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Smart Ophthalmics[©]
An Exemplar of Autonomous Tele-Medicine
Enabling PHM for Human Assets

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Associate Professor

Edward & Maria Keonjian Endowed Chair

AIMBE Fellow, Senior Member IEEE, UA da Vinci Fellow, UA ACABI Fellow

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Aerospace & Mechanical Engineering, and Ophthalmology & Vision Science
Visual and Autonomous Exploration Systems Research Laboratory, University of Arizona, Tucson, AZ



Acknowledgements



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Visiting Scientist and Senior Research Scientist

Visual and Autonomous Exploration Systems Research Laboratory

Caltech/University of Arizona

Keonjian Endowment:

Maria Keonjian



Acknowledgements



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DOD/CDMRP, DOE, NASA, NSF, Industry



\$0.8 Million NSF PFI:BIC grant (Aug. 2014 – Jul. 2017)



Financial Disclosure:



Associated Caltech and UofA Intellectual Property (IP)

Patent number: US 6,578,966

Title: "Computer-based 3D visual field test system and analysis"

Patent number: EP 1276411

Title: "Computer-based 3d visual field test method"

Patent number: US 6,769,770

Title: "Computer-based 3D visual field testing with peripheral fixation points"

Patent number: US 7,101,044

Title: "Automated objective characterization of visual field defects in 3D"

Patent number: US 7,481,534

Title: "Optomechanical and digital ocular sensor reader systems"

Patent number: US 7,762,664

Title: "Optomechanical and digital ocular sensor reader systems"

Patent number: US 9,122,956

Title: "Automated feature analysis, comparison, and anomaly detection"

Patent number: US 9,424,489

Title: "Automated feature analysis, comparison, and anomaly detection"

Several PCT, Patent, and Provisional Patent Applications filed on behalf of Caltech and University of Arizona on *Smart Ophthalmics*®

Ceeable Technologies: Startup Company marketing vision testing Caltech IP
Dr. Wolfgang Fink is Chief Technology Officer





Need and Industrial Relevance



- In **civilian life** there are many conditions that, if undetected or detected too late, may lead to (irreversible) vision impairment and even to blindness, such as:
 - Glaucoma (~76 million worldwide by 2020)
 - Macular Degeneration (~196 million worldwide by 2020)
 - Diabetic Retinopathy (~247 million worldwide by 2030).
- **Military and space 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.
- **Early detection and therapeutic countermeasures will have a significant savings potential in healthcare costs to patients, health insurers, and economies at large.**

Future of “Vision Testing on Earth and in Space” ???



[Image courtesy Keith Manuel]



Motivation for *Smart Ophthalmics*® and its Impact



- Development and deployment of low-cost but high quality mobile examination devices for rapid deployment in the theatre, space, disaster-stricken areas, third world, remote areas, and in hospitals (i.e., at the bedside).
- To provide **quality and comprehensive ophthalmic healthcare** to people who:
 - are **geographically dispersed** (e.g., populations in rural/remote areas)
 - operate/live in **austere environments** (e.g., theatre, space, third world, natural disaster areas)where time, cost, and possibility of travel make access to even adequate medical care difficult if not impossible.
- As a result, significant causes of preventable vision loss, such as ocular trauma, glaucoma, and macular degeneration, may be detected early and treated in time to prevent permanent vision impairment or even blindness.
- M-Health and T-Health harbor significant savings potential in healthcare costs to patients, health insurers, and economies at large.

State-of-the-art Standalone Ophthalmic Instruments



Ophthalmic Microscope



Ophthalmic Slit Lamp



Ophthalmoscope/Fundoscope



State-of-the-art Ophthalmic Instruments vs. Handheld Smartphone-based Examination Devices



State-of-the-art Standalone Ophthalmic Instruments



Ophthalmic Microscope



Ophthalmic Slit Lamp



Ophthalmoscope/Fundoscope

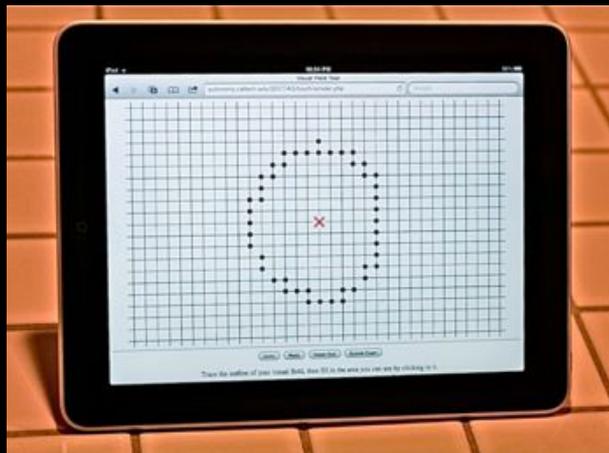


Examples of Miniaturized Portable Smartphone-based Ophthalmic Instruments





State-of-the-art Ophthalmic Instruments vs. Handheld Smart-Tablet-based Examination Devices



What is *Smart Ophthalmics*®?

Example COTS and Custom Smartphone-based Ophthalmic Examination Devices



Example Custom Smartphone-based Smart Ophthalmics Apps®



Server-based/Cloud-based Smart Telediagnostic Capability®



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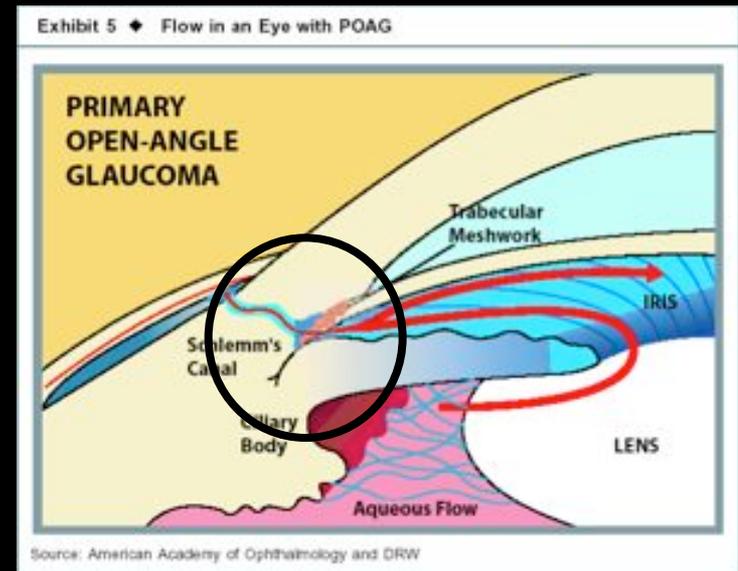
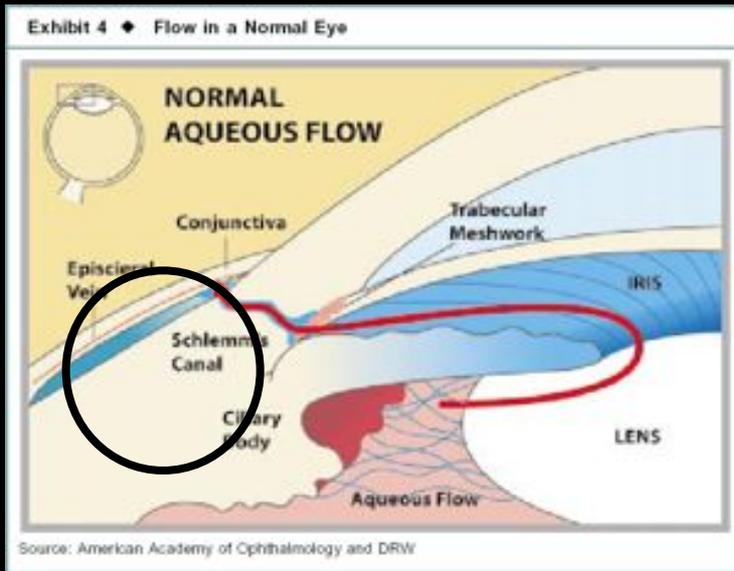
In-Situ Display Examples of Telediagnostic Analysis Results®



