

COMPREHENSIVE VISUAL FIELD TEST AND DIAGNOSIS SYSTEM FOR VISUAL PERFORMANCE ASSESSMENT IN MILITARY SETTINGS

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ABSTRACT

We have developed an Internet-based, integrated, and comprehensive visual field test and diagnosis system to assess the visual performance of warfighters, veterans, and civilians. The system is based on the 3D Computer-automated Threshold Amsler Grid (3D-CTAG) test. In multiple clinical studies 3D-CTAG has proven to be innovative and successful for fast, easy, accurate, non-invasive, and comprehensive visual field testing. With one eye covered, the subject is positioned in front of a touch-sensitive computer screen on a head-chin rest and finger-traces the areas of an Amsler grid that are missing from his field of vision. Various degrees of contrast of the Amsler grid are presented by repeating the test at different grayscale levels. The resulting 3D data represent the measured contrast sensitivity across the tested visual field and are stored in a relational MySQL database. We have created an automated and integrated artifact removal, analysis, and characterization system, which analyzes 3D-CTAG visual field data and objectively identifies and characterizes the occurring visual field defects (scotomas) within according to visual field data transforms and scotoma data transforms. Following each test, a topographical contour map, a 3D depiction of the central hill-of-vision, and the comprehensive visual field and scotoma characterization are automatically generated and displayed onscreen, using the freely available Gnuplot[®] plotting package.

1. INTRODUCTION

Vision is the primary sense used by warfighters and civilians in daily life, and visual information is essential during all phases of military operations. Military environments have many significant effects on the visual and ocular system that can adversely affect warfighter performance, and may lead to long-term health consequences. Risks during military operations include possible corneal, lens and retinal damage from military combat, UV exposure, retinal thermal damage from excessive visible light and IR/laser exposure, intracranial and/or intraocular hypertension such as from head trauma, and toxic environmental poisoning. Moreover, in civilian

life there are many conditions that, if undetected or detected too late, may lead to irreversible visual field loss and eventually to blindness, such as glaucoma and macular degeneration. Therefore, the development and deployment of a portable, easy-to-use, Web-based comprehensive test and diagnosis system is warranted for:

- (1) Accurately assessing visual fields on a regional to global scale;
- (2) Characterizing and diagnosing visual field defects and eye conditions;
- (3) Detecting the onset of eye conditions to allow for timely countermeasures as well as patient follow-up over time.

2. COMPREHENSIVE VISUAL FIELD TEST AND DIAGNOSIS SYSTEM

We have developed a Web-based integrated visual field test and diagnosis system to assess the visual performance of warfighters, veterans, and civilians. In the following subsections we describe the various system components in more detail.

2.1 3D Computer-automated Threshold Amsler Grid Testing Method

The visual field test and diagnosis system is based on the *3D Computer-automated Threshold Amsler Grid (3D-CTAG)* test (Fink and Sadun, 2004). In multiple clinical studies since 2000, 3D-CTAG has proven to be innovative and successful for fast (<5 minutes per eye), easy (intuitive use of finger), accurate (<1 degree), non-invasive, and comprehensive visual field testing: Conditions such as glaucoma (Nguyen et al., 2009), ocular hypertension (Nazemi et al., 2007), age-related macular degeneration with distinction between wet and dry AMD (Nazemi et al., 2004), macular edema (Jivrajka et al., 2008), ethambutol toxicity (Kim et al., 2008), anterior ischemic optic neuropathy and optic neuritis (Fink et al., 2000) have been successfully detected.

With one eye covered, the subject is positioned in front of a touch-sensitive computer screen on a head-chin rest and finger-traces the areas of an Amsler grid that are

missing from his field of vision. Various degrees of contrast of the Amsler grid are presented by repeating the test at different grayscale levels. Results of the 3D-CTAG test are recorded by the computer in form of a 3D data array. The 3D data represent the measured contrast sensitivity across the tested visual field.

