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(54) **APPARATUS FOR DETECTION OF EARLY-STAGE GLAUCOMA AND OTHER OPTIC NERVE DISEASES**

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(57) **ABSTRACT**

A method and apparatus of early-stage detection of glaucoma and other optic nerve or retinal diseases employs dynamic images that are processed differently by Y-like cells and X-like cells to provide a sensitive detection of early Y-like cell impairment which provides early indications of glaucoma isolated from non-specific information from X-like cells.

17 Claims, 3 Drawing Sheets
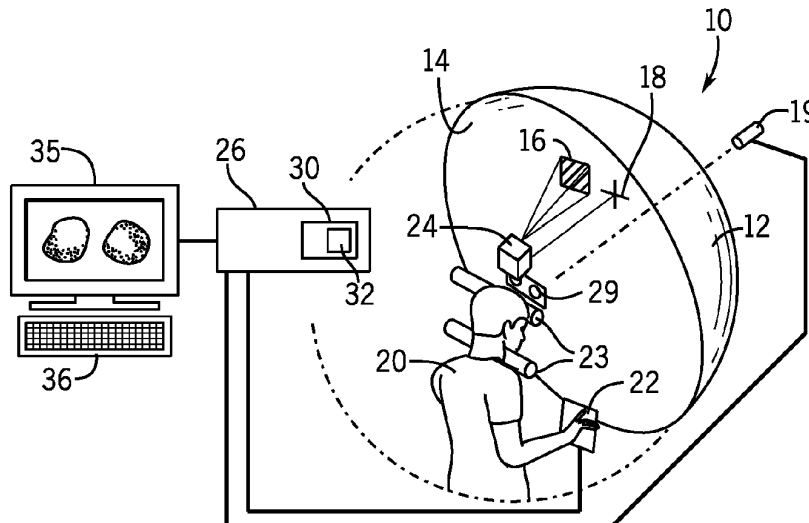
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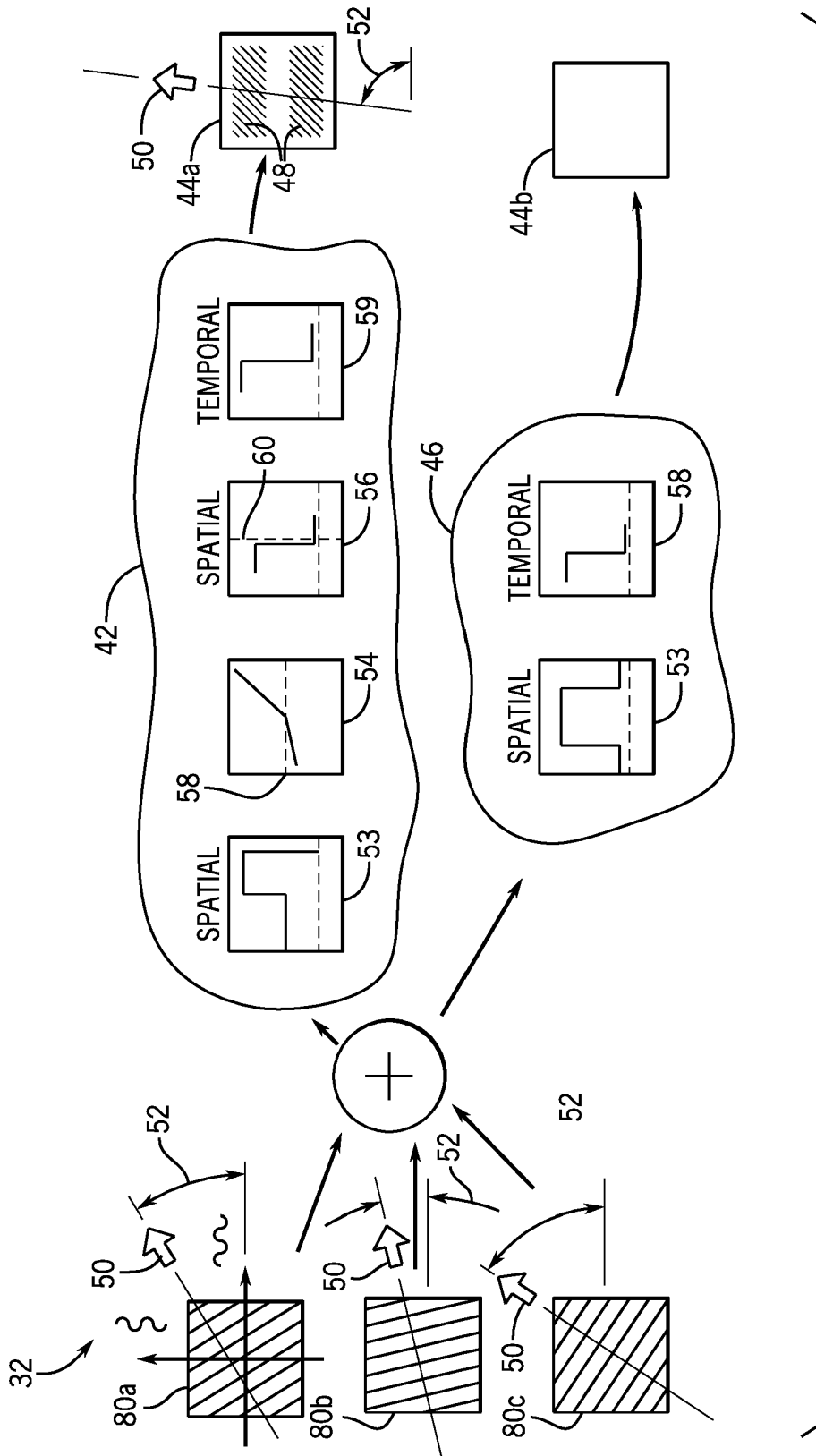
FIG. 1
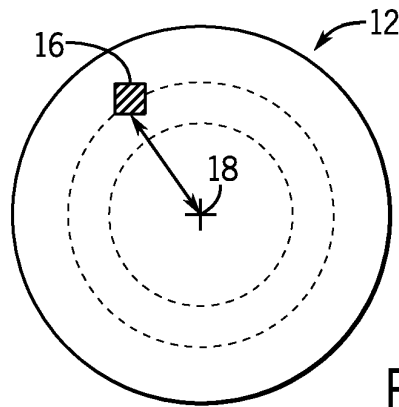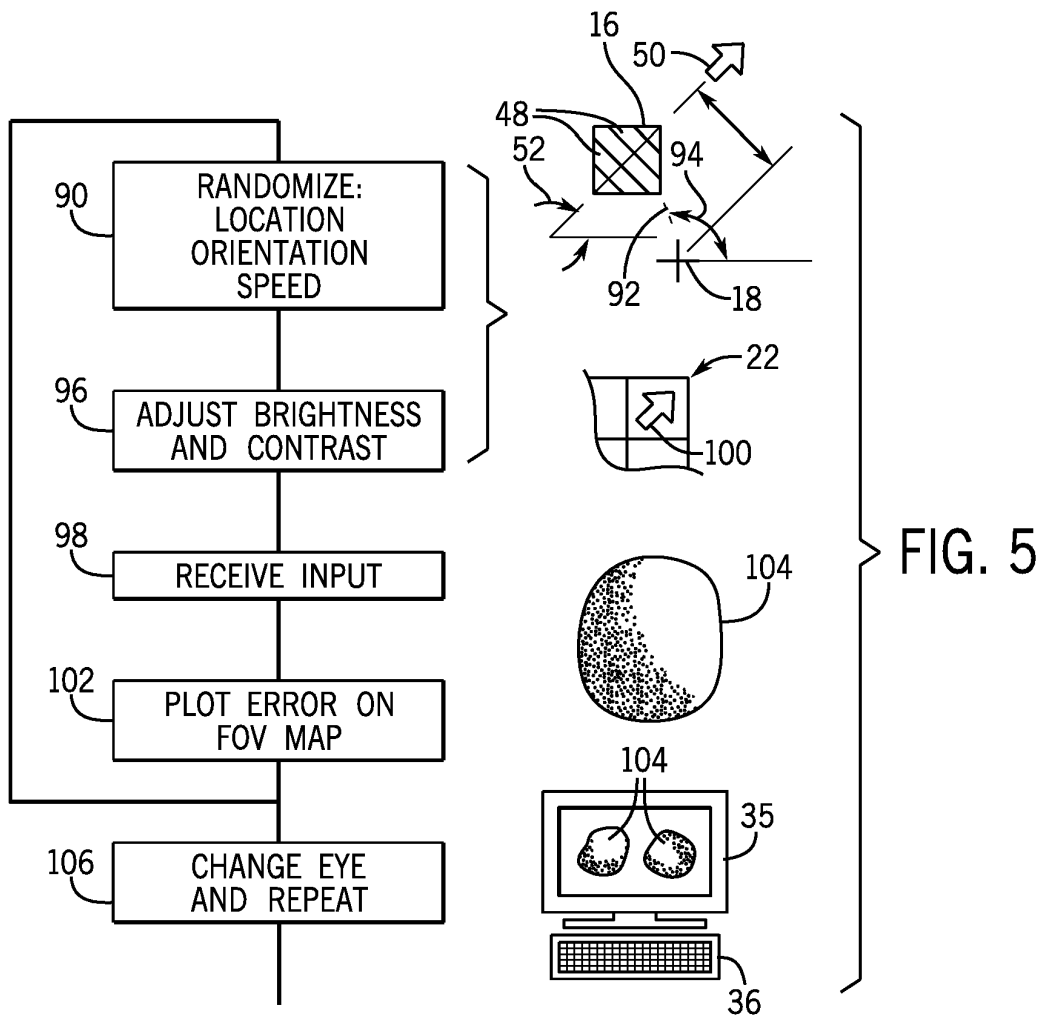