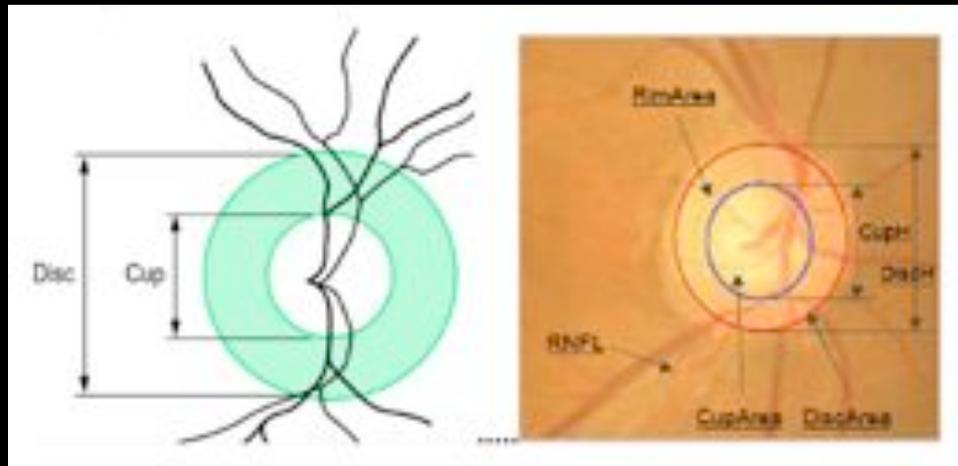
Bring
healthcare
exam to
the patient
rather than
the patient
to the
exam!

Caltech Patents:
#6,578,966
#6,769,770
#7,101,044
#7,481,534
#7,762,664
#9,122,956
#9,424,489
EP #1276411