2.2 Configuration of Visual Field Test and Diagnosis System prior to Testing

Before a patient can undergo 3D-CTAG visual field testing, the examination device, i.e., test computer with touch-sensitive computer screen, has to be configured as follows:

- (1) The user registers the name and the specifications/parameters (e.g., geometry) of the computer monitor to be used as the examination device;
- (2) The user determines the DPI of the computer monitor;
- (3) The user calibrates the Gamma-setting of the computer monitor;
- (4) Then the patient determines the lowest perceivable grayscale value for the subsequent 3D-CTAG testing of his visual field.

After these steps the examination device is ready for 3D-CTAG testing.

2.3 Online Performance of 3D-CTAG Visual Field Testing

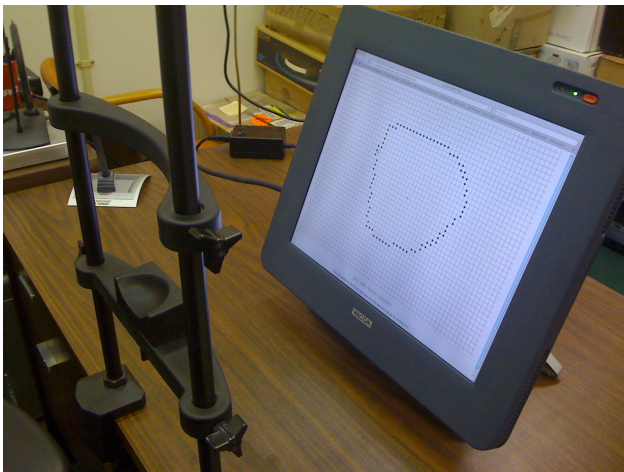


Fig. 1. Test setup for the (Internet-based) visual field test and diagnosis system at the Visual and Autonomous Exploration Systems Research Laboratory at Caltech: head-chin rest and touch-sensitive computer monitor with an Amsler grid displayed at a particular contrast level. The test subject has outlined on the touch-sensitive computer screen a central area of the Amsler grid that is not visible to him.

Visual field testing via 3D-CTAG is optimally conducted in a room with controlled lighting. With one eye covered, the subject is positioned in front of the touch-sensitive computer screen on a head-chin rest (Fig.

1), and, while remaining focused on a central fixation marker, finger-traces the areas of an Amsler grid that are missing from his field of vision (Fig. 2, top). These areas are subsequently filled in (Fig. 2, bottom). Various degrees of contrast of the Amsler grid are presented by repeating the test at different grayscale levels (Fig. 3). When necessary, subjects can wear their own refractive corrections, such as contact lenses or eyeglasses. Results of 3D-CTAG visual field testing are recorded by the computer in form of 3-dimensional data arrays: $(x, y, \text{contrast sensitivity}(x, y))$. x and y mark the horizontal/vertical location and hence the eccentricity of a tested Amsler grid point in the visual field with respect to the fovea $(0, 0)$. Contrast sensitivity (x, y) denotes the measured contrast sensitivity of the particular visual field location (x, y) .

