luminance of 10 cd/m^2. To indicate use of such an instrument the unit symbol dB$_s$ (subscript "s" for "standardized") will be used.

Threshold Luminance - Differential Luminance Sensitivity (DLS)

Perimetry seeks to determine the stimulus intensity (contrast) at which the stimulus is visible approximately half of the time. This value is not attained abruptly, but rather appears within a certain contrast region in which the probability of stimulus perception transitions from nearly 100% (100 minus the false negative rate) to nearly 0% (0 plus the false positive rate) as the stimulus intensity is progressively diminished (Figure 4). This relationship between stimulus intensity and probability of perception is called a "psychometric function".

Threshold or the ***differential luminance sensitivity*** is generally defined as the stimulus intensity that results in a 50% probability of perception. The threshold for both functions in Figure 4 is indicated at a stimulus value of 20 dB. This example assumes a false negative response rate of 10% and a false positive response rate of 10% for both functions. The bright red function runs a steep course with a relatively quick transition from subthreshold to suprathreshold responses. The brighter red background area marks the corresponding statistical variance (±σ) for the responses, which for this function is relatively small. This is a typical result for a healthy visual field location. The black curve has a flatter profile with a greater degree of statistical variance, marked by the wider background zone of ±σ.

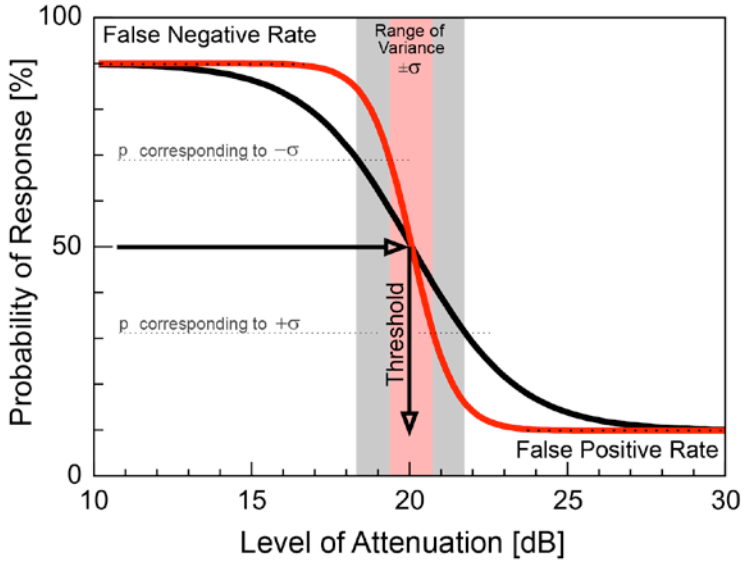

Figure 4:
Two psychometric functions are given which plot the probability of perception on the ordinate (y axis) and the strength of the stimulus on the abscissa (x axis). Threshold is defined as the stimulus value yielding a 50% probability of perception.
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Bloch's Law of Temporal Summation - The Effect of Stimulus Duration

If the duration of stimulus presentations is less than 100 ms, temporal summation may become an important factor. Temporal summation means that short flashes of stimulus at high levels of luminance evoke the same response as longer-lasting stimuli (up to a maximum of 100 ms) at lower levels of luminance. This relationship was formulated by Bloch as follows:

$T \times L = C_{onstant}$ (, where T = stimulus duration and L = stimulus illuminance)

Since temporal summation needs to be kept constant during static perimetry, the duration of stimuli has been chosen to lie between 100 ms and 200 ms. The latter value should not be exceeded because it is the approximate latency of saccadic eye movements.

Ricco and Piper - Laws of Spatial Summation - The Interrelationship Between Stimulus Size and Illuminance

Ricco and Piper discovered natural laws that govern changes in threshold luminance (L) in the visual field as a function of stimulus size (A = *area of stimulus*), a property called spatial summation. Stimuli with a diameter of less than 10' (corresponding to the object size I and smaller of the Goldmann perimeter) lie completely within the receptive fields of single retinal ganglion cells. For these stimuli there is a direct reciprocal relationship between stimulus intensity (luminance) and stimulus area. Thus, a halving of the stimulus luminance requires a doubling of the area to produce the same sensation (as long as a given "critical area" is not exceeded). According to ***Ricco's*** law:

$$\frac{L}{A} = const.$$

The critical area of Ricco's Law depends on many factors including luminance, stimulus location, colour, and state of adaptation. As a rule of thumb, stimuli with a diameter above 10' (corresponding to the size II and larger test objects of the Goldmann perimeter) exceed the size of the receptive fields of most retinal ganglion cells, inducing lateral inhibition of neighboring neurons. In this case there is a direct reciprocal relationship between stimulus intensity and the square root of the stimulus area, i.e. the stimulus radius. For these larger stimuli ***Piper's*** law applies.