UofA Patents
pending



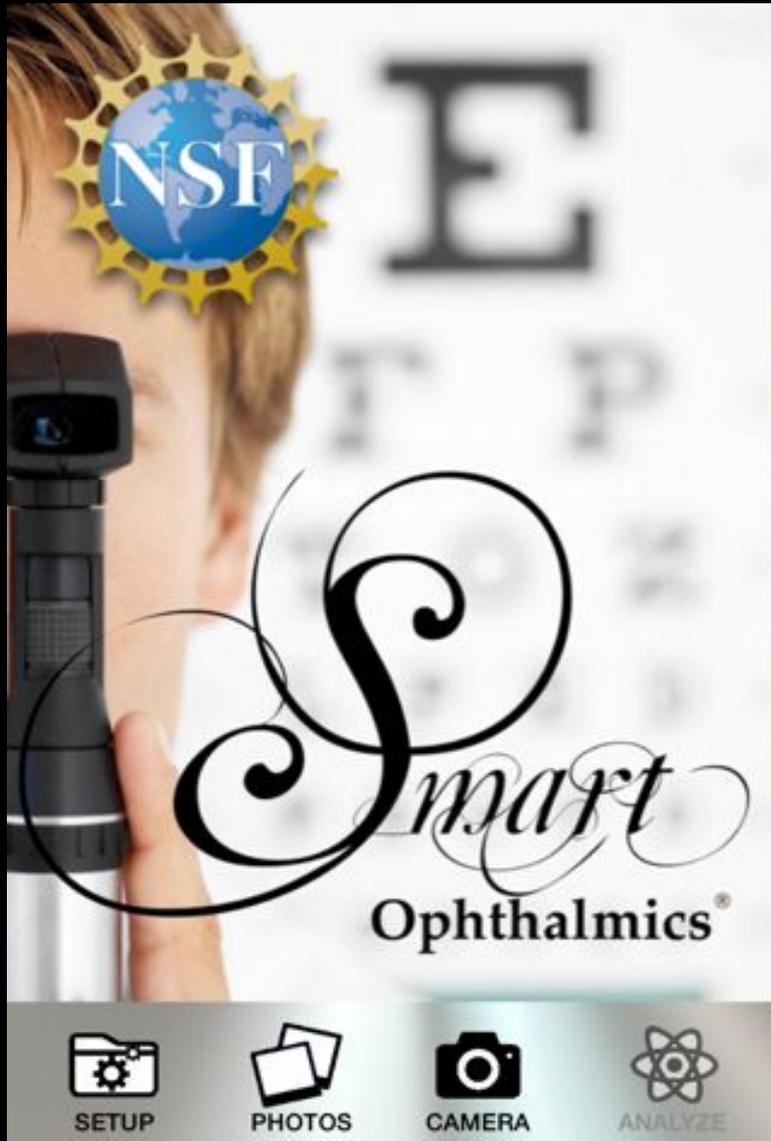
Cup-to-Disk Ratio



<http://www.fiteyes.com/home/understanding-your-test-results>



Smart Ophthalmics[®] Application Example #1: Fundus Imaging & Analysis





Proof of Concept

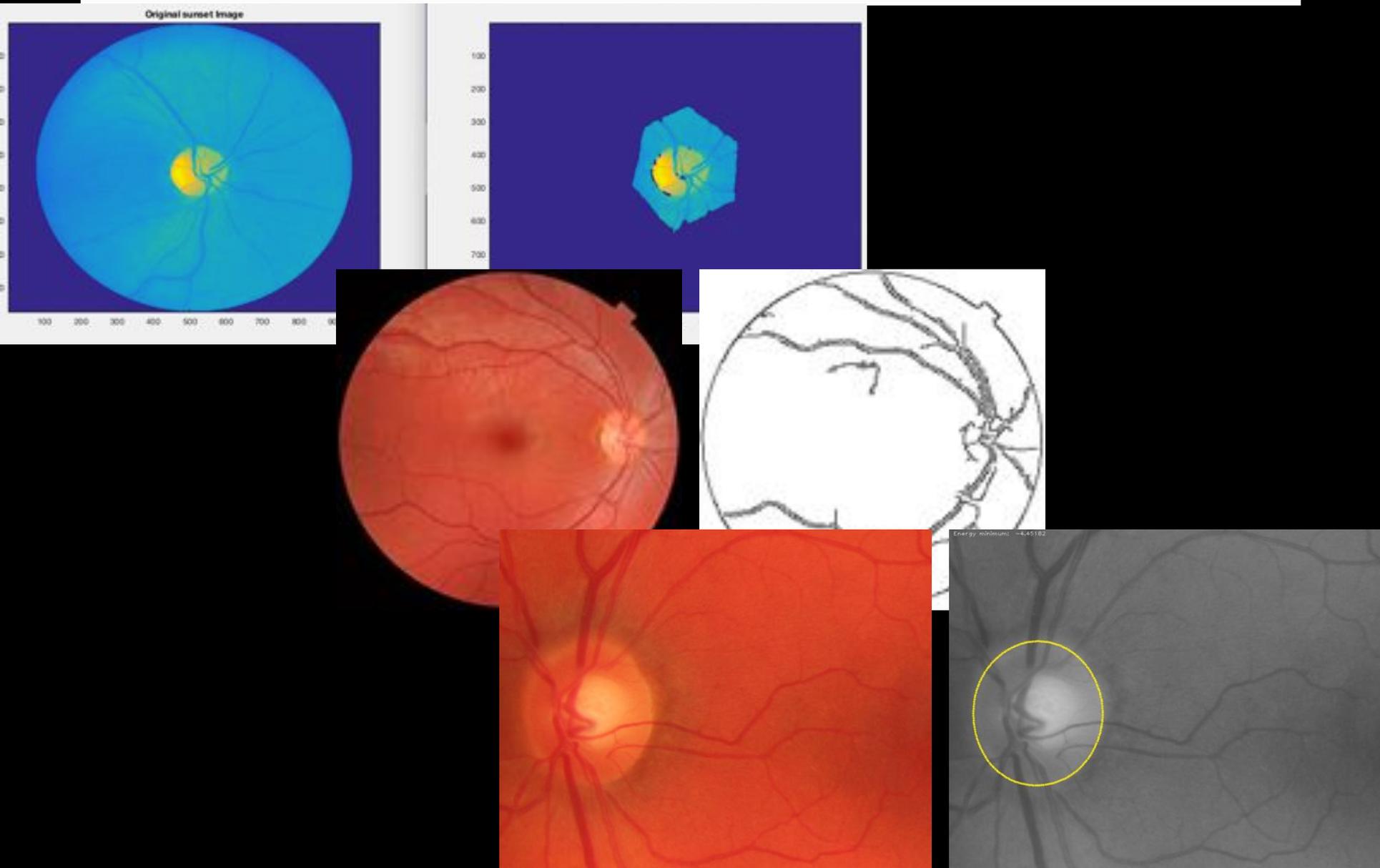




Proof of Concept

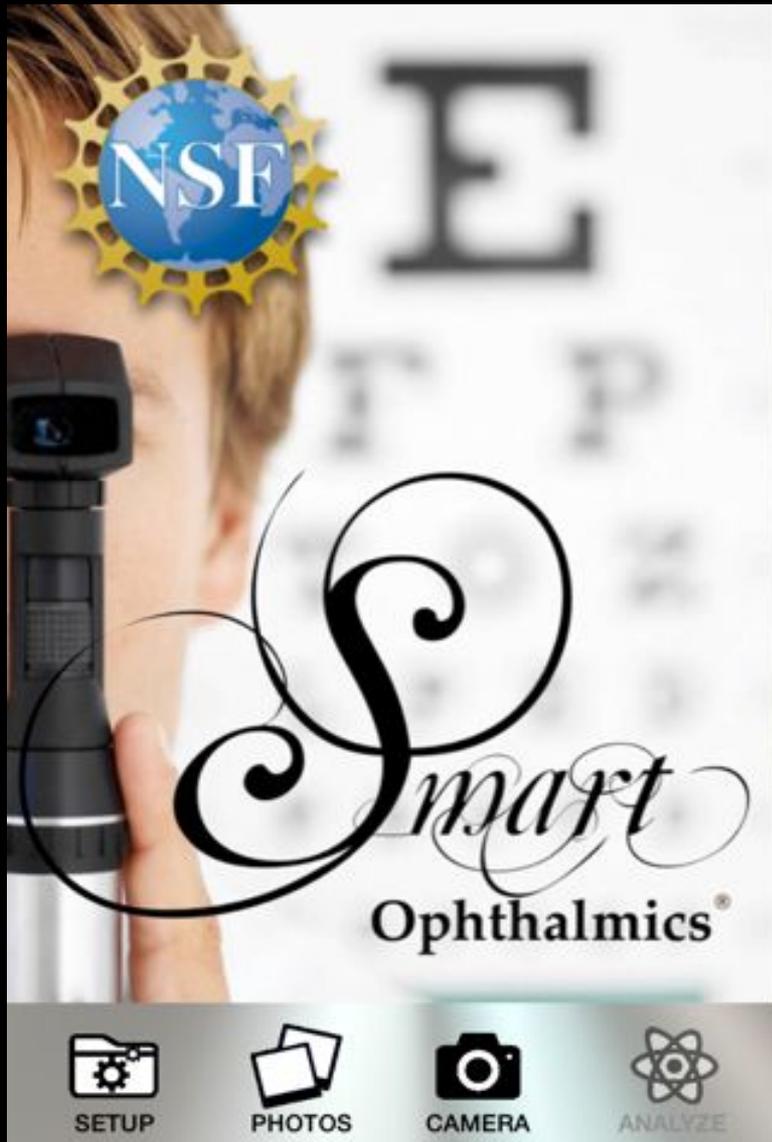


Proof of Concept





Smart Ophthalmics[®] Application Example #1: Fundus Imaging & Analysis





Motivation for *Pupillometry*



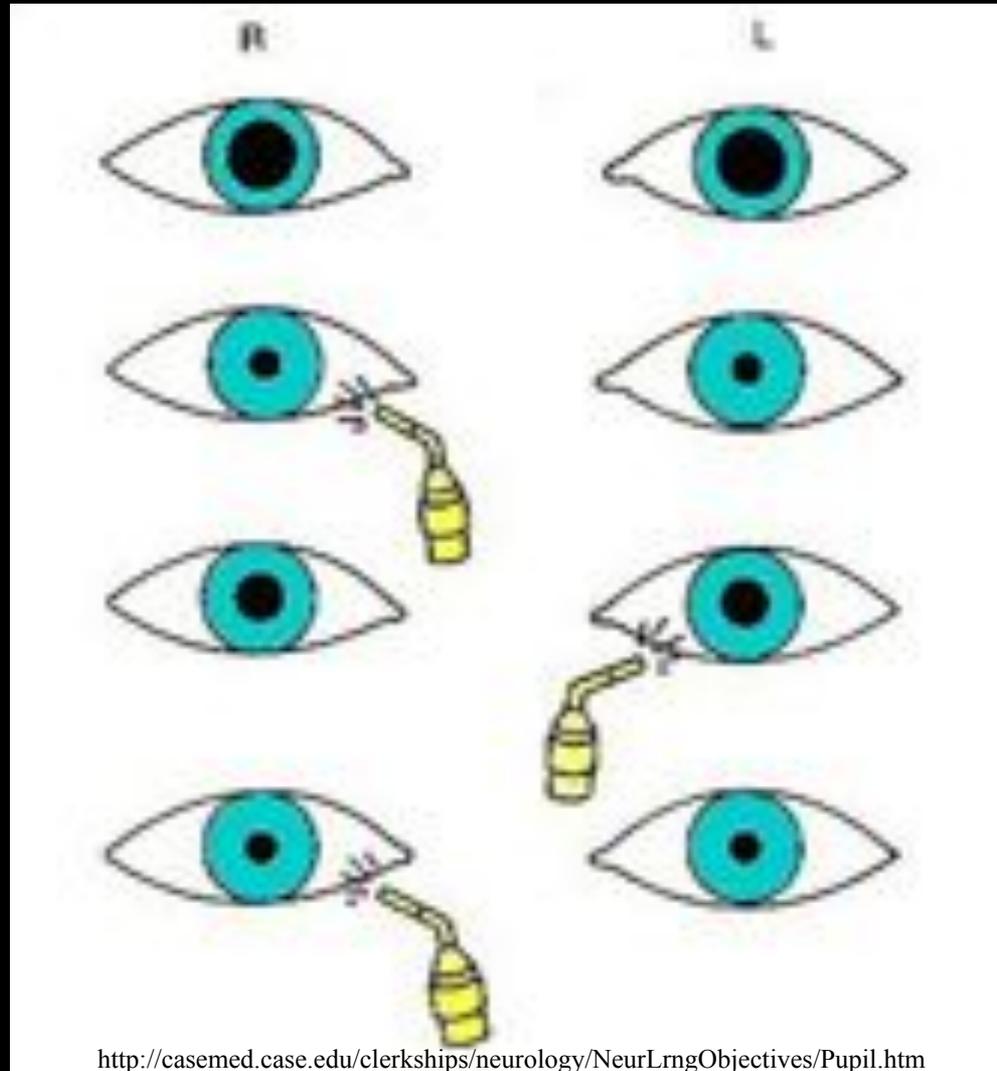
- Monitoring both pupils of a person, merely with a flashlight (so-called **“*swinging-flashlight test*”**), tells first responders whether the person has suffered critical brain damage.
- Monitoring the pupil may indicate drug (ab)use, e.g., cocaine.
- Monitoring the pupillary movement in darkness has the potential to reveal whether a person is fatigued or suffering from sleep disorders (i.e., sleep apnea).
- Pupillometry is non-invasive.