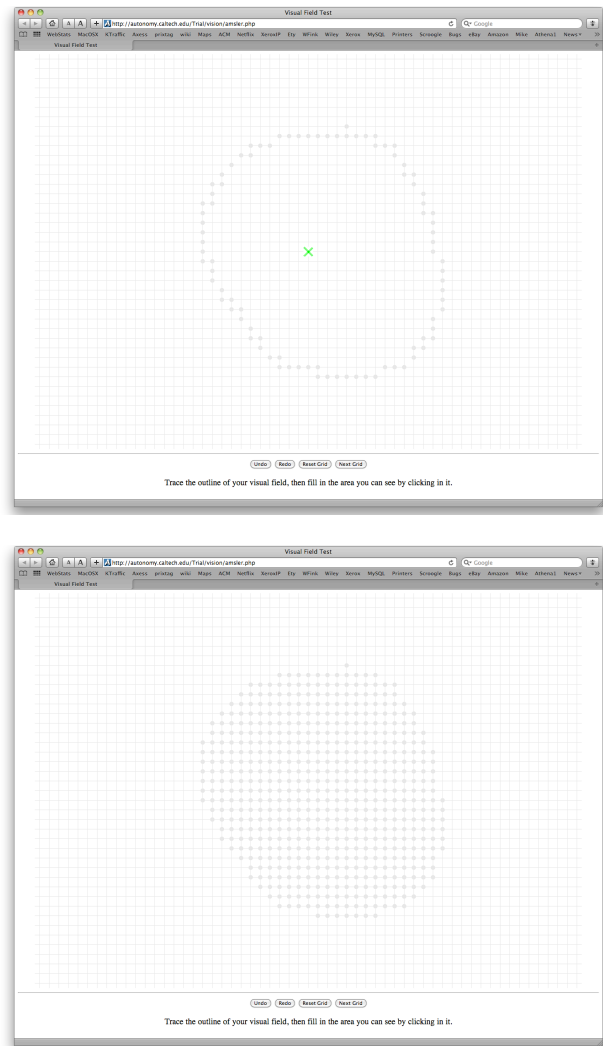


Fig. 2. *Top:* Finger-traced outline on Amsler grid of visual field that is missing at a low contrast setting (i.e., harder to see). The green “X” at screen-center is the central fixation marker. *Bottom:* The finger-traced areas are subsequently filled in as “non visible”, i.e., scotoma, and the test is repeated at varying degrees of contrast (Fig. 3).

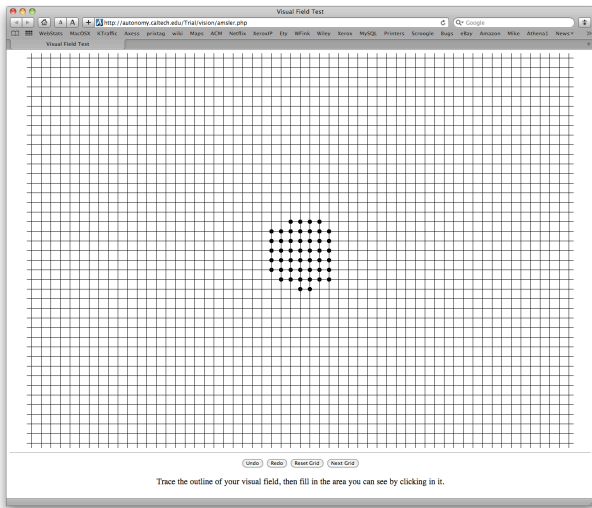
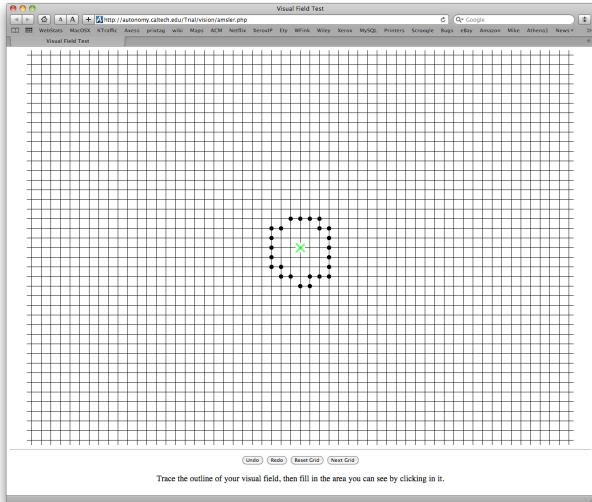


Fig. 3. *Top:* Finger-traced outline on Amsler grid of visual field that is missing at a *high* contrast setting (i.e., easier to see). The green “X” at screen-center is the central fixation marker. *Bottom:* The finger-traced areas are subsequently filled in as “non visible”, i.e., scotoma, and the test is repeated at varying degrees of contrast (Fig. 2).

2.4 3D Plotting Capability via Gnuplot[®] Interface

The 3D data obtained via 3D-CTAG testing represent the measured contrast sensitivity across the tested visual field. Following each 3D-CTAG test, a 3D depiction of the central hill-of-vision (third dimension being contrast sensitivity) and a topographical contour map to illustrate the location, extent, grade, and shape of visual field defects are automatically generated and displayed onscreen (Fig. 4) using the freely available Gnuplot[®] plotting package.

