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REVIEW

A History of Perimetry and Visual Field Testing

Chris A. Johnson*, Michael Wall†, and H. Stanley Thompson†

ABSTRACT

Perimetry and visual field testing have been used as clinical ophthalmic diagnostic tools for many years, and this manuscript will provide a brief historical overview of these procedures and the individuals who developed them. Today, we have many different forms of perimetry that are designed to evaluate different locations within the visual pathways and various mechanisms and subsets of mechanisms within the visual system. However, the most widely used method of performing perimetry and visual field testing has not substantially changed for more than 150 years, consisting of detecting a small target superimposed on a uniform background at different locations within the field of view. Although the basic test procedure has remained similar throughout the ages, there have been many advances in test administration, standardization, statistical evaluation, clinical analysis, interpretation, and prediction of outcome based on visual field findings.

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Key Words: visual field, perimetry, glaucoma, history, visual function

As clinicians and scientists, we often become so focused on current issues that we forget to conduct a historical review of the subject matter. This can frequently lead to the rediscovery of certain phenomena that have already been well characterized, the loss of key insights and approaches to providing a thorough and thoughtful investigation of the problem, and the lack of having a full perspective on the logical chronological development of the procedure. William James, a noted Psychologist in the late 1800s and early 1900s, provided a summary of fundamental questions that needed to be assessed (unfinished business), and many of them are still without a definite answer.[1] Sometimes, it is the basic, simple clinical and research questions that are the most difficult to answer. It is within this context that we wish to present a historical overview of perimetry and visual field testing, a diagnostic test procedure that is commonly used in the clinic to detect, diagnose, and follow-up many ocular and neurologic diseases. Although we have made great strides in making these procedures more standardized, automated, accurate, precise, efficient, quantitative, statistically reliable, and easy to use, there are still many issues that remain to be improved and refined. We hope that this article will serve as an incentive for investigators to take an active interest in pursuing these remaining challenges.

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Evaluation of the peripheral visual field was performed more than 2000 years ago, and quantitative measurements of visual field sensitivity have been conducted for nearly 200 years. During this time, there have been many advances in this ophthalmic diagnostic test procedure, although the task of detecting a small target on a uniform background has not been replaced by any other procedure for routine clinical assessment of the visual field in glaucoma patients. This article presents an overview of the historical developments that have occurred for perimetry and visual field testing up to the present time period and challenges investigators to explore new procedures for evaluating the functional status of the peripheral field of view.

Historical Background

One of the first recorded accounts of peripheral visual field evaluation was from Hippocrates (Fig. 1) around the late fifth century B.C., when he observed and described a hemianopsia.[2–4] Ptolemy (Fig. 2) in 150 B.C. attempted to quantify the visual field and noted that its shape was roughly circular.[2–4] Perhaps the first instance of recording the recognition of extramacular visual fields was performed by Galen around 175 AD.[2–4] The first illustration of visual fields was published by Ulmus in 1602.[2–4] Somewhat later, Mariotte (Fig. 3) in 1668 reported the physiologic blind spot and related it to the location of the optic disc.[2–4] It has often been reported by others that one of Mariotte's favorite tasks was to optically "behead" individuals by closing one eye and directing fixation of the open eye to place a person's head within his blind spot location.

FIGURE 1.
Hippocrates. A color version of this figure is available online at www.optvissci.com.

FIGURE 2.
Ptolemy. A color version of this figure is available online at www.optvissci.com.

Measurement of the visual field extent was performed by Thomas Young (Fig. 4) in the early 1800s, where he reported the size of the normal human visual field to be 50° radius superiorly, 70° radius inferiorly, 60° radius nasally, and 90° radius temporally.[2–4] This was later refined by Purkinje to extend a bit farther in all directions, which may be related to the use of better testing conditions that used targets that were more detectable.[2–4] Visual field areas of non-seeing (scotomas) were described by Boerhaave in 1708, and the shape and location of scotomas was characterized by Beer in 1817.[2–4] However, until the middle of the 1800s, evaluation of the visual field was still mostly qualitative, and it was not until von Graefe's contributions in 1856 that quantitative visual field measurements were obtained.