Serious pupillometry usually requires a laboratory setup:

- **Dedicated light-controlled (dark) room + dark adaptation**
- **Chin-head rest**

“Swinging Flashlight Test”

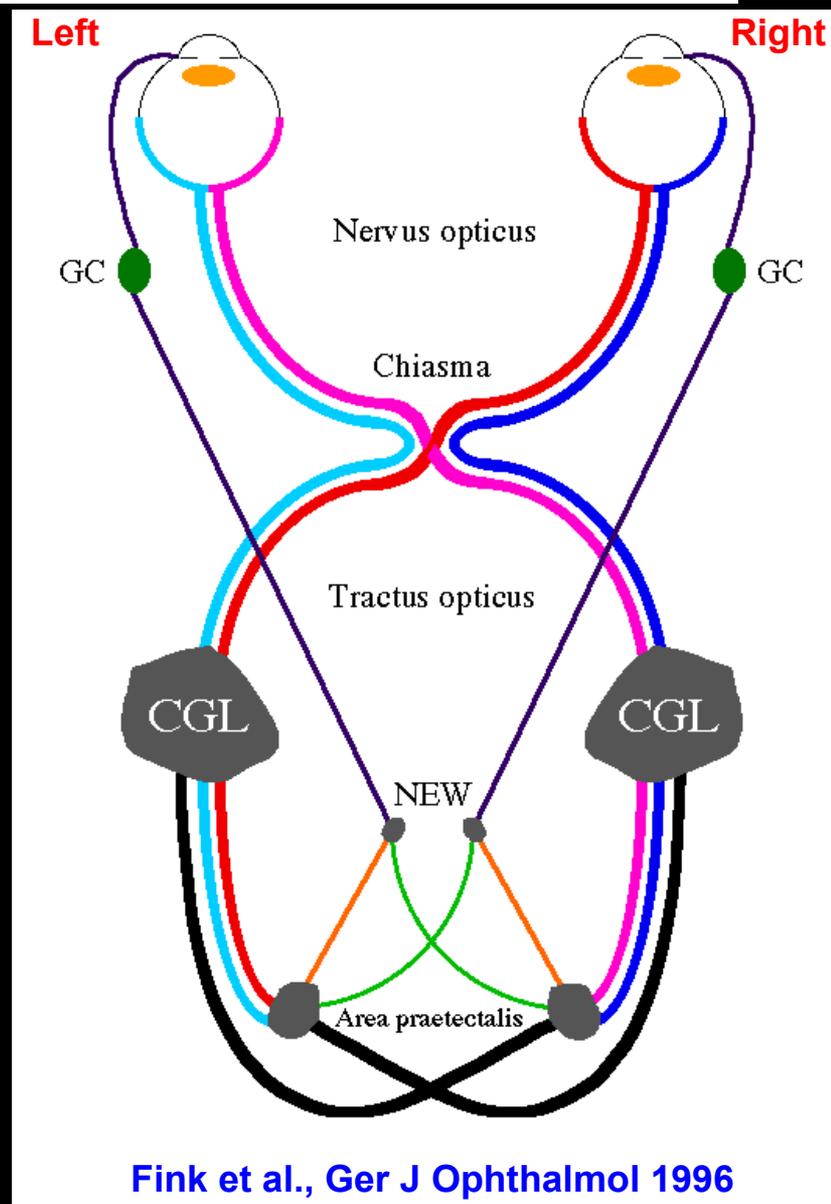
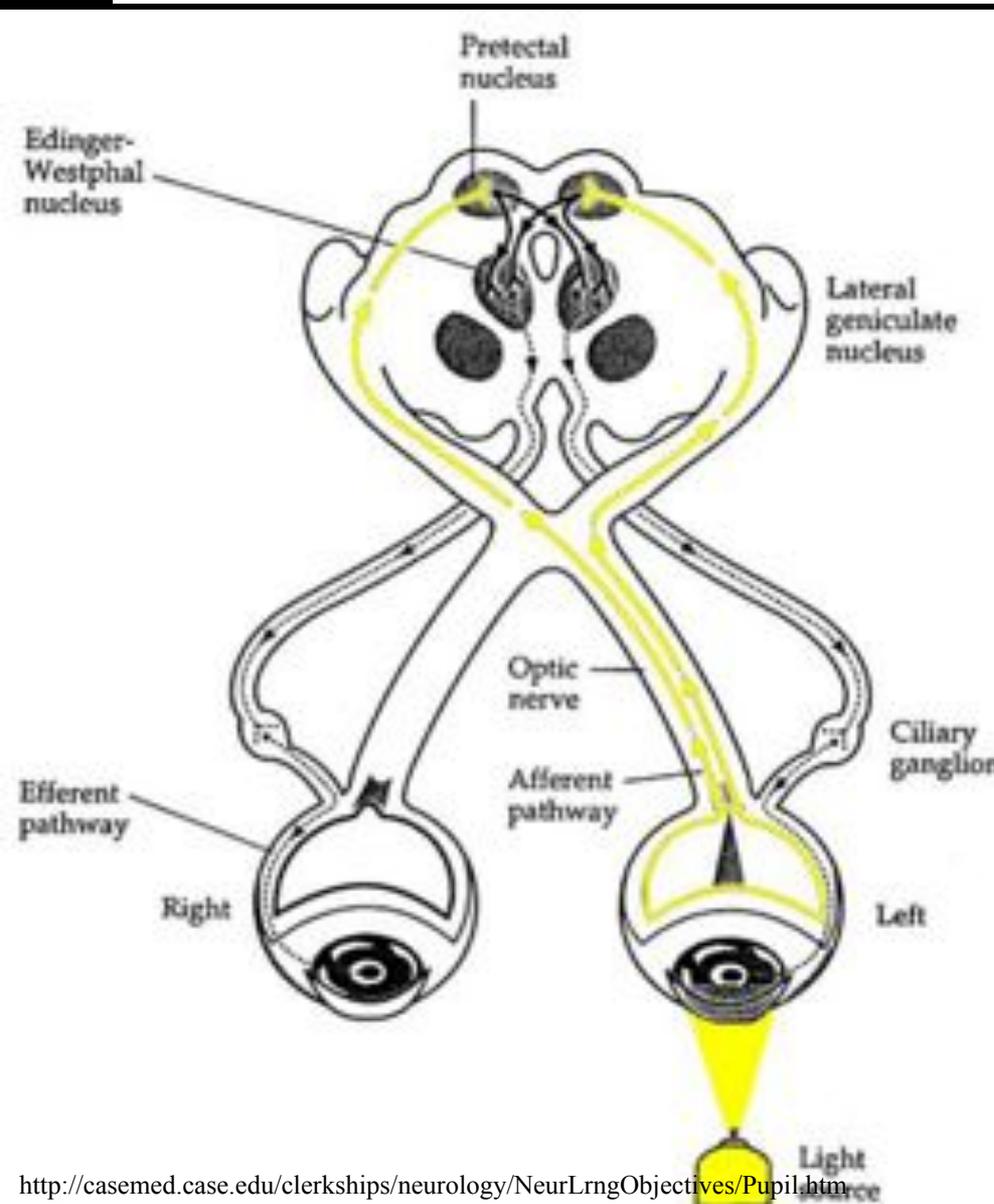
Direct & Consensual Pupillary Reaction