FIG. 2

FIG. 3

FIG. 4

FIG. 5

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APPARATUS FOR DETECTION OF EARLY-STAGE GLAUCOMA AND OTHER OPTIC NERVE DISEASES

STATEMENT REGARDING FEDERALLY SPONSORED RESEARCH OR DEVELOPMENT

CROSS REFERENCE TO RELATED APPLICATION

BACKGROUND OF THE INVENTION

The present invention relates generally to medical diagnostic equipment and in particular to an apparatus for the detection of glaucoma and other optic nerve diseases in human patients.

Glaucoma is a progressive, degenerative eye disease that is the most common cause of irreversible blindness. Glaucoma is manifested as damage to the optic nerve and, specifically, to the ganglion cells of the retina, typically from high intraocular pressure. The retinal ganglion cells first impacted include a minority of cells that have large cell bodies and large branching dendrite networks, including parasol cells and other types with analogous nonlinear properties (e.g. smooth or upsilon cells), henceforth termed Y-like cells, that provide information about more coarse spatial scales of luminance as well as fine-grain texture. In addition, there are a numerous subset, midget cells, (henceforth termed X-like cells) which have smaller cell bodies and smaller dendritic trees, and provide more sensitivity to fine detail and color. The Y-like cells are more susceptible to high intraocular pressure and thus are the earliest cells to be damaged as glaucoma progresses.

Glaucoma typically first affects the patient's peripheral vision before progressing to more central vision, and therefore may often not be noticeable to the patient until substantial and irreversible retinal damage has occurred.

The diagnosis of glaucoma is conventionally based on a combination of different clinical tests, such as direct and indirect ophthalmoscopic observation of the optic nerve head, and measurement of intraocular pressure using tonometry, which applies a slight pressure to the outer surface of the eye. Morphological assessments of possible optic nerve damage are often based on OCT (optical coherence tomography) imaging of the optic disc. While these techniques provide some information for early-stage detection, they do not estimate the reduction of the visual field and need to be accompanied by a functional assessment for a patient to be considered positive for glaucoma.

Functional or behavioral tests assess consequences for visual perception, where the SAP (Standard Automated Perimetry) is the most widely used test, in part because it is accurate and fast and thus suitable for many screening situations. In this approach, a dynamic image is positioned at different locations throughout the patient's field-of-view. The patient presses a button when the stimulus is perceptually visible to them, and a map is generated indicating portions of the patient's field where vision has been lost. However, substantial cell death, including both Y-like and X-like cells, is required before loss of peripheral vision is measurable by this test, thus the test lacks specificity and delays critical diagnostic information in early stages.

SUMMARY OF THE INVENTION

The present invention provides a sensitive, early detection of glaucoma or other eye diseases suitable for screening like

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SAP, while providing more sensitive detection of early-stage cell loss. This early sensitivity is possible by measuring behavioral responses that are dependent on neural signals from the Y-like cells, which are more prone to damage from glaucoma than the X-like cells, and thus provide earlier indications of cell loss. Sensitivity to Y-like cells is possible by having the patient identify perceptual attributes in specially prepared dynamic images that are primarily perceived through Y-like cells. Impairment of the patient's ability to detect, identify, or discriminate these features indicates Y-like cell loss even when X-like cells are largely unaffected.

In one embodiment, the invention provides an apparatus for glaucoma detection having an electronically controlled dynamic image display adapted for viewing by a human patient and a display driver for generating a series of dynamic images presentable on the electronically controlled display, each dynamic image providing a distinguishably different perception when received by only X-like cells than when received by Y-like cells. A patient input device is provided to receive a patient input describing orientation or direction of motion of a perceived pattern in the series of dynamic images displayed on the electronically controlled display; and a controller communicates with the display driver and electronically controlled display to:

(1) display different dynamic images at different locations within a field-of-view of a patient viewing the electronically controllable display; and

(2) analyze the patient input for the different locations of each of the dynamic images to assess a loss of Y-like cells in different portions of the retina corresponding to the different visual field locations.

It is thus a feature of at least one embodiment of the invention to extract early information specific to glaucoma, by assessing functional perception that is dependent on the integrity of Y-like cells, and relatively isolated from the functioning of X-like cells that might otherwise lead an automated perimetry machine to indicate that the visual field has not been lost or compromised. Significantly, the device invention eliminates the need for the patient to make difficult assessments of spatial frequency in favor or simple assessment of orientation and/or motion determination.

The perception of the dynamic images that are selective to Y-like cell function may result from a nonlinearity in the processing of the dynamic images by the Y-like cells, and not by the X-like cells.

It is thus a feature of at least one embodiment of the invention to exploit a difference in the processing of dynamic images by X- and Y-like cells, to assess the health of the Y-like cells without effects of the X-like cells.

The different dynamic images may provide perceptions of features having at least one of varying orientations and spacing when processed by Y-like cells and the patient input may identify at least one of a perceived feature orientation and spacing of given displayed dynamic image. In turn, the controller may vary at least one of the feature orientation and spacing of successive dynamic images and compares corresponding patient input to assess the functioning of Y-like cells in different portions of the retina corresponding to the different visual field locations.

It is thus a feature of at least one embodiment of the invention to provide an easily identifiable stimulus pattern that may be discerned using peripheral as well as central vision and thus is suitable for glaucoma testing and tracking disease progression.

Alternatively, or in addition, the dynamic images may provide perception of motion when received by the Y-like

cells and wherein the controller varies at least one of speed and direction of the motion in successive dynamic images and the patient input identifies a corresponding one of at least speed and direction of motion in the dynamic images and wherein the controller compares corresponding patient input to assess the functioning of Y-like cells in different portions of the retina corresponding to the different visual field locations.

It is thus a feature of at least one embodiment of the invention to provide different options for dynamic images that are sensitive to Y-like cell health that may be used alternatively or in addition to provide improved clinical sensitivity and specificity for given patients.