$$\frac{L}{\sqrt{A}} = const.$$

Indications

Visual field examinations are demanding and time-consuming; they should be done only after proper consideration of the indications. The presence of a relative afferent pupillary defect (RAPD), or historical, fundoscopic and/or diagnostic imaging evidence of a lesion in the afferent

visual pathways are sufficient reasons for perimetric testing. Additional reasons are reductions in visual acuity that cannot be improved with a pinhole aperture, stenopaic slit, or refractive correction, visual disturbances of unknown cause, including desaturation of color perception, subjectively reduced brightness perception, disturbances of orientation, or (less commonly) self-perception of visual field defects on the part of the patient. In addition perimetry is essential for formal certification of visual function or to follow the temporal course of visual disorders. The perimetric method to be used must be determined by the nature of the patient's problem and the type of suspected visual field defect:

- For pre-school children or severely disabled patients with limited ability to participate or those with subtotal visual field loss, orientation via simple confrontation perimetry can be very useful.
- For school-age children with the ability to cooperate, kinetic perimetry is usually the preferred method of testing. Given the real-world nature of visual detection of moving objects in the peripheral visual field, kinetic perimetry is also appropriate for certification examinations.
- Circumscribed scotomas in cooperative patients are best examined by threshold static perimetry. This method is largely independent of examiner participation and guarantees good procedural control.

Proper surveillance of the course of visual field impairment depends on numerous factors and must be determined on an individual basis: progressive loss of an uncertain nature with suspicion of cerebral lesions requires very short term follow-up testing, meaning in some cases on the next day. If necessary, the examination should be repeated with a more suitable method. Rapidly progressive or fluctuating findings generally require close surveillance at intervals of a few weeks or months, since this is required for detection of progression and/or periods of fluctuating impairment. Known cases of chronic disease with probably stable defects may need perimetric re-examination only after several years, depending on circumstances. In general, follow-up testing makes sense only when the findings are likely to be consequential.

Site and Patient Preparation

As in the examination of all sensory modalities, perimetry makes significant demands on the patient for vigilance, concentration and cooperation. Prior to starting the examination, all current data should be recorded including acuity, refraction, condition of the optical media and fundus, as well as the suspected diagnosis and the results of prior perimetric examinations. The study should be done in a room that is adequately large, free of stray light sources from outside, quiet (free of distracting noises), and has good ventilation with a comfortable temperature. These factors can have significant influence on the outcome, and proper consideration of all of them can help to ensure reliable and reproducible results. Even more important is the presence of an experienced technician/examiner who can explain the test clearly, match the instructions to the patient's ability to understand, answer all questions, and give encouragement.

- At each examination the patient should be instructed again, while stressing the importance of maintaining steady gaze on the instrument's fixation target, that the

diagnostic value of the test depends critically on good fixation throughout the entire examination.

- It should be explained that some spots of light will be weak, while others will be strong, and that the patient should respond equally to all that are seen.
- In particular (with threshold determination testing) it should be explained that the test is so designed that, even for a healthy person, a large portion of the test spot presentations will be invisible. The examiner should explain that the patient can rest at any time by holding down the response button, which will pause the examination.
- The selection of a suitable occluder can be difficult: opaque "eye patches" effectively block the contralateral eye from seeing even the brightest stimuli, but can produce dark adaptation with an unintended change in apparent threshold values during immediately subsequent testing. In addition, complete occlusion can lead to disruptive interocular conflict that affects the results of the examination. A translucent covering should not be so clear as to allow the brighter test objects to be seen by the covered eye.
- The elastic band holding the occluder in place must not contact the upper lid of the eye being examined.
- For kinetic perimetry it is helpful to demonstrate for the patient the appearance of the moving test objects prior to starting the examination.
- During the examination fixation and pupillary diameter should be monitored and documented. It is important to offer a rest from time to time and to point out any mistakes. Immediately after the examination the results and any abnormal findings should be carefully documented. Difficulties and any uncertain findings should subsequently be discussed directly with the requesting physician. It is also desirable to record the findings in an electronic database, if one is available.
- Examination of the peripheral visual field beyond an eccentricity of 30° must be done without any optic correction. (Exception: contact lens wearers should be permitted to keep them in place.) Examination of the central 30° of the visual field requires use of a proper correction for near[5] with a *narrow-frame(!)* lens (the specific cupoloa diameters of the various perimeters have to be taken into consideration). The lens should be positioned as closely as possible to the eye being examined to minimize lens rim artifacts, although one should avoid contacting the lashes of the upper lid.
- Cylindrical ametropias ≥ 1 dpt should be neutralized, and in doing so the positive or negative cylinder that minimizes the thickness of the sphero-cylindrical combination of lenses should be used. For the conversion of sphero-cylindrical combinations, the dioptric power of the sphere should be added algebraically to that of the cylinder, the sign of the cylinder reversed and its axis rotated by ±90°.