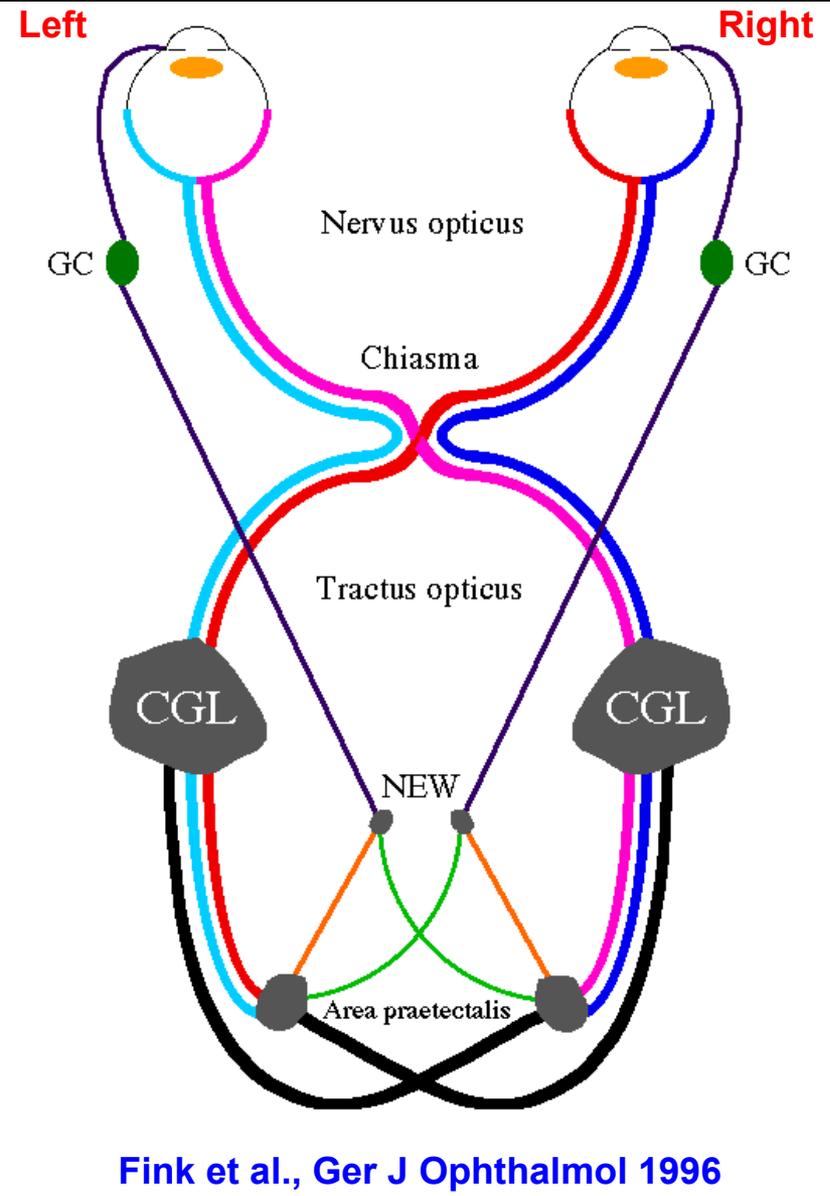
<http://casemed.case.edu/clerkships/neurology/NeurLrngObjectives/Pupil.htm>