Albrecht von Graefe (Fig. 5) is considered by many to be a primary force in bringing perimetry and visual field testing to clinical ophthalmology. At the young age of 28 years, he published an article entitled "Examination of the visual functions in amblyopic affections"[5] (this is the English translation of the article that was written in German). This article presented examples of visual field loss that is characteristic of glaucoma but it was referred to as amblyopia because, at that time, the association of elevated intraocular pressure, optic disc cupping, and visual field loss had not been fully integrated into a working definition of glaucoma. Von Graefe also published examples of visual field losses associated with many other ocular and neurologic diseases.

Jannik Bjerrum (Fig. 6) popularized campimetry and placed a tangent screen on the back of his office door. Eventually, he constructed a 2-m tangent screen so that details of the central 30° diameter visual field could be accurately mapped. He and his assistant Henning Rönne used different sizes of targets to generate multiple isopters to characterize the shape and three-dimensional characteristics of the visual field sensitivity map. They were also careful to maintain a constant dark background on which to superimpose white stimuli that were generated by the use of white hat pins mounted onto the end of a dark wand. Bjerrum also introduced the use of colored stimuli for perimetric testing. Through

FIGURE 3.
Marriotte. A color version of this figure is available online at www.optvissci.com.

FIGURE 4.
Thomas Young. A color version of this figure is available online at www.optvissci.com.

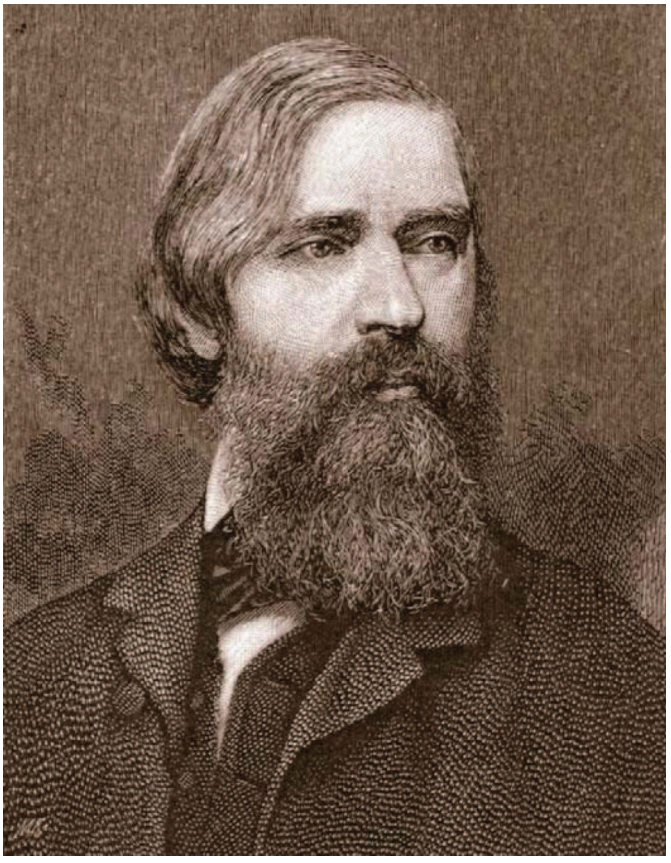

FIGURE 5.
Abbrecht von Graefe.

their efforts, the value of perimetry and visual field testing became apparent to many individuals, and there was a large increase in perimetric evaluation by other investigators.[2–4]