Example: a) +2.50 sph -3.0 cyl x 160°
after conversion
b) -0.50 sph +3.0 cyl x 70°
[*The combination of choice in this instance would be b)*]

The view into the hemisphere of a perimeter is largely featureless and provides only a very poor stimulus for accommodation. For this reason a rather generous near addition is needed. One should ask the patient whether the chosen near correction allows a clear image of the fixation target. A fine adjustment can be made by gradually adding additional plus power in fine

increments until the fixation spot is slightly blurred, i.e. until there is full relaxation of accommodation. The maximal near addition will be determined by the perimeter used: it amounts, for example, to +3 dpt for a hemisphere radius of 33 cm, but would be +2.5 dpt for a radius of 40 cm. The recommendation of the instrument manufacturer should be considered.

Scotoma Classification – Topographical Import – Typical Symptoms

An acquired visual field defect under the usual circumstances, at least in its earlier stages, will not be noticed by the patient in most cases (appox. 90%); such scotomata are referred to as ***negative***. Positive scotomas on the other hand, such as those accompanying a central serous retinopathy, will cause early and significant impairment of vision that will be immediately noticed by the patient. An additional factor for classification is the depth of a scotoma. Defects within which the brightest stimuli are not visible are characterized as ***maximal luminance scotomas***. Defects that are blind to any light, no matter how strong, are called ***absolute scotomas***. Defects that retain some degree of differential light sensitivity and do not meet the above descriptions are classified as ***relative scotomas***. It should be mentioned that very high brightness stimuli can cause light scatter and be seen by functioning areas that lie peripheral to an absolute scotoma, leading to an incorrect classification of the defect as a relative scotoma.

When evaluating the visual field, and particularly when there is an unexplained loss of vision, the visual fields of *both* eyes should receive equal attention. Not uncommonly, the seemingly unaffected eye will show a defect that leads toward the correct diagnosis, while the more severely affected eye having fixation and/or cooperation artifacts) yields little diagnostically useful information. It has proved to be important that the visual field charts of both eyes be examined side-by-side from the patient's point of view: the left visual field on the left, and the right visual field on the right. To avoid confusion it also helps to keep in mind that the physiologic blind spots are located in their respective temporal hemifields. Visual field defects produced by retinal disease are the result of damage to the retinal neurons themselves and/or the axons of the retinal ganglion cells at the level of the optic nerve head. There is a strong topographical correspondence between the location of the visual field defect and the retinal site of damage, conforming to the natural laws of optics. A locus in the external world and its associated scotoma correspond precisely to the locus of retinal disease following optical inversion. Images falling on the retina are inverted left for right and upside down. Keep in mind that a patient will see the deficit in a direction that lies opposite to its retinal location.