RAPD:
Relative
Afferent
Pupillary
Defect

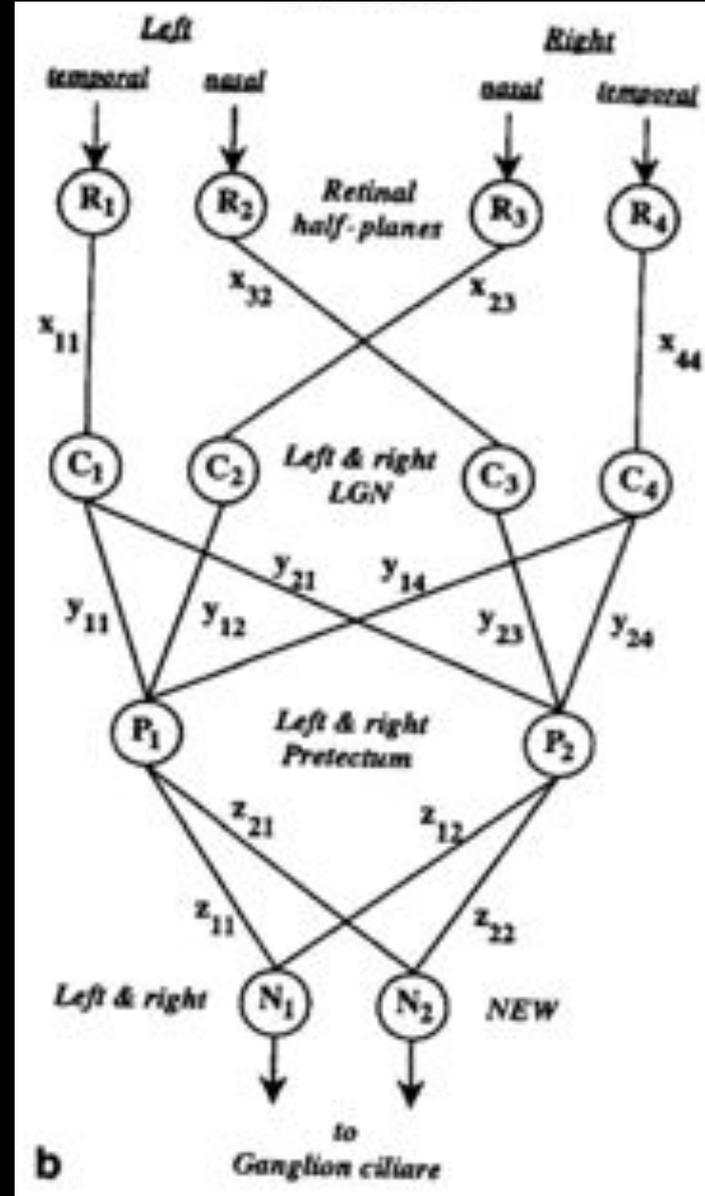
Anatomic Pupillary Pathway



Fink et al., Ger J Ophthalmol 1996

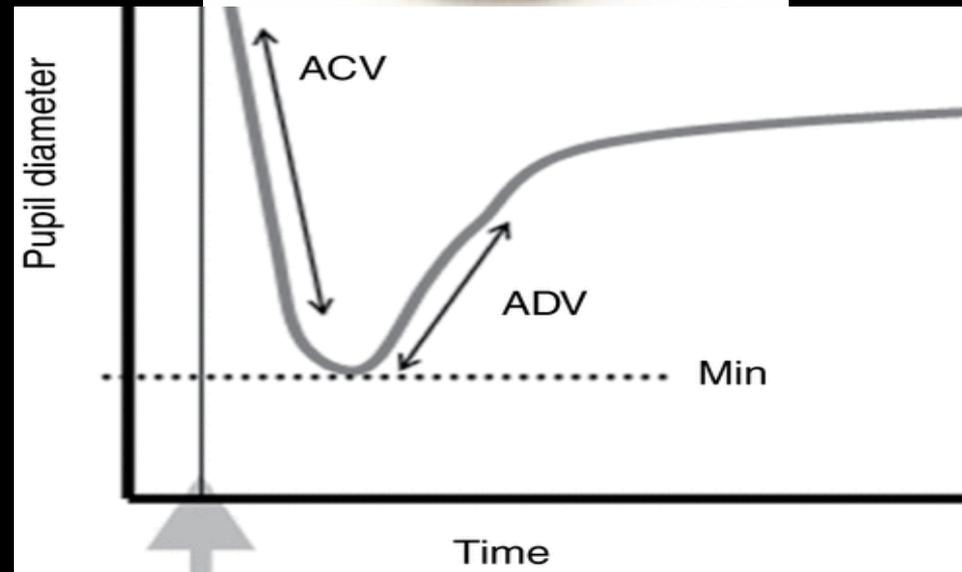
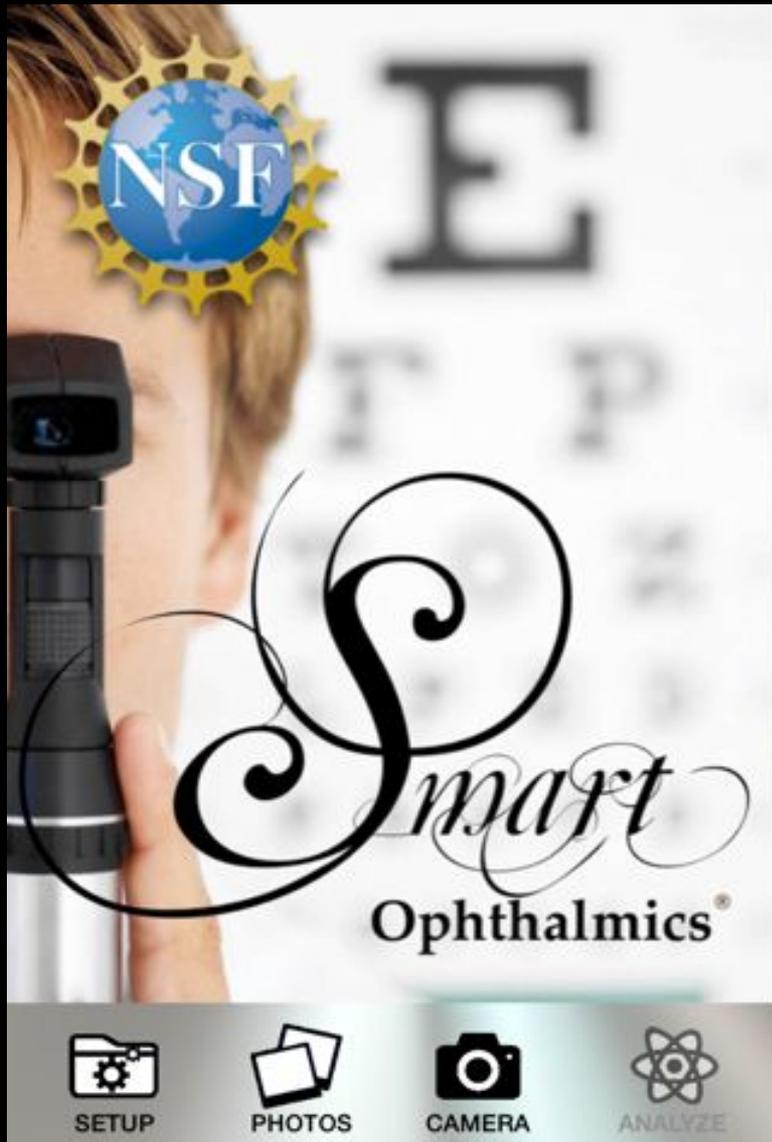


Fink et al.,
Ger J Ophthalmol
1996





Smart Ophthalmics[®] Application Example #2: Pupillometry & Analysis

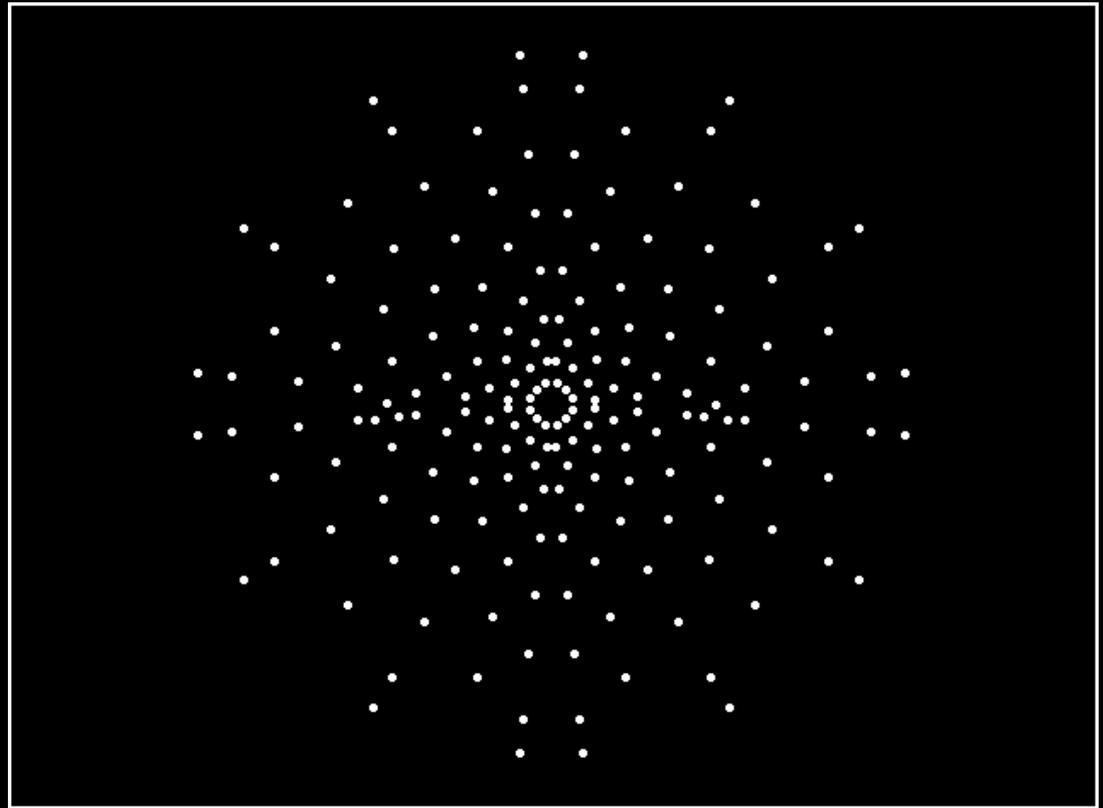




Perimeter (Oculus TAP 2000)