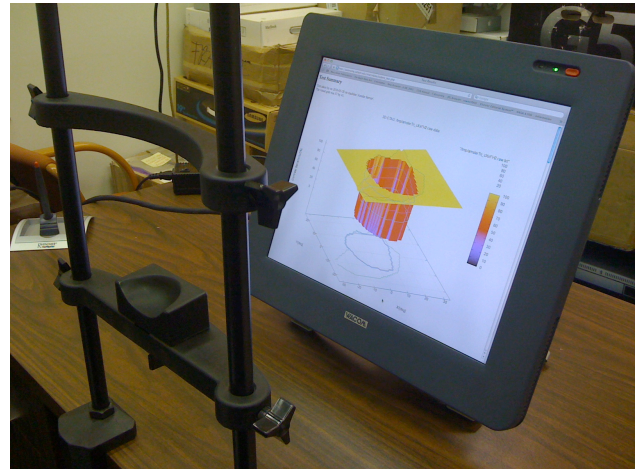


Fig. 4. 3D depiction of central hill-of-vision and topographical contour map for a visual field data set obtained with the 3D computer-automated threshold Amsler grid test. Displayed is a case of age-related macular degeneration (i.e., central absolute visual field defect).

2.5 Overview of Auto-Characterization System

To analyze the 3D visual field datasets and to characterize the occurring visual field defects (i.e., scotomas) within, we have devised, implemented, and integrated a suite of numerical methods (You and Fink, 2010a) that:

- (1) Automatically remove artifacts present in the 3D-CTAG raw data;
- (2) Assess the visual field as a whole (i.e., *visual field data transforms*);
- (3) Characterize scotomas within the visual field (i.e., *scotoma data transforms*).

Visual field data transforms comprise area and volume of visual field loss, lost and preserved area grades, and slope distribution. *Scotoma data transforms* comprise scotoma perimeter/scallopedness and scotoma center location. In collaboration with neuro-ophthalmologists, these analyses have proven to be useful in objectively characterizing visual fields and visual field defects within. Moreover, these analyses permit follow-up assessment of visual fields over time.

In particular we have created an automated and integrated artifact removal, analysis, and characterization system, which, in the absence of clinical experts, analyzes 3D-CTAG visual field data and objectively characterizes visual field defects according to the above devised numerical methods. The *auto-characterization system* for visual field defects in its current form performs the following analyses:

- Removal of input artifacts from raw data;
- Calculation of overall area of visual field loss at each tested contrast sensitivity level;
- Calculation of volume of visual field loss compared to a normal unimpaired hill-of-vision;

- Calculation of slope grades of visual field loss and generation of slope grade histograms for the vertical, horizontal, and combined visual field dimensions;
- Identification and allocation of raw data points to respective scotomas within overall tested visual field;
- Individual analysis of each identified scotoma at each contrast sensitivity level for determination of:
 - Scotoma centers;
 - Scotoma perimeters;
- Determination of shape (i.e., scallopedness of perimeter) of each scotoma at each contrast sensitivity level;
- Output of all above listed data transforms into separate, appropriately documented ASCII-files;
- Automated graphical representation of analysis data via Gnuplot[®] script.

The above outlined analyses are detailed in (You and Fink, 2010b).

2.6 MySQL Database for 3D Examination Data

The visual field test and diagnosis system is supported on the backend by a lightweight relational MySQL database. The database provides the system with a method of persistent storage. The database is designed in accordance with the relational database model, such that all the system's data are stored in tables, and each table in the database represents an element of the system.

The visual field test and diagnosis system is logically divided into three main elements: PATIENTS, MACHINES, and TESTS. Each element is represented in the database as its own table (Fig. 5). The MACHINES table records information concerning each computer system upon which a test may be run. Machine-specific characteristics such as display geometry, dots per inch, resolution, and gamma factor are recorded. In this way, should a new patient undergo a test on a known system, this information will not need to be gleaned again. Likewise, the PATIENTS database table represents user information, such as first and last name, password, usage history, test history, etc. The last major table in the database is the TESTS table, which records the results of each test session, cross-referenced by patient, machine, date, etc.

Consider the case of a known patient undergoing the first test ever on a new computer system. The visual field test and diagnosis system will try to match database records by cross-referencing the patient and machine, resulting in a null match in this case. The visual field test and diagnosis system will then perform methods to obtain the required machine parameters, such as display geometry, etc. Once PATIENT and MACHINE database tables are complete, a new 3D-CTAG test is then performed.