The perceptions may be derived from fine-grain texture-like features of the dynamic images having a relatively high spatial frequency of 1.0 to 20.0 cycles per degree, which are static or moving or dynamically modulated at a temporal frequency up to 30 cycles per second.

It is thus a feature of at least one embodiment of the invention to provide fine resolution and rapidly changing dynamic images that are substantially featureless when processed by X-like cells, but which are perceptually visible when processed by Y-like cells and in this way make it easier for the patient to make accurate pattern assessments, distin-guishing a pattern from a featureless or nearly featureless display compared to distinguishing two different bar pat-terns.

In one embodiment, the dynamic images may provide a spatiotemporal pattern of intensity following an amplitude modulation of a carrier pattern, the latter of which alone is imperceptible to the patient.

It is thus a feature of at least one embodiment of the invention to provide a contrast modulated signal that can reveal nonlinear downstream processing uniquely dependent on signals from Y-like cells.

The electronically controllable display may provide a center fixation target for the patient to focus on during the test and wherein the locations of the dynamic images are arranged at varying distances and angles about the fixation target, and an eye movement monitoring device to verify that the patient's gaze is directed to the fixation target.

It is thus a feature of at least one embodiment of the invention to provide an apparatus that can be used as a replacement for a current, well understood automated perim-etry device that is conventionally used to test for glaucoma.

The electronically controllable display may include a digital light projector (DLP) using micromirrors, and pro-viding a refresh rate of at least 100 hertz, and projecting on a screen viewable by the patient.

It is thus a feature of at least one embodiment of the invention to provide an electronically controllable display that can produce high resolution, high contrast, and high frame rate dynamic images suitable for the present inven-tion. It is another object of the invention to provide an electronic display providing a well-characterized linear rela-tionship between the control signal and image intensity, eliminating the need for gamma correction or the like to compensate for display device nonlinearity.

The controller may vary at least one of contrast and size of the dynamic images according to the location of the stimulus with respect to the fixation target.

It is thus a feature of at least one embodiment of the invention to account for normal variations in the contrast sensitivity and size-scaling of retinal cells as a function of distance from the fovea, and to allow adjustment of the apparatus for variations between different individuals.

These particular objects and advantages may apply to only some embodiments falling within the claims and thus do not define the scope of the invention.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a simplified perspective view of an automated perimetry system incorporating the present invention and showing a projector under the control of a programmable controller system for projecting Y-like cell specific dynamic images on a screen viewed by a patient;

FIG. 2 is a block diagram of the projector of FIG. 1 providing a high-resolution dynamic image at various loca-tions in the periphery of the patient's vision, and a fixation target projector providing a central fixation target;

FIG. 3 is a flow diagram of the process of generating Y-like cell specific dynamic images by the programmable controller in FIG. 1;

FIG. 4 is a front elevational view of the screen of FIG. 1 showing the location of a Y-like cell-specific dynamic image with respect to a screen center such as can be used to control contrast and size-scaling of the dynamic images; and

FIG. 5 is a flowchart of the program executed by the electronic programmable controller of FIG. 1 during a glaucoma screening test.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

Referring now to FIG. 1, a glaucoma detection apparatus 10 constructed according to one embodiment of the present invention may provide for a hemispherical screen 12 having an inner reflective surface 14 onto which a dynamic image pattern 16 and center fixation target 18 may be projected. The hemispherical screen 12 may be positioned with respect to a patient 20 to substantially subtend the field of view of the patient 20 when the patient 20 has his or her eyes fixed on the center fixation target 18. In this respect the hemi-spherical screen 12 may be a portion of a sphere centered at a location near the patient's eyes. An eye tracking camera 19 may be positioned to focus on the patient's eye that is to be tested, to determine times when the patient 20 is viewing the center fixation target 18 as will be discussed below.

The patient 20 may rest his or her head against a head and chin rest 23 to help stabilize the patient's head. The chin rest 23 will have two positions, for the patient 20 to use one or the other of, to test either the left or right eye of the patient 20 for separate testing of each eye, with the other eye being occluded. In this regard, the head and chin rest 23 will include spectacle lenses 29 to bring the patient's eyes into focus on the displayed fixation target 18. A response device 22 such as a button box, keypad, or other hardware input device, may be provided to the patient 20 to receive patient input describing a perception of the patient 20 of the dynamic images 16 viewed by the patient using the patient's central or peripheral vision. The response device 22 may, for example, allow the patient 20 to distinguish between orien-tation, motion, motion direction, motion speed, and pattern coarseness of the dynamic image 16 as will be discussed below.

The dynamic images 16 may be presented by a projector 24 at a series of sequentially different locations on the hemispherical screen 12 about the center fixation target 18, the latter of which is desirably fixed in position at a center point on the hemispherical screen 12.

The projector 24 and response device 22 communicate with a programmable controller 26, for example a micro-

computer or FPGA (field programmable gate array) or the like, communicating with an electronic memory **30** holding a program **32** as will be discussed below. The programmable controller **26** may further provide for the operator, a display screen **35**, for example, a standard LCD computer display, and operator input devices **36** such as a keyboard, a mouse or the like for providing inputs to the program **32**.