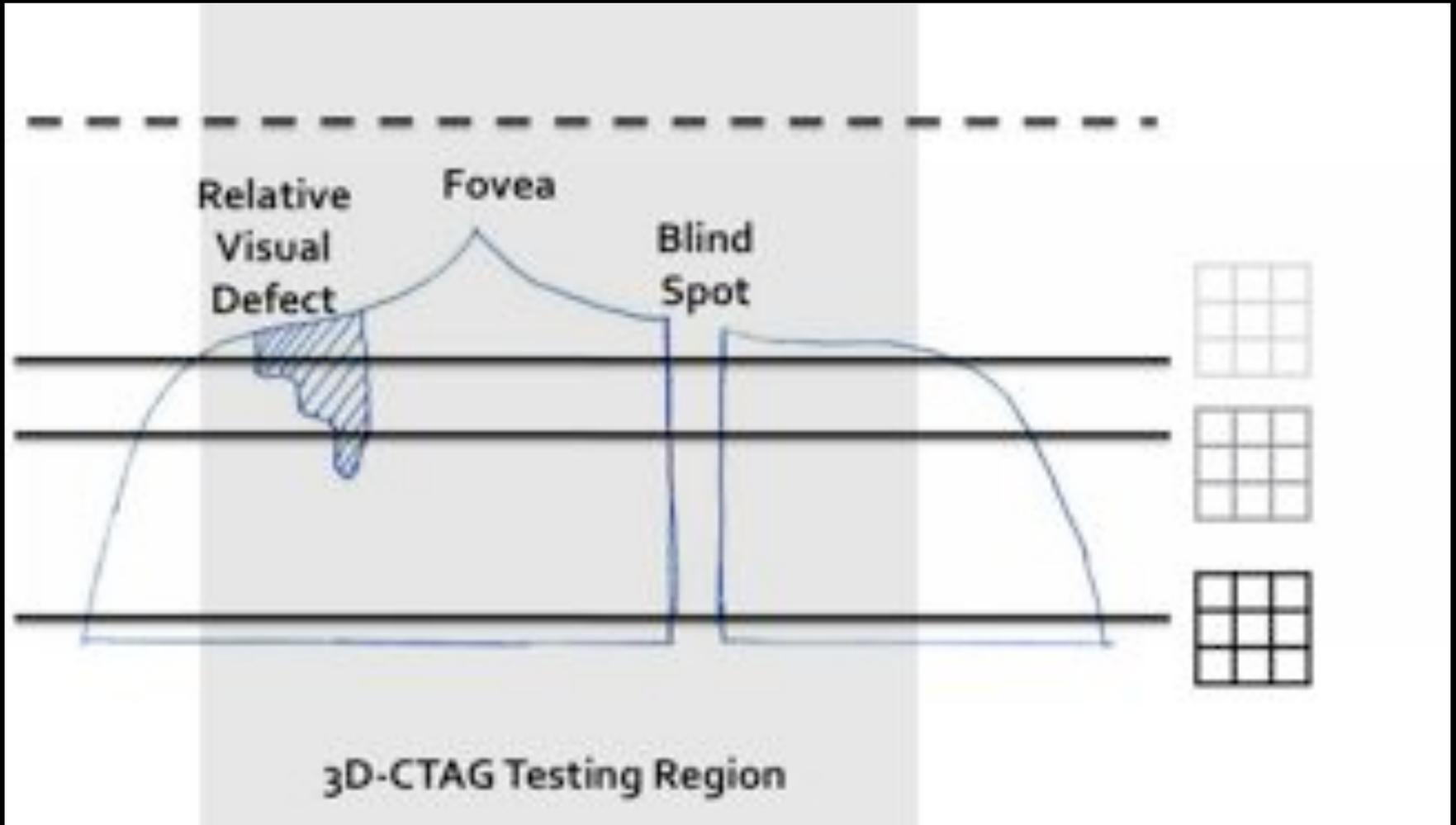
Arrangement of Point Stimuli



CON: Examination time up to tens (40) of minutes, strenuous!

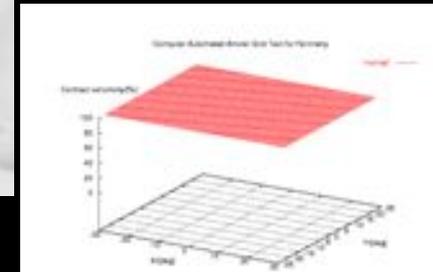
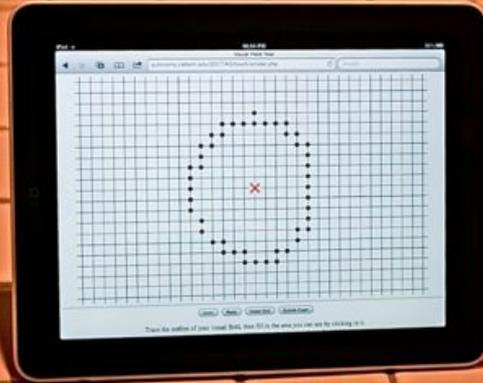


3D-Computer-automated Threshold Amsler Grid (3D-CTAG) Testing Principle

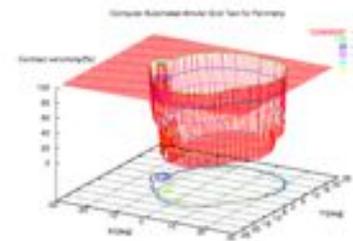




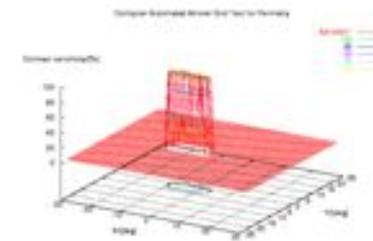
Smart Ophthalmics® Application Example #3: Comprehensive Visual Field Examination