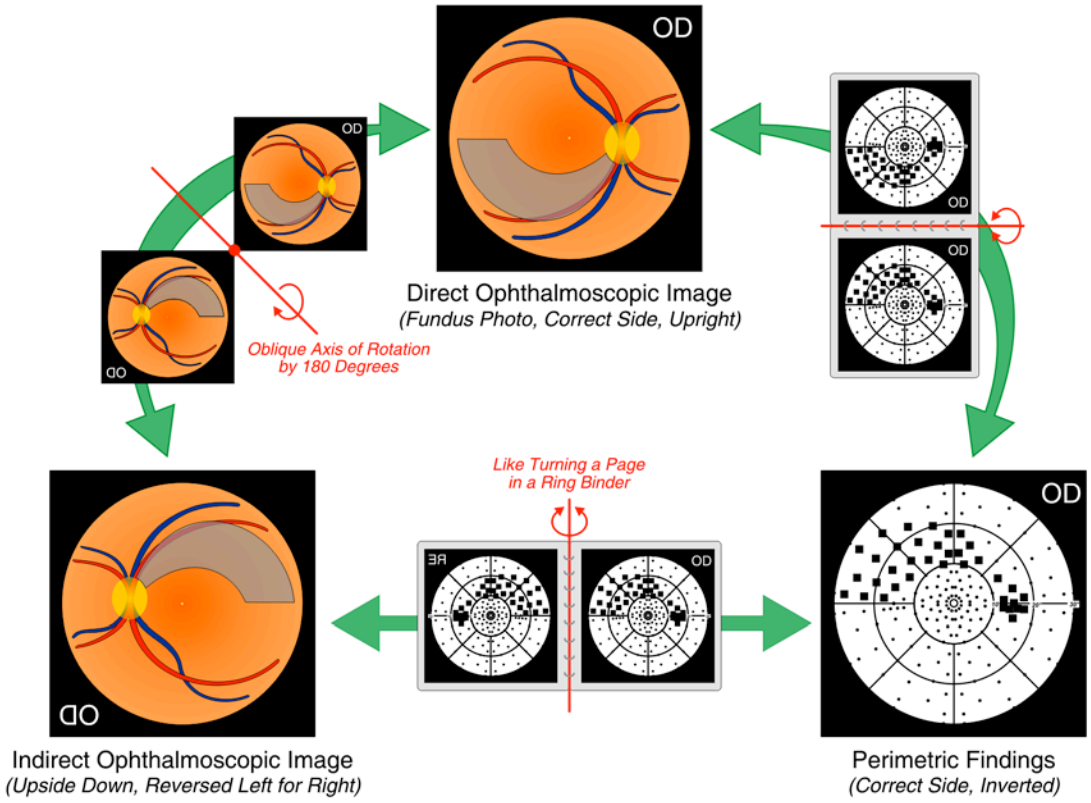

Figure 5

Topographical correspondence between perimetric charts and direct and indirect ophthalmoscopic images (modified after [13]).

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Topographical comparisons of fundus images and visual field charts requires inversion of one chart for direct comparison with the other. When comparing the visual field chart with the direct ophthalmoscopic image of the eye (which is seen upright), one must flip the field chart around its horizontal axis (much like flipping the page in a spiral bound notebook) and view it from behind (top right in Figure 5). Examiners viewing the fundus with an indirect ophthalmoscope (or through a loupe at the slit lamp) see an image that is reversed left for right and upside down. When comparing the fundus image with the perimetric chart, the chart should be flipped around its vertical axis (like turning the page in a 3-ring loose leaf notebook) and viewed from behind (bottom center in Figure 5).

The interpretation of visual field charts and their topographical and diagnostic significance is a task unique to ophthalmology. Classification of the findings, assigning the individual defects to particular types, is a form of visual pattern recognition for which 7 subdivisions are thought to be sufficient (see Figure 6 below). It is often difficult to classify a particular visual field chart as normal in the presence of numerous artifacts, none of which are specific.