Referring also to FIG. **2**, the projector **24** may provide a graphic image projector assembly **27** allowing the projection of a high-resolution two-dimensional dynamic image **16** with a spatial resolution viewed by the patient **20** (measured along two orthogonal directions) sufficient to render spatial frequencies of at least 20 cycles per degree, and with a refresh rate of at least 100 frames per second. In this regard, the graphic image projector assembly **27** may include a collimated light source **28** (for example, an LED array) whose light is modified by a digital light processor (DLP) mirror array **31**. The DLP mirror array **31** provides an array of micro mirrors that can be switched rapidly between on and off states as is generally understood in the art to provide highly linear control of the illumination of each pixel of a dynamic image by control of duty cycle modulation of the mirrors. Light modified by the DLP mirror array **31** is focused by focusing optics **33** (set to provide focused dynamic images **16** on the hemispherical screen **12**). Light from the focusing optics **33** is then reflected off of a front surface mirror **37** of a pair of mirror galvanometers **34** that may steer the location of the dynamic image **16** to a variety of locations over a majority of the surface **14** of the hemispherical screen **12** by orthogonal deflections of the front surface mirror **37**.

The fixation point projector **38** may include a laser pointer or other such device for producing a simple static image to serve as the center fixation target **18** (for example, in the form of concentric circles or a letter such as an "E") and may provide for mechanical adjustment together with other elements of the projector **24** to locate the center fixation target **18** at the center of the hemispherical screen **12** while providing a known relationship between the center of the hemispherical screen **12** and each location of a dynamic image **16**.

Each of the servo controller **40**, light source **28**, DLP mirror array **31**, and laser pointer **38** may be actuated by a programmable controller device **26** incorporating an electronic interface that allows the projector **24** to receive from the programmable controller **26** image data to generate the dynamic image **16** by control of the DLP mirror array **31**. A servo-controller **40** may also receive from the programmable controller **26** location data for the dynamic image to control the mirror galvanometer **34** and hence the position of the dynamic image **16**.

Referring now to FIG. **3**, generally the program **32** executing on the programmable controller **26** will generate a dynamic image **16** such that the resulting percept **44a** or **44b** (perceived images by the patient **20**) differs according to whether the dynamic images **16** are processed by the Y-like cells **42** or the X-like cells **46**. In particular, the patient's percept of the dynamic images **44a** processed by the Y-like cells **42** may show a series of stripes **48**, either stationary or having a drift direction and speed **50** at an orientation angle **52**. More generally, the stripes **48** may be other coarse-scale features such as bars, edges, discs, or the like. The periodicity of the stripes **48**, their drift direction and speed **50**, and their orientation angle **52** may be adjusted (as will be discussed below) by the programmable controller **26**. In contrast, the patient's percept of the dynamic images **44b** processed by the X-like cells **46** may have no perceived

stripes **48** or exhibit the stripes **48** in extremely attenuated form to be practically imperceptible to the extent that it can be readily distinguished from the percept **44a** (perceived images by the patient **20**).

While the inventors do not wish to be bound by a particular theory, this difference in perceived dynamic images **44a** and **44b** is believed to be the result of a nonlinearity in the processing of the dynamic image **16** by the Y-like cells **42** that does not occur to a substantial degree in the processing performed by the X-like cells **46**. In this respect, the processing of the Y-like cells **42** may be modeled as providing a spatial bandpass filter **53** followed by a nonlinearity such as a rectification function **54** followed by a spatial low-pass filter function **56** having cutoff frequency **60** and a temporal low-pass filter **59**. For example, a rectification function **54** provides relatively high-gain mapping between luminance values and Y-like cell **42** output response when the received luminance is above a nonzero luminance threshold **58**. Luminance values below this luminance threshold **58** are largely attenuated with a low-gain mapping in the manner of a rectifier.

Consider now the situation where the dynamic image **16** has a high spatial frequency and high temporal frequency "carrier signal", and a low spatial frequency and low temporal frequency envelope modulation of that high frequency carrier. The spatial bandpass filter **53** allows passage of this high spatial frequency carrier which is then received by the rectification function **54**. The rectification function **54** essentially demodulates the carrier to produce a low spatial frequency and low temporal frequency signal at the envelope frequencies in addition to the high spatial frequency carrier signal. The spatial low-pass filter function **56** and temporal low-pass filter function **59** block the carrier signal but allow the low-frequency envelope signal having low spatial frequency and low temporal frequency to be passed as stripes **48** or other features.

In other words, the result of the rectification function **54** and the low-pass filter functions **56** and **59** is that an "envelope" of a contrast modulated dynamic image **16** will be extracted, or demodulated, by the Y-like cells **42** while the underlying carrier signal is blocked. This effect is obtained in any image that can be characterized as "non-Fourier" or "second order", that is, images having fine spatial scale features whose spatial variation are revealed only by a nonlinearity, in the retinal cells that "demodulate" the stimulus, such a nonlinearity being in contrast to the linear superposition that characterizes Fourier decomposition.

In contrast to the Y-like cells **42**, the X-like cells **46** are believed not to have the nonlinearity of the rectification function **54** to a significant degree and have spatial bandpass filter functions **53** shifted to higher spatial frequencies, and temporal low-pass filter functions **59**. As a result, there is no demodulated envelope that can be passed by the low-pass filter **59** yet again the "carrier" frequency of the dynamic images **16** is blocked or highly attenuated resulting in a practically featureless percept **44b**. Importantly, even if perceptible, the carrier will be distinguishable from the percept **44a** so there is low risk that viewing of the carrier will be confused with being able to view the percept **44a**.