Harry Traquair (Fig. 7) advanced the utility of the tangent screen and published a classic book of examples of its use for diagnosing and evaluating a variety of ocular and neurologic disorders. His book also provides many helpful hints concerning the methodology underlying perimetry and visual field testing and remains well worth reading.[6] Undoubtedly, the most important contributions to modern perimetry and visual field testing was the work of Hans Goldmann (Fig. 8) in 1945 and subsequent years. He developed a hemispherical bowl perimeter that provided a uniform background illumination and a moving optical projection system that was able to superimpose bright stimuli on the background. The device was capable of performing both static and kinetic perimetry using a variety of targets of varying sizes, luminance levels, and color characteristics. He also determined the relationships among size, luminance, and visual field location and published a series of articles that thoroughly described his research efforts in evaluating normal controls and patients with glaucoma and other diseases affecting the visual pathways.[2–4] In honor of his contributions, the device is referred to as the Goldmann perimeter (common usage for visual field examinations done with this device is "Goldmann perimetry"; Goldmann disliked this term and said it should only be used for examinations he performed). A similar innovation for perimetry was the Tübinger perimeter that was constructed by Elfriede Aulhorn and Heinrich Harms in the late 1950s and early 1960s.[7] The Tübinger perimeter was primarily designed for performing static perimetry, although kinetic testing could also be performed. In addition, there was a gear ratio adjustment that would expand the central testing area to allow more detailed perimetry mapping of the central visual field. The Tübinger perimeter was also capable of performing spatial and temporal summation measures throughout the visual field, as well as chromatic sensitivity thresholds peripheral visual acuity measures, flicker sensitivity, and many other psychophysical procedures, making it a tremendously useful clinical research tool.

In the late 1960s and early 1970s, some investigators were attempting to automate visual field testing procedures. Drs. John R. Lynn and George W. Tate developed one of the first automated perimeters,[8] although the foremost expert in this area was Franz Fankhauser (Fig. 9) and co-workers,[9–12] who produced the first automated perimeter known as the Octopus. Their work paved the way for the advent of automated testing and analysis procedures for perimetry and visual field testing. These procedures are by far the most common methods of performing visual field testing today, and it was Fankhauser's efforts that provided a major shift in this type of testing. It should also be noted that Anders Heijl and his colleagues have been instrumental in the development of the Humphrey Field Analyzer as well as the test and analysis methods that it uses.[13]

Another individual with key insights into the proper use of this technology and interpretation of information derived from auto-

FIGURE 6.
Jannik Bjerrum.

FIGURE 7.
Harry Traquair.

mated perimetry is Douglas Anderson (Fig. 10).[14] In the past 20 years, he has authored several books that provide instruction on the principles underlying automated visual field testing, how to perform automated perimetry, how to interpret the results, how to avoid artifactual results, and many other useful hints.[15] Although many others have made important contributions and still advance the utility of this diagnostic test procedure, these individuals represent the clinical investigators who have been successful in making significant contributions that have resulted in significant, meaningful leaps forward in the advancement of this technology. All of us are greatly indebted to their monumental efforts and willingness to share their insights.

Methods of Performing Perimetry and Visual Field Testing

Many procedures have been developed for evaluation of the peripheral visual field, and their use depends on the availability of equipment and resources, the physical and mental status of the patient, and the time available for testing.[16,17] The most common qualitative procedure is known as confrontation visual field testing. It can be performed by having the patient count the number of fingers presented to different parts of the field of view, assessing the detection or vividness of colored objects, and comparing them across the vertical midline, using finger puppets or other objects and many other procedures. Another qualitative procedure is the Amsler grid, which is described later in more detail. The patient is asked to observe a grid of horizontal and vertical lines held at a near distance (⅓ m) and report which lines are missing, blurred distorted, bent, or irregular. Quantitative versions of this procedure have also been developed.