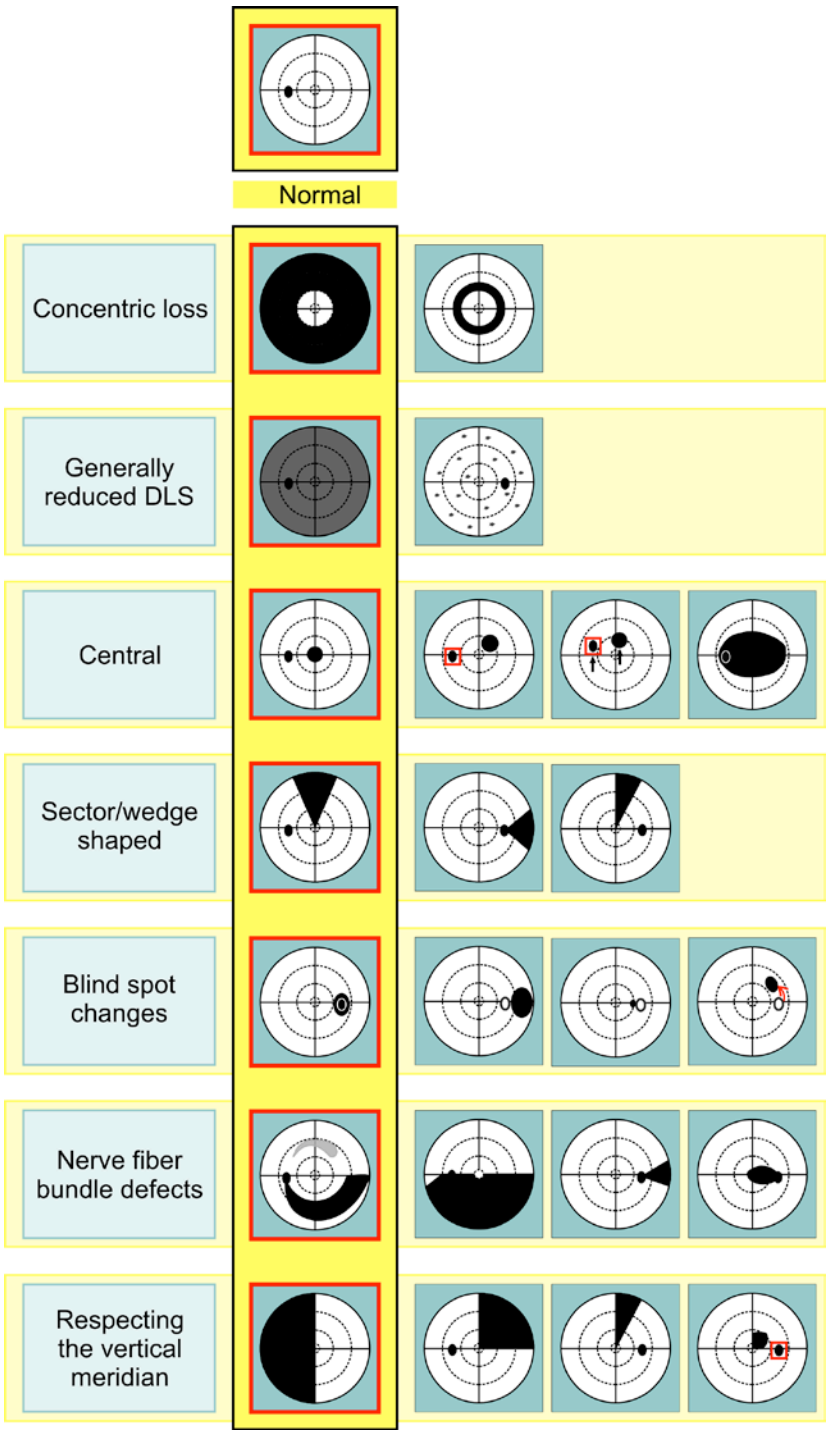

Figure 6
A topo-diagnostically relevant classification of visual field defects.
Division into 8 primary classes, marked by red frames.
Sub-classes have a background of a lighter color.
DLS = differential luminance sensitivity.

Among patients with **concentric restriction** of the visual field, the most common disorders include the various forms of *nyctalopia* ("night blindness"), caused by widespread loss of rod function and suggesting a tapetoretinal degeneration. A ***ring scotoma*** often appears in the earliest stages of development of visual loss in these disorders and it is classified as a subdivision of concentric restriction. Concentric loss is often first noted only after it has already developed to an advanced stage, since numerous compensation strategies are used by affected patients to avoid collisions with objects or disorientation in unfamiliar surroundings. Loss of rod induced inhibition of retinal cones can lead to an (unfortunately non-specific) symptom of increased photophobia. One must be on guard with concentric defects to rule out problems like lens-rim artifacts, misunderstandings by the patient, or feigned loss of vision. An apparently high degree of visual field constriction can be quickly confirmed by confrontation testing; feigned loss is usually marked by a "cylindrical" visual field that has a constant width at widely varying distances between patient and examiner. Fundoscopy and electro-diagnostic testing are additional measures that help to differentiate these entities. It should be mentioned that widespread nerve fiber bundle defects (see below) or bi-hemispheric cerebral disease producing widespread, bilateral hemianopsias (see below) can also mimic concentric visual field loss. Visual field findings characterized by a general or diffusely irregular reduction in visual sensitivity are usually not the result of structural disease in the afferent visual pathways, but are rather more commonly caused by "artifacts", such as incorrect refractions, media opacities, extreme miosis, or by inadequate patient attention or cooperation.

Central scotomas strike the affected patient in the form of reduced visual acuity, reading disturbances, color deficits, increased photophobia, associated metamorphopsia, and problems with facial recognition. **Cecocentral scotomas** are also included in this group; They affect not only the immediate, central area of the visual field, but extend to include the physiologic blind spot (lat. caecus = blind). They should elicit a search for toxic (occupational or pharmacological), nutritional, and/or hereditary optic neuropathies. They can also appear as a grouping of nerve fiber bundle defects (see below). Central scotomas can also cause the affected patient to adopt a compensatory fixation locus in the nearest retinal site that remains functional. Adoption of this fixation locus causes in turn a displacement of the scotoma away from the center of the visual field chart along with an identical displacement of all other scotomas, including the physiological blind spot. This is to be distinguished from paracentral scotomas with which there is no associated displacement of the physiological blind spot. Appropriate diagnostic tests in this setting include fundoscopy of the optic nerve head and papillomacular bundle, including determination of fixation locus, as well as studies of color perception and electro-physiological tests (pattern-VEP, multifocal ERG).