The spatial and temporal sensitivities of the Y-like cells **42** and X-like cells **46**, and nonlinearities of the Y-like cells **42**, act so that the lower temporal and spatial frequency stripes **48** of dynamic percept **44a** and **44b** are more pronounced perceptually than the spatially fine-grain features of the dynamic image **16**.

In one example, a set of dynamic images **16** may be generated from the sum of three different two-dimensional sinusoidal fields **80a**, **80b**, and **80c** each having an independently controllable spatial frequency, orientation angle **52**, and drift direction and speed **50** orthogonal to that orientation. The sum of these fields may be expressed by the equation:

$$I(x,y,t)=\cos(\omega_C \cdot [x,y,t])+0.5\cdot\{\cos([\omega_C-\omega_E]\cdot[x,y,t])+\cos([\omega_C+\omega_E]\cdot[x,y,t])\}$$ (1)

where I is intensity at a pixel,

[x, y, t] is a vector describing the Cartesian location and time of the pixel,

ω_C is a vector defining a "carrier" spatial and temporal frequency (having x- and y-components that define the orientation angle **52** and the time component describing the drift direction and speed **50**) and,

ω_E is a vector describing the spatial and temporal "modulating" frequency.

The three terms to the right side of equation (1) that sum together to define the intensity are represented by **80a**, **80b**, and **80c** as shown in FIG. **3**. Field **80a** may be interpreted as a carrier sinusoidal field $\cos(\omega_C \cdot [x, y, t])$ and fields **80b** and **80c** that represent a multiplication between the carrier $\cos(\omega_C \cdot [x, y, t])$ and the modulating frequency $\cos(\omega_E \cdot [x, y, t])$ converted to a summation by a trigonometric identity for ease of processing. Generally, it will be understood that the drift direction and speed **50** and orientation angle **52** of the stripes **48** may be easily controlled by adjusting the vectors ω_C and ω_E in the program **32**.

The dynamic images **16** are, in their most general form, produced by any spatially fine-grain, texture-like dynamical pattern, the "carrier", whose contrast is modulated by a more coarse-grain pattern, the "envelope", as follows:

$$I(x,y,t)=I_0+Carr([x,y,t])[1+Env([x,y,t])]$$

where I(x, y, t) is the luminance intensity of a pixel at spatial location (x,y) at time t, I_0 is the space- and time-average luminance of the spatiotemporal pattern I(x, y, t),

[x,y,t] is a vector describing the Cartesian location and time of the pixel,

Carr is a 3d zero-mean matrix defining a "carrier" pattern as a function of spatial location [x,y] and time [t] and,

Env is a 3d zero-mean matrix defining an "envelope" pattern as a function of spatial location [x,y] and time [t], that "modulates" the amplitude of the carrier.

Referring still to FIG. **3**, the dynamic images **16** may be generated procedurally by the programmable controller **26**, for example, by generating a three-dimensional sinusoidal variation in image intensity where that sinusoidal variation is modulated by multiplication with a second three-dimensional sinusoid. For example, in one embodiment, a dynamic image **16** may be generated from a carrier pattern that may be a drifting sinewave grating with a high spatial frequency and high temporal frequency, and an envelope pattern that may be a drifting sinewave grating with a low spatial frequency and low temporal frequency, the carrier and envelope patterns having independently controllable spatial frequency, orientation angle **52**, and drift direction and speed **50**. The resultant dynamic image may be expressed by the equations:

$$Carr(x,y,t)=C_c \cos(\omega_C \cdot [x,y,t])$$

where Carr([x,y,t]) is the spatiotemporal carrier pattern (as above)

[x,y,t] is a vector describing the Cartesian location and time of the pixel,

C_c is the amplitude of the carrier sinewave grating

ω_C is a vector defining a "carrier" spatial and temporal frequency (having x- and y-components that define the orientation angle **52** and the time component describing the drift direction and speed **50**)

$$Env(x,y,t)=C_e \cos(\omega_e \cdot [x,y,t])$$

where Env(x,y,t) is the spatiotemporal envelope ("modulating") pattern (as above)

[x,y,t] is a vector describing the Cartesian location and time of the pixel,

C_e is the Michelson contrast (0.0 to 1.0), or "modulation depth", of the envelope sinewave grating

ω_C is a vector defining an "envelope" spatial and temporal frequency (having x- and y-components that define the orientation angle **52** and the time component describing the drift direction and speed **50**)

Generally, it will be understood that the envelope modulation depth C_e, orientation angle θ_e **52**, direction of motion, spatial frequency, and temporal frequency of the envelope pattern (sinusoidal stripes) **48**, as well as the carrier amplitude, orientation angle stripes, direction of motion, spatial frequency, and temporal frequency will be easily controlled by adjusting the parameters in the controller program **32**. It will be generally understood that temporal frequency may be considered separately from direction of motion (where the temporal frequency is positive only) or may subsume direction of motion by considering direction of motion to be defined by positive and negative values of temporal frequency.

Referring now to FIG. **4**, the present invention also contemplates that the contrast and/or size-scaling of the dynamic image **16** may be adjusted as a function of its distance from the center fixation target **18**, for example, to compensate for known variations in the sensitivity of retinal cells, as well as normal variations between individuals, not necessarily associated with glaucoma.