Quantitative perimetric methods include the tangent screen, which uses a 1- or 2-m diameter uniform dark flat screen made of black felt or some similar dark matte (non-reflecting) material on which small targets (white, gray, or colored beads) are presented on the tip of a dark wand to map out visual field sensitivity. One of the drawbacks of this method of visual field evaluation is that it is only able to measure the central 30° radius of the visual field. This is why the arc perimeter was developed (Aubert and Förster, 1869)[2–4] to provide a means of testing the full peripheral visual field. These instruments were effective in evaluating the full extent of the peripheral visual field but were not able to provide a consistent background adaptation level for the entire field of view. To overcome this, the bowl perimeter was introduced, whereby a uniform background adaptation level could be achieved for the full visual field, and stimuli could be projected and superimposed onto the background to determine the minimum increment of light needed to detect the target (differential light threshold). The perimeter developed by Hans Goldmann in the 1940s (the Goldmann perimeter) and the Tübinger perimeter (developed by Elfriede Aulhorn and Heinrich Harms) represent the most common perimeters that have been used for performing manual quantitative perimetry.[2,7]

FIGURE 8.
Hans Goldmann.

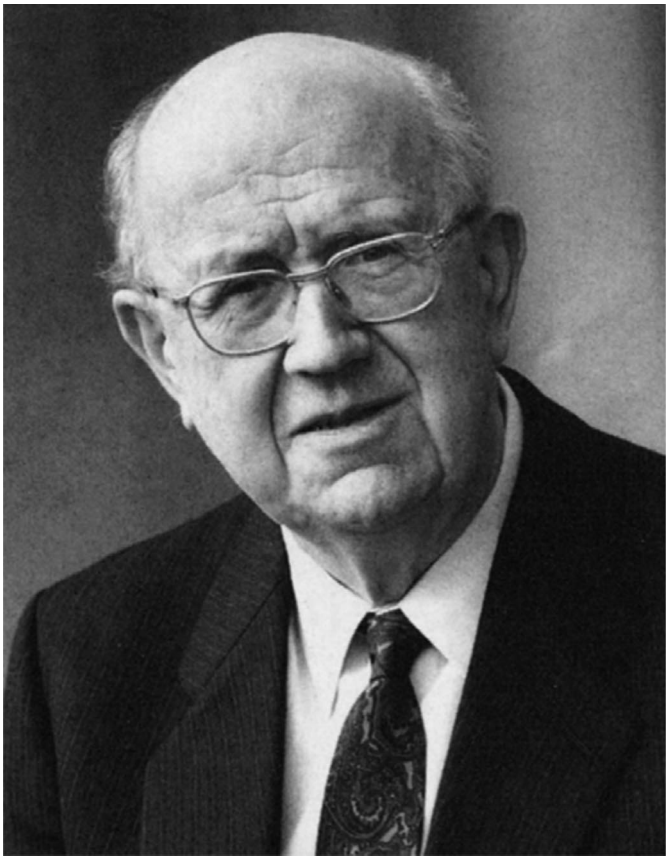

FIGURE 9.
Frank Fankhauser. Reprinted with permission from: Gloor BP. Franz Fankhauser: the father of the automated perimeter. Surv Ophthalmol 2009;54:417–25.[43]

Automated Perimetry

The advent of automated perimetry began around 1970 with the automated perimeter developed by Drs. John Lynn and George Tate,[8] which was significantly augmented by the development of the Octopus perimeter in the laboratory of Dr. Fankhauser (Fig. 9) and co-workers.[9–12,46] Following many attempts to develop this procedure, Fankhauser and co-workers were able to achieve the first fully automated visual field device known as the Octopus perimeter. Although it has undergone many changes since it was first invented, the Octopus perimeter is still commercially available approximately 40 years later. Many other automated and semiautomated perimeters followed (e.g., the Fieldmaster, DICON, BIO-RAD, Humphrey Field Analyzer, and numerous other devices). A fairly comprehensive listing of automated perimeters may be found in selected references.[17–26] Currently, the Fieldmaster, Humphrey Field Analyzer, Humphrey Matrix, Octopus, Easyfield (Oculus), and Medmont automated perimeters are available, as well as additional devices that are not as commonly used throughout the world.