Sector- or **wedge-shaped** visual field defects can be subdivided into two groups:

- If the peak of the sector points toward the center of the visual field, disturbances of the choroidal blood supply are likely: the area of field loss reflects damage to the segmental, "lobular" structure of the choroidal vessels. In this case appropriate additional tests would include fluorescein or indocyanine green fluorescence angiography, in addition to fundoscopy and electro-physiological testing. A medical consultation to rule out

hemorrheological and/or cardiovascular risk factors is indicated when there is confirmed evidence of damage to the choroidal circulation. Also, if the sector or wedge-shaped defect shows respect for the vertical meridian, monocular loss would suggest prechiasmal disease, bitemporal loss chiasmal disease, and homonymous loss postchiasmal disease. In this case further diagnostic testing – after completion of the ophthalmological evaluation – should include neuroradiological imaging (MRI or CT scan).

- If the peak of the sector points toward the physiological blind spot, a form of nerve fiber bundle defect is suggested, caused by damage to the nasal portions of the optic nerve head.

The blind spot is a valuable, physiological "reference scotoma" that gives (by its position, size and shape) an indication of the status of the optic nerve head and its surrounding structures, as well as evidence of the technical quality of the visual field examination. Under ordinary circumstances with a normal appearing fundus and with normal refractive findings, the blind spot should appear as an absolute scotoma with a width in the horizontal direction of ca. 6° and in the vertical direction of ca. 9°. It lies at an eccentricity of ca. 14° and has 40% of its area above and 60% of its area below the horizontal meridian.

Alterations in the region of the blind spot can appear as changes in its size, its position or in a combination of both. An enlargement of the blind spot can appear as the result of papilledema, monocular disc edema, or peripapillary scarring or choroidal atrophy. Additionally, displacement of the blind spot to the temporal side suggests high myopia. An isolated reduction in blind spot size is uncommon (e.g. with developmental micropapilla), but in combination with high hyperopia (e.g. with microphthalmos) the shrunken blind spot will be displaced nasally. A cyclodeviation of the eye, e.g. with a 4^{th} nerve palsy, or a supranuclear gaze disturbance ("skew deviation") can cause a rotational displacement of the blind spot.

Careful ophthalmoscopy with attention to the optic nerve head and the orientation of the papillomacular bundle is particularly important in cases of rotational displacement of the blind spot. If papilledema is suspected, neuroradiological imaging (MRI or CT) is indicated.

The orientation of **retinal nerve fiber bundle (RNFB) defects** reflects the anatomical course of the axons of the retinal ganglion cells: their arcuate course – nearly parallel to the vascular arcades in the (temporal) superior and inferior hemiretinas – explains the configuration of the classical Bjerrum scotoma. Since these axons in the temporal retina near the so-called temporal horizontal raphe do not cross the horizontal meridian, their associated defects "respect" the horizontal meridian, ending in the typical *nasal step*, a configuration that was first described by the Danish ophthalmologist Henning Kristian Trappaud Rønne [10]. The horizontally arcuate course of the nerve fiber bundles corresponds with the location of early defects that presage the formation of arcuate scotomas in the nasal periphery of the visual field. Starting as isolated focal depressions of sensitivity in this area, the defects characteristically merge over time with one another to form the fully expressed arcuate defect with a nasal step and, finally, "breakthrough into the periphery", leaving an absolute arcuate deficit that extends from the nasal periphery all the way to the physiologic blind spot.

Aulhorn and Karmeyer have developed a 5-level, primarily morphological, system for the grading of nerve fiber bundle defects [1]. In stage I there are only relative scotomas. Stage II is characterized by absolute defects that remain separated from the physiologic blind spot, while the absolute scotomas of stage III are seen to merge with the blind spot. In stage IV the deficits have coalesced and spread out to involve an entire nasal quadrant of visual field, while stage V is marked by total loss of function in the nasal quadrant with retention of an isolated island of vision in the temporal quadrant. Corresponding to the more rectilinear approach to the disc margin by the nerve fiber bundles in the nasal retina, the visual field defects associated with their loss of function are appear as sector-shaped areas in the temporal hemifield with their apices directed towards the physiologic blind spot. Widespread RNFB defects that involve an entire superior or inferior hemifield are referred to as *altitudinal defects* (often mistakenly called superior or inferior hemianopias).