Referring now to FIG. **5** as well as FIGS. **3** and **4**, the program **32** of the programmable controller **26** may operate repeatedly to randomize a location being a distance **92** and angle **94** of a dynamic image **16** generated as discussed above with respect to the center fixation target **18**. Each successive, presented dynamic image **16** may have a different orientation **52** and/or drift direction and/or speed **50** so as to generate perceived stripes **48** in the dynamic image **16** that will have different perceivable orientations or different stripe motions per process block **90**. In this process block **90**, the envelope contrast or carrier amplitude can also be varied on successive trials to change the level of difficulty of perceptual judgment.

Optionally, per process block **96**, adjustment of size-scaling or contrast of the dynamic image **16** may be made based on the distance **92** and/or a combination of distance **92** and angle **94** as discussed above.

At process block **98**, the programmable controller **26** may receive an input from the patient **20**, for example, using the response device **22** indicating direction and/or speed and/or orientation and/or spacing of the perceived stripes **48**, for example, through arrow, letter or number labels **100** on the various buttons or keys of the response device **22** indicating motion, direction, speed, and orientation. This input may be tested to see if the patient **20** has their eyes fixed on the fixation target **18** using the eye tracking camera **19** and may be discounted or uncounted if not. In addition, the process of process blocks **90**, **96**, **98**, **102**, and **106** may initiate only

after the patient has eyes fixed on the fixation target **18**. The period of time for receiving the input per process block **98** may be limited to a predetermined window after placement of the dynamic image **16**.

At process block **102**, a determination is made as to whether the direction and/or speed and/or orientation and/or spacing of the perceived stripes **48** identified by the patient per process block **98** match the actual stripes **48** generated per process block **90** and **96**. Whether the matching is correct or in error, across the ensemble of tests in different visual field locations, is used to construct the field-of-view map **104** showing schematically the patient's field-of-view for one of the left or right eye. This field-of-view map **104** may show a density of errors in identification of the stripes **48** by the patient **20** in corresponding to the locations of the dynamic images **16** invoking the error, and in this respect shows loss of Y-like cells **42** in the patient's retina responsible for representing those areas of the field-of-view. Successive field-of-view maps **104** taken over time (typically many days, weeks, months, and/or years) can provide a sensitive indication of progression of glaucoma. When the level of difficulty of the tests is varied, this information may be used to weight the assessment of whether the patient has correctly identified the stripes **48** and thus to provide a more nuanced output in the field-of-view map **104**.

This sequence of process blocks **90**, **96**, **98**, and **102** may be repeated for a desired number of dynamic images **16** needed to build up a detailed field-of-view map **104**. At process block **106**, the patient **20** may change eyes being tested by changing position on the chin rest, and thereby which eye is occluded, as discussed above. For each different eye, the sequence of process blocks **90**, **96**, **98**, and **102** is repeated.

At the conclusion of this testing of each eye, a pair of field-of-view maps **104** may be displayed together with analysis, for example, quantifying the usable field-of-view of the patient, for example, which is helpful in making longitudinal comparisons of these changes over time. Other types of displays commonly obtained with automated perimetry can be duplicated with the additional specificity obtained by isolation of the Y-like cells, providing advanced indication of cell death.

As used herein, "Y-like cell" shall be understood to be "parasol retinal ganglion cells" or "smooth retinal ganglion cells", or "upsilon retinal ganglion cells" as is understood in the art and "X-like cell" shall be understood to be "midget retinal ganglion cells" as is also understood in the art.

Certain terminology is used herein for purposes of reference only, and thus is not intended to be limiting. For example, terms such as "upper", "lower", "above", and "below" refer to directions in the drawings to which reference is made. Terms such as "front", "back", "rear", "bottom" and "side", describe the orientation of portions of the component within a consistent but arbitrary frame of reference which is made clear by reference to the text and the associated drawings describing the component under discussion. Such terminology may include the words specifically mentioned above, derivatives thereof, and words of similar import. Similarly, the terms "first", "second" and other such numerical terms referring to structures do not imply a sequence or order unless clearly indicated by the context.

When introducing elements or features of the present disclosure and the exemplary embodiments, the articles "a", "an", "the" and "said" are intended to mean that there are one or more of such elements or features. The terms "comprising", "including" and "having" are intended to be inclu-sive and mean that there may be additional elements or features other than those specifically noted. It is further to be understood that the method steps, processes, and operations described herein are not to be construed as necessarily requiring their performance in the particular order discussed or illustrated, unless specifically identified as an order of performance. It is also to be understood that additional or alternative steps may be employed.

References to "a controller" and "a processor" or "the microprocessor" and "the processor," can be understood to include one or more microprocessors, FPGAs (field pro-grammable gate arrays) that can communicate in a stand-alone and/or a distributed environment(s), and can thus be configured to communicate via wired or wireless communications with other processors, where such one or more processor can be configured to operate on one or more processor-controlled devices that can be similar or different devices. Furthermore, references to memory, unless otherwise specified, can include one or more processor-readable and accessible memory elements and/or components that can be internal to the processor-controlled device, external to the processor-controlled device, and can be accessed via a wired or wireless network.