New Developments and Non-Conventional Perimetric Procedures

In recent times, there have been many different approaches and innovations related to perimetry and visual field testing. The main emphases of these new procedures have been directed toward development of procedures to improve accuracy, enhance efficiency, provide easier tests to administer and perform, isolate and measure the status of subsets of visual mechanisms, and establish robust and informative clinical diagnostic tools for detection, differential diagnosis, and follow-up of patients. Many of these new testing methods have not provided a lasting positive impression for routine clinical use. Listed below (in alphabetical order) are brief descriptions of the perimetric tests that have provided helpful clinical information.

Amsler Grid

The Amsler grid is a series of intersecting horizontal and vertical lines that are displayed on a uniform background.[15,16,27,30,31] In its most common form, the Amsler grid is printed on a near vision card that is typically held at 25 or 40 cm from the eye and consists of black lines on a white background. Other forms of the Amsler grid (variable contrast, color, white lines on a dark background, etc.) have also been developed. The patient's task is to determine whether there are any parts of the grid that are missing, distorted, or dimmer or lower in contrast than other parts of the display. The Amsler grid is particularly useful for evaluating the central macular portion of the visual field to detect subtle retinal problems, the presence of fluid (edema) in the macula and other ocular disorders.

FIGURE 10.
Douglas Anderson. A color version of this figure is available online at www.optvissci.com.

Color Perimetry

Many investigators have evaluated the ability to detect stimuli of various wavelengths in the peripheral visual field or to be able to distinguish one colored stimulus from another. This form of perimetric testing is more difficult than other visual field tests and requires very careful instrument calibration and experimental control.

The first color perimeter (and the first computer graphics perimeter) was developed by William Hart. The procedure used isoluminant blue and yellow and was successful in mapping a variety of visual field defects. Hart et al.[32] eventually concluded it was not worth all the extra effort to provide a marginally more sensitive test.

Perhaps the most common form of color perimetry involves the isolation of specific color vision mechanisms known as two-color increment thresholds. With this procedure, most procedures use a uniform background illumination of specified luminance and chromaticity to desensitize some color vision mechanisms and a stimulus of different chromaticity to isolate and measure the sensitivity of a single color vision mechanism. The most common form of color vision testing of this type has been short-wavelength automated perimetry, which incorporates a bright yellow background [to desensitize the middle (green) and long (red) wavelength mechanisms] and a large short-wavelength (blue) stimulus to measure the sensitivity of sort wavelength mechanisms.[27,33–36] Many studies have demonstrated that this procedure is effective in detecting early visual field changes in glaucoma and various other retinal and optic nerve disorders.

Flicker Perimetry

The ability to detect an intermittent flashing stimulus that is superimposed on a uniform background forms the basis of flicker perimetry.[27] There are three types of flicker perimetry tests that have been developed: (1) determination of the highest rate of flicker that can be detected at high contrast (critical flicker fusion perimetry), (2) evaluation of the amplitude of contrast needed to detect a flickering stimulus of fixed flicker rate (temporal modulation perimetry), and (3) detection of a flickering stimulus that is superimposed on a luminance increment above the background (luminance pedestal flicker). Each of the procedures has been shown to be sensitive for detecting early visual field losses in glaucoma and retinal diseases, and each of the procedures has its own distinct advantages and disadvantages. One advantage of all flicker perimetry methods is that they are relatively unaffected by variations in blur.

Frequency Doubling Perimetry

When a low spatial frequency (<1 cycle per degree) sinusoidal grating undergoes high temporal frequency counterphase flicker, the stimulus appears to have about twice as many light and dark bars than are physically present. This has been referred to as the frequency doubling effect. The patient's task is to detect the presence of a shimmering stimulus of light and dark bars presented to various visual field locations on a uniform background of the same luminance as the average of the light and dark bars of the stimulus.[27] A number of investigators have demonstrated that this procedure is effective in detecting early visual field deficits. It has also been shown to be an effective and efficient method of screening for visual field loss, both in a clinical setting and for population-based investigations. This form of perimetric testing is resistant to many variations in the clinical testing environment.