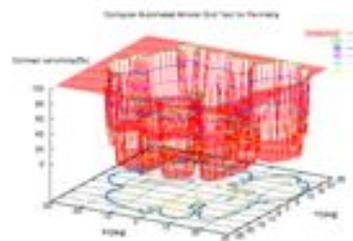
NORMAL



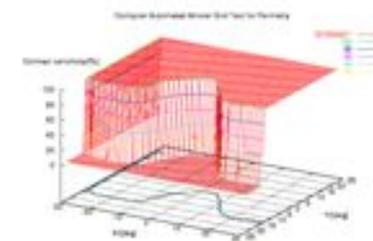
AMD



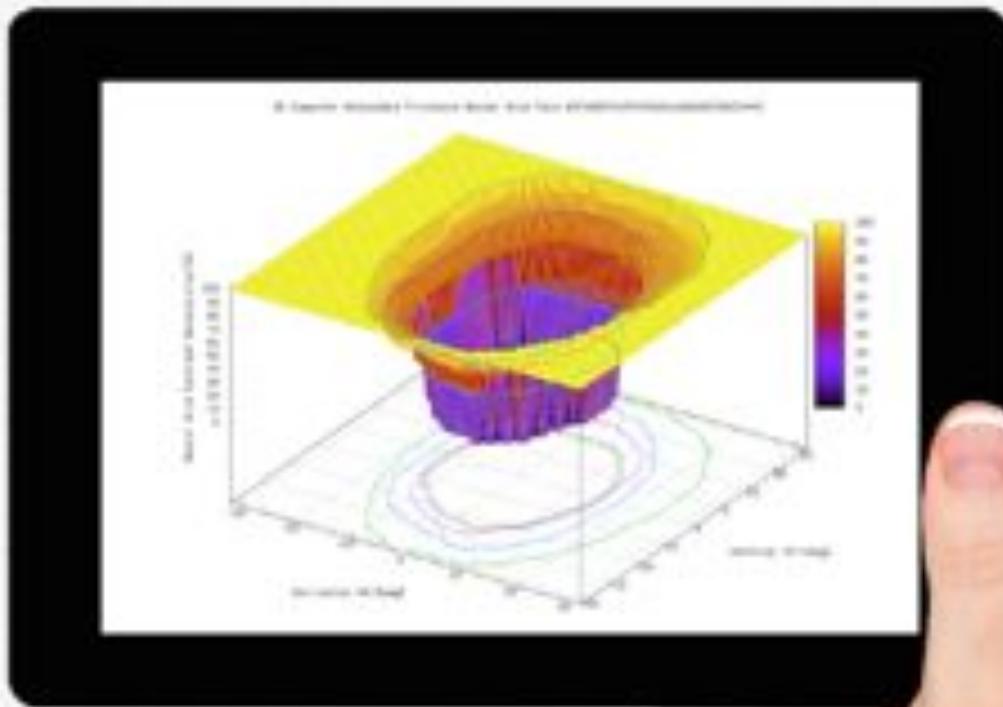
GLAUCOMA



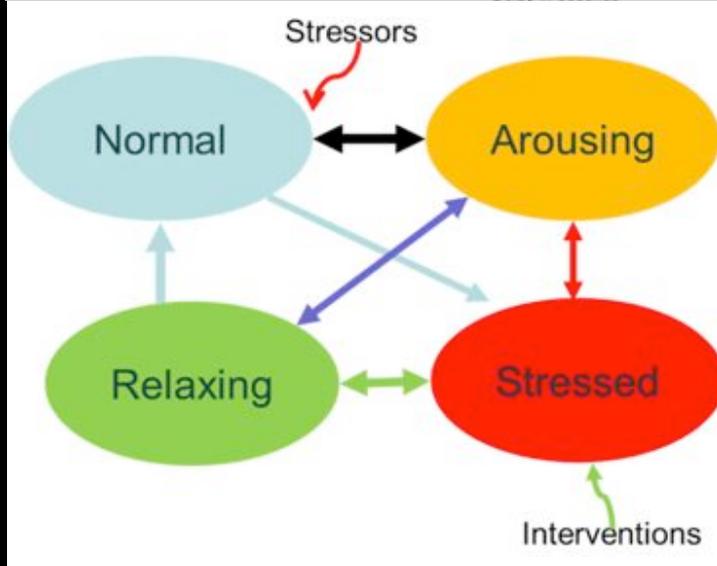
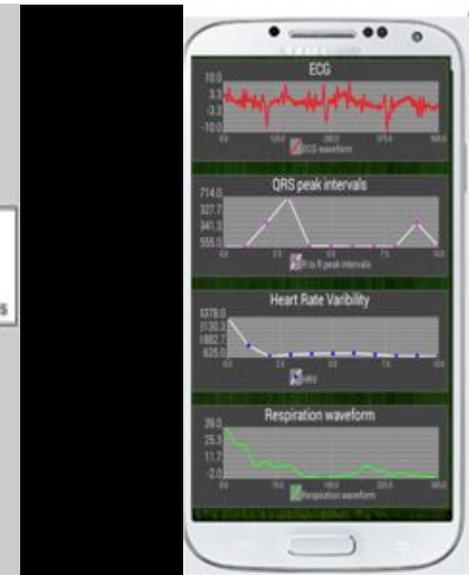
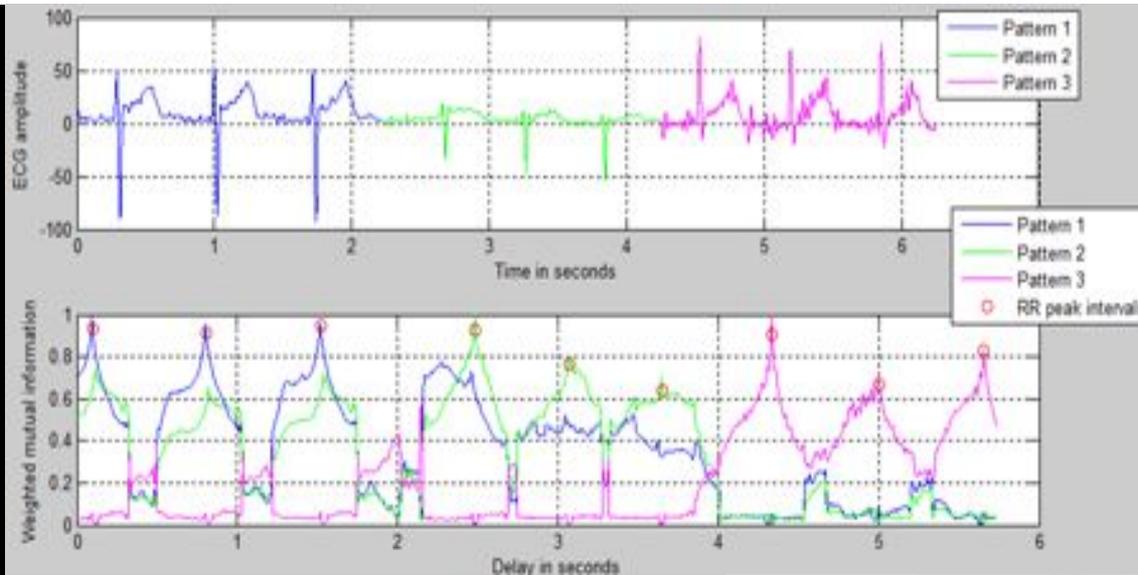
OPTIC NEURITIS



AION



Current & Future Examples: Biofeedback-controlled Wearable Sensors



“Apparatus for Electrical Stimulation of Cell and Method of Use” (UA patent)



NSF I/UCRC:

Informatics and Tele-Health in Medicine (InTelMed)



Website: InTelMed.arizona.edu



Summary & Outlook



Smart Ophthalmics® addresses the following major market needs:

- (1) *Professional medical market*, such as paramedics, medics, optometrists, and ophthalmologists
- (2) *Military market*, as evidenced by a recent Army SBIR Call “Adapting SmartPhones for Ocular Diagnosis”
- (3) *Emerging field of Mobile Health (M-Health)* and growing global markets for *Telemedicine Technologies*
- (4) *Enabler for PHM for Human Assets: all data mining, data understanding, and predictive techniques applicable*
- (5) *Exemplar for other Medical Applications: same framework*



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