It is specifically intended that the present invention not be limited to the embodiments and illustrations contained herein and the claims should be understood to include modified forms of those embodiments including portions of the embodiments and combinations of elements of different embodiments as come within the scope of the following claims. All of the publications described herein, including patents and non-patent publications, are hereby incorporated herein by reference in their entireties.

To aid the Patent Office and any readers of any patent issued on this application in interpreting the claims appended hereto, applicants wish to note that they do not intend any of the appended claims or claim elements to invoke 35 U.S.C. 112(f) unless the words "means for" or "step for" are explicitly used in the particular claim.

What we claim is:

1. An apparatus for glaucoma and retinal diseases diagnosis comprising:

an electronically controlled dynamic image display adapted for viewing by a human patient;

a display driver for generating a series of dynamic images presentable on the electronically controlled display, each dynamic image providing a distinguishably different perception when received by only X-like cells than when received by Y-like cells;

a patient input device for receiving a patient input describing orientation or direction of motion of a perceived pattern in the series of dynamic images displayed on the electronically controlled display; and

a controller communicating with the display driver and electronically controlled display to:

(1) display different dynamic images at different locations within a field-of-view of a patient viewing the electronically controllable display; and

(2) analyze the patient input for the different locations of each of the dynamic images to assess a loss of Y-like cells in different portions of the retina corresponding to the different locations.

2. The apparatus of claim **1** wherein the perceptions of the dynamic image result from a nonlinearity in a processing of the dynamic image by the Y-like cells and not by the X-like cells.

3. The apparatus of claim **1** wherein the different dynamic images provide perceptions of stripes having at least one of

varying orientations and spacing when processed by Y-like cells and wherein the patient input identifies at least one of a perceived stripe orientation and spacing of given displayed dynamic image and wherein the controller varies at least one of the stripe orientation and spacing of successive dynamic images and compares corresponding patient input to assess the functioning of Y-like cells in different portions of the retina corresponding to the different locations.

4. The apparatus of claim 1 wherein the dynamic images provide a perception of motion when received by the Y-like cells and wherein the controller varies at least one of speed and direction of the motion in successive dynamic images and the patient input identifies a corresponding one of at least speed and direction of motion in the dynamic images and wherein the controller compares corresponding patient input to assess the functioning of Y-like cells in different portions of the retina corresponding to the different locations.

5. The apparatus of claim 1 wherein the perceptions are derived from features of the images having a spatial frequency of greater than 1 cycles per degree and have a spatial frequency of less than 20 cycles per degree.

6. The apparatus of claim 1 wherein the perceptions are derived from features of the images having a temporal frequency magnitude of less than 30 cycles per second.

7. The apparatus of claim 1 wherein the images provide a spatiotemporal pattern of intensity following an amplitude modulation of a carrier pattern, the latter of which is distinguishably different from the perception resulting from processing of the Y-like cells.

8. The apparatus of claim 1 wherein the electronically controllable display provides a center fixation target for the patient to focus on during use of the apparatus and wherein the locations of the images are arranged at varying distances and angles about the fixation target.

9. The apparatus of claim 1 wherein the electronically controllable display includes a digital light projector using micromirrors and provides a refresh rate of at least 100 hertz and projects on a screen viewable by the patient.

10. The apparatus of claim 1 wherein the controller varies at least one of contrast and size-scaling of the images according to the location of the image with respect to a predetermined center of the electronically controllable display.

11. The apparatus of claim 1 further including a head support stabilizing the patient's head and occluders for alternatively blocking the left or right eye of the patient.

12. A method of glaucoma and retinal diseases diagnosis comprising:
(a) displaying a series of dynamic images on an electronically controlled display at different locations within a field-of-view of a patient viewing the electronically controllable display, each dynamic image providing a distinguishably different perception when processed by only X-like cells than when processed by Y-like cells;
(b) receiving patient input describing orientation or direction of motion of a perceived pattern in the dynamic images displayed on the electronically controlled display; and
(c) analyzing the patient input and location of each of the dynamic images to assess a loss of Y-like cells in different portions of the retina corresponding to the different locations.

13. The method of claim 12 wherein the perceptions of the dynamic images result from a nonlinearity in a processing of the dynamic images by the Y-like cells and not by the X-like cells.

14. Method of claim 12 wherein the different dynamic images provide perceptions of stripes having at least one of varying orientations and spacing when processed by Y-like cells and wherein the patient input identifies at least one of a perceived stripe orientation and spacing of given displayed dynamic image and wherein the controller varies at least one of the stripe orientation and spacing of successive dynamic images and compares corresponding patient input to assess the functioning of Y-like cells in different portions of the retina corresponding to the different locations.

15. The method of claim 12 wherein the dynamic images provide a perception of motion when received by the Y-like cells and wherein the controller varies at least one of speed and direction of the motion in successive dynamic images and the patient input identifies a corresponding one of at least speed and direction of motion in the dynamic images and wherein the controller compares corresponding patient input to assess the functioning of Y-like cells in different portions of the retina corresponding to the different locations.

16. The method of claim 12 wherein the perceptions are derived from features of the images having a spatial frequency of greater than 1 cycles per degree and have a spatial frequency of less than 20 cycles per degree.

17. The method claim 12 wherein the perceptions are derived from features of the images having a temporal frequency magnitude of less than 30 cycles per second.

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