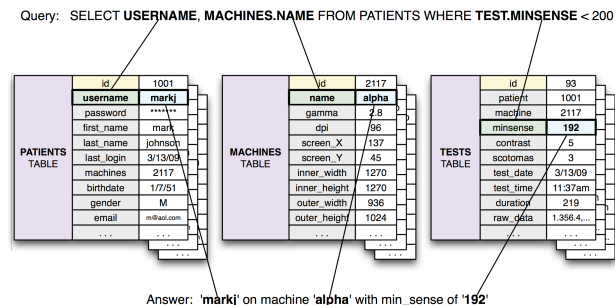


Fig. 5. Architecture of MySQL database for the visual field test and diagnosis system: A database query is depicted that tries to determine if any patients ran 3D-CTAG tests with a minimum contrast sensitivity setting of less than 200. The result ('markj' on machine 'alpha' with min_sense of '192') is possible because of the relational nature of the information stored in the database.

The results of each 3D-CTAG test are recorded in the TESTS database table, cross-referenced by the particular patient and machine (Fig. 5). This provides the review flexibility to determine which users have performed which tests on which machines, etc.

3. ADVANTAGES OVER STATE-OF-THE-ART VISUAL FIELD TESTING

The 3D-CTAG based visual field test system provides several advantages over state-of-the-art standard automated perimetry ("Gold Standard") such as the Humphrey Visual Field Analyzer:

- It measures a 3D rather than a 2D depiction of scotomas, providing unique insight into visual field defects.
- 3D-CTAG also has a superior angular resolution: The 1-degree (or less) grid spacing compared to the typical 6 degrees for state-of-the-art automated perimetry results in a 36 times higher spatial resolution, allowing for an unprecedented characterization of the structure of visual fields and scotomas, typical for various diseases, in 3D.
- Standard perimetry devices are costly and bulky thereby precluding practical application in a military setting. In contrast, 3D-CTAG requires only a touch-sensitive computer screen, which may already be in use for other purposes, and the actual 3D-CTAG software package.
- State-of-the-art automated perimetry is time consuming – on the order of tens of minutes per eye – making it difficult for frequent use. 3D-CTAG in contrast is straightforward to use and tests are performed quickly (4-5 minutes per eye), making frequent retesting feasible for patient follow-up over time.
- Previous studies using the 3D computer-automated threshold Amsler grid test, especially with glaucoma suspect patients (Nazemi et al., 2007), have demonstrated the effectiveness in detecting and visualizing visual field defects: Scotomas,

undetectable by state-of-the-art standard automated perimetry, were repeatedly identified by this test early on.

CONCLUSIONS

Vision is the primary sense and visual information is essential during daily life. There are many conditions that, if undetected or detected too late, may lead to irreversible visual field loss and eventually to blindness, such as glaucoma and macular degeneration, to name the two leading causes for blindness.

The newly developed integrated visual field test and diagnosis system provides medical support personnel both in hospitals and in the field with a non-invasive, accurate, sensitive, and fast visual field test, a relational MySQL database for patient data, and a software package of sophisticated analysis and characterization algorithms to help classify and diagnose visual field defects. The objectively derived visual field and scotoma characterization data will serve as the input for an *automated classification system* for visual field defects, currently under development, that will probabilistically predict ailments using statistical methods and artificial neural networks (e.g., Fink, 2004). The system is capable of detecting and diagnosing conditions affecting the visual performance of warfighters in the field, allowing for the timely application of therapeutic countermeasures.

The visual field test and diagnosis system can be hosted locally on a computer (Intranet/standalone application). Moreover, thanks to the global accessibility of the World Wide Web, it also permits screening and examining patients (e.g., veterans and civilians) on a regional to global scale. As such, the automated visual field test and diagnosis system may assist physicians with an independent second opinion and provide expertise where otherwise not readily available, offering a promising perspective towards modern computer-assisted diagnosis in medicine and telemedicine (e.g., Fink, 2004) in military settings and beyond.

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