Motion Perimetry

As with flicker and other psychophysical measures, motion perimetry is performed according to several different procedures. Motion sensitivity is particularly useful because it is a very primitive visual function and is resistant to changes in many different stimulus conditions (contrast, size, background illumination, blur, etc.). Motion perimetry can be performed by: (1) determining the minimum amount of movement needed for detection of change in position (displacement perimetry), (2) evaluating the amount of motion coherence needed to detect a direction of motion from within a group of randomly moving dots (motion coherence perimetry), (3) determining the direction of motion, (4) assessing the velocity needed for motion detection, and (5) measuring the size a number of moving dots needed to localize the direction of motion.[27,28] Many studies have reported that motion perimetry is able to detect early visual field deficits in glaucoma and other ocular and neurologic disorders.

High-Pass Resolution Perimetry

The stimuli used in high-pass resolution perimetry are light and dark concentric rings similar to a bull's eye or Mexican hat luminance profile configuration in which the low spatial frequency components have been removed to augment the appreciation of the light and dark edges (high spatial frequencies). Most acuity letters can be detected at a much smaller size than they can be resolved or identified, and the intent of the high-pass resolution perimetry targets is to raise the detection threshold so that the detection and identification thresholds occur at the same size, i.e., as the target becomes smaller it suddenly disappears (vanishing optotype).[26] Many investigations have shown that this test is effective in detecting glaucomatous visual field loss and also appears to determine glaucomatous visual field progression earlier than conventional automated differential light threshold perimetry (automated static perimetry).[26] Additional features and advantages and disadvantages of this procedure have been described by Frisen.[29]

Multifocal Visual-Evoked Potential

Traditionally, clinical electrophysiologic responses from the retina and higher visual pathways were produced by stimulating a major portion of the visual field and recording the mass electrical response of the visual system to these stimuli. Signals generated by the higher visual pathways [the visual-evoked potential (VEP)] could be recorded.[37–40] More recently, the use of rapid stimulus presentation using a binary m-sequence or related mathematical model has made it possible to obtain local visual field responses for the VEP at many different perimetric locations.[37–40] The multifocal VEP is most useful for glaucoma, other optic neuropathies, chiasmal, postchiasmal disorders, and malingering). Measures corresponding to the amplitude and latency of these electrophysiologic signals provide the most helpful clinical information.

Pupil Perimetry

With many forms of perimetry and visual field testing, the patient is required to make a decision as to whether the stimulus was see or not and to maintain a high level of attention to the task. Pupil perimetry was designed to measure a more direct response to small flashes of light by determining the change in pupil size when a small intense light is flashed on a uniform background. Although there are some limitations with this approach, this form of testing makes it possible to obtain visual field measurements in patients who may not be able to perform conventional perimetry due to cognitive or attentional impairment.[41–43]

Rarebit Perimetry

Rarebit perimetry is an attempt to provide fine detail mapping of localized regions of the visual field. By using very small stimuli (pixels) on a video display, this procedure presents 0, 1, or 2 suprathreshold dots at various local visual field regions and requests the patient to indicate the number of dots that they were able to detect. By evaluating a number of combinations of dots in a small localized region, it is possible to determine visual performance (detection or "hit" rate) in these areas. Rarebit perimetry has been used to evaluate glaucoma and many other retinal and neuro-ophthalmologic disorders and is able to detect early defects.[44,45]

CONCLUSIONS

Perimetry has undergone evolutionary changes over the past 2000 years, particularly with regard to instrumentation, standardization, quantitative assessment, statistical evaluation, optimization of accuracy, precision and efficiency of testing, and distribution of results. However, the primary method of performing perimetry has remained highly similar for more than 200 years. Thus, it remains both a challenge and an opportunity for investigators to augment our current methods by developing new procedure with neuroscience underpinnings that will allow more accurate, precise, and efficient identification of damage to the peripheral visual field.

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