The causes of the various sorts of NFB defects are numerous. Most commonly they are the result of glaucomatous damage or ischemic optic neuropathy, but other pathological processes in the vicinity of the optic disc, such as drusen, chronic papilledema, or retinal vascular occlusions (sometimes recanalized), can also cause similar visual field defects. Ophthalmoscopy is particularly suited to a detailed examination of the retinal nerve fiber layer, particularly with the use of "red-free" light. Equal attention should be given to inspection of the optic nerve head, the peripapillary retina, and the retinal vessels. Note should be taken of disc excavations or notches, peripapillary hemorrhages and segments of disc edema or atrophy. Additional diagnostic procedures should be directed toward detection of underlying problems, including B-scan echography to rule out papillary drusen, IOP measurements and gonioscopy for suspected glaucoma, and internal medical evaluation to rule out hematological or cardiovascular disorders and their risk factors.

Visual field defects that respect the vertical midline indicate pre- or post-chiasmal lesions of the afferent visual pathways and generally require neuroradiological evaluation (MRI or CT) when first discovered. Ophthalmoscopy can reveal the presence of optic atrophy in cases of chronic pregeniculate lesions, but retrogeniculate disease of the afferent pathways does not produce trans-synaptic degeneration after early childhood and cannot be diagnosed by ophthalmoscopy.

When defects appear to respect the vertical midline, the examination of *both* eyes is essential, for only in this way can one determine whether the problem **a)** is merely monocular (and prechiasmal in origin), **b)** is binocular and heteronymous, either bitemporal (and chiasmal in origin) or – very rarely – binasal, or **c)** is homonymous (and retrochiasmal in origin).

The differential diagnosis of NFB defects requires exclusion of so-called "refraction scotomas". Posterior ocular wall ectasias and myopic deformations of the posterior pole can produce local areas of ametropia, causing test object stimuli to be defocused with corresponding areas of relative scotoma. These are most commonly located in the superotemporal quadrant of the central visual field, and careful analysis will show that they do not really respect the vertical midline. They can be reversed by placement of an appropriate optical correction before the eye. Fundoscopy and streak retinoscopy will usually clarify the nature of the problem.

The perimetric and topodiagnostic aspects of visual field defects associated with space occupying lesions affecting the chiasm are summarized in Figure 7:

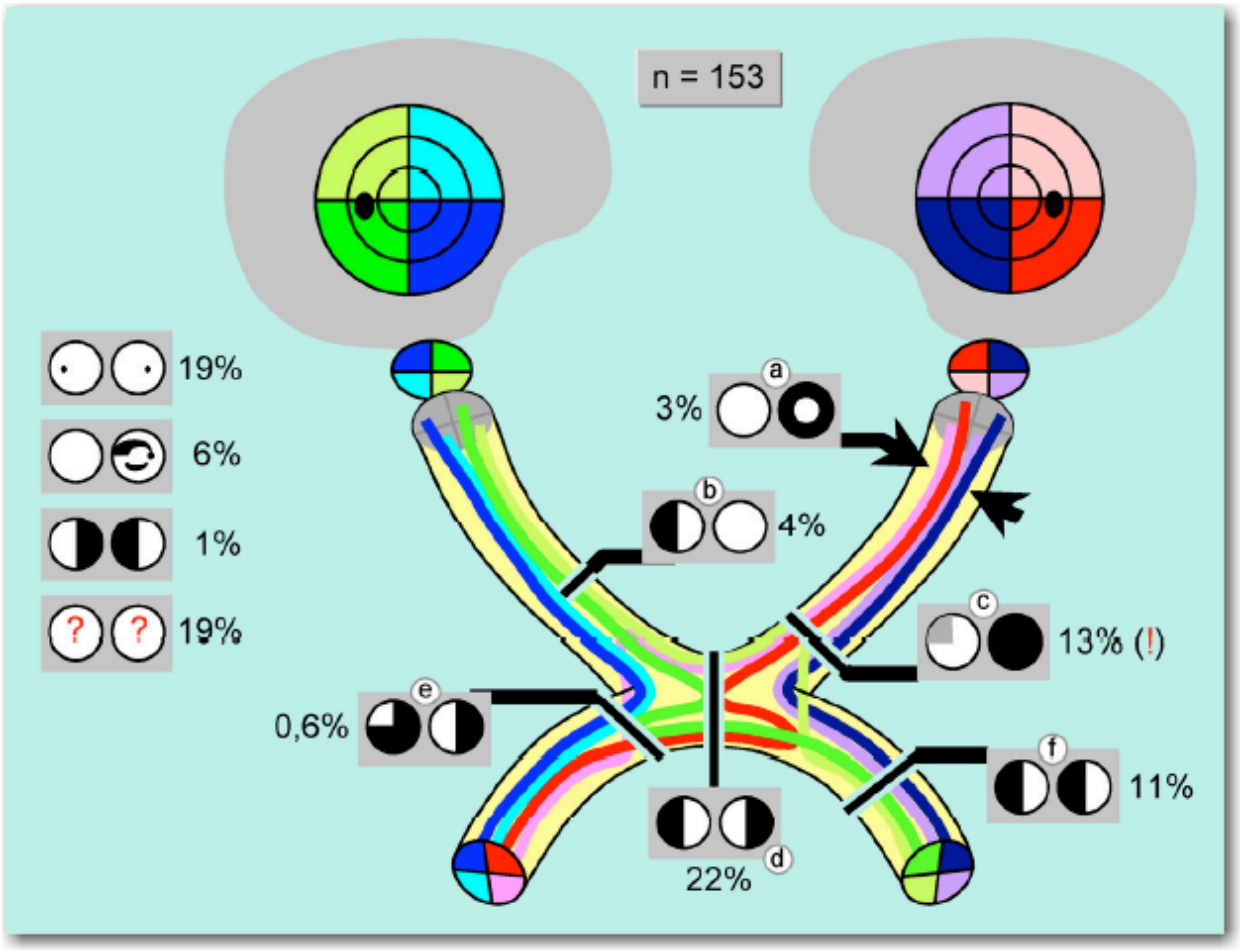

Figure 7
Schematic course of the afferent visual pathway in the vicinity of the optic chiasm with associated scotoma configurations in the central 30° region of the visual field and their frequencies of occurrence among a group of 153 patients (modified after [11]).
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Etiologically, the problems include:

a) compressive optic neuropathies,
b) incomplete, prechiasmal lesions,
c) the "anterior junction syndrome": compression of the proximal optic nerve at its junction with the chiasm, causing central visual loss in the ipsilateral eye and damage to anterior Wilbrand's knee, causing a superotemporal quadrant defect in the contralateral eye,
d) mid-chiasmal lesions (e.g. trauma, compression, demyelination),
e) the "posterior junction syndrome": partial damage to posterior Wilbrand's knee at the junction of the chiasm with the optic tract, causing a contralateral homonymous hemianopia and loss of the inferotemporal quadrant of visual field in the ipsilateral eye, and
d) optic tract lesions.

Homonymous defects are caused by damage to the post chiasmal visual pathways (optic tract, lateral geniculate body, optic radiations, visual cortex) on the side that is contralateral to the field loss. They can affect an entire hemifield of both right and left eyes (complete homonymous hemianopia), or may be limited to subtotal degrees of loss, such as *quadrantanopias*. This commonly occurs with lesions of the inferior half of the optic radiations in the temporal lobe, producing a contralateral superior homonymous quadrantanopia. Less common are lesions affecting the superior half of the optic radiations (usually in the parietal lobe), causing a contralateral inferior homonymous quadrantanopia. Sector-shaped hemianopic defects can also occur (see above). Further, due to their small size, homonymous defects lying in paracentral regions of the visual field can be very difficult to detect. When present with a high degree of congruence (high interocular correspondence of the size, location and density of defects), they indicate damage at the level of the visual cortex. If a homonymous defect reaches to the very center of the visual field, fluency of reading will be significantly impaired. Even small areas of sparing in the paracentral field (of 2° or more) will be sufficient to retain reasonably good reading ability. In the latter case, small areas of the primary visual cortex in the affected hemisphere remain functional.

As a general rule, the congruence of homonymous defects increases with closer proximity of lesions to the occipital pole of the cerebral hemisphere. Damage in the most anterior portions of the primary visual cortex (i.e. far rostral locations in the interhemispheric cleft just posterior to the splenium of the corpus callosum) produce a monocular form of visual loss confined to the "monocular temporal crescent" in the visual field of the contralateral eye.

The Peripheral Limits of the Visual Field

The peripheral limits of the visual field are revealed by the locations at which the strongest test object stimuli are first visible, e.g. when moving from non-seeing to seeing areas during kinetic perimetry. These limits are largely determined by the anatomic locations of relevant structures (e.g. the orbital location of the globe, the configuration of the upper eyelid, the prominence of the brow, the size of the nose and the position of the retinal ora serrata). These limits are for the most part age-independent (see also part 2 of this series of monographs). As a rule of thumb, one can expect the peripheral boundary to be located 100° temporally, 70° inferiorly, and 50° nasally and superiorly. There are instrument-specific limits that can interfere with the determination of true physiological responses. None of the currently available instruments, for example, can present stimuli beyond 90° of eccentricity and are incapable of measuring the extreme temporal limits of the visual field.

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