Disclosure Information

I have a financial interest in the Blind Spot Amsler Grid and the Waggoner Computerized Color Vision Test. Both helped support the diagnosis in this presentation.

I will not discuss off-label use and/or investigational use in my presentation.

The views expressed in this presentation are those of the presenter and do not necessarily reflect the official position of the AOA, Department of the Navy, Department of Defense, nor the U.S. government.

I became personally involved with color vision deficiencies when my 6 year old son, T.J., came home with a note from his school Nurse notifying me he was colorblind.

T.J. Waggoner in the first grade

Color Vision 101
Validated the Waggoner Computerized Color Vision Test Validation Studies by the Naval Aerospace Medical Institute Pensacola, Florida

**Conclusion:** Uncalibrated Surface Pro 3 Tablet and calibrated PC have similar high sensitivity (98% - 100%) for detecting red/green CVD's as compared to Nagel Anomaloscope.

**Validation of a Tablet-based Waggoner Computerized Color Vision Test**

**Hereditary Color Vision Deficiency**
- 8% of males 1/12 and 0.5% of females 1/200 are born with a red or green color vision deficiency. Sex-linked recessive condition (X Chromosome)
- Protanomaly-red cone peak shifted toward green 1%
- Protan Dichromat-red cones absent 1%
- Deuteranomaly-green cone peak shifted toward red 5%
- Deutan Dichromat-green cones absent 1%
- Hereditary tritan defects are rare 0.008% (Chromosome 7)

**Retinal Cones—Normal Color Vision**
- Red cones
- Green cones
- Blue cones
- Red cones outnumber green cones 2/1
- Red + Green cones outnumber blue cones 10/1

**Where the cone sensitivity curves peak**

<table>
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<tr>
<th>654 nm</th>
<th>533 nm</th>
<th>473 nm</th>
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</table>

Visible Spectrum
What happens in hereditary color deficiency?

- Red or green cone peak sensitivity is shifted.
- Red or green cones absent.

5% of Males

Deuteranomaly
(Starts normal then Green shifts toward red)
1% of Males No red cones; only green and blue cones

473 nm  533 nm

B  G

Protan Dichromate
(There is no red sensitivity curve)

---

Why do colors that look different to us appear the same to color deficient individuals?

---

Normal Color Individual

The amount of stimulation to each cone determines the color you see.
Not surprisingly green (deutan - being the most common deficiency) was the most difficult color to discriminate. Interestingly, red was not the second hardest, rather, it was purple!

Dr. Blake Porter asked 406 color blind subjects “What color is the most difficult for you to distinguish?”

<table>
<thead>
<tr>
<th>Color Vision Test</th>
<th>Example Image</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Pseudoisochromatic Plate Tests (PPP)</td>
<td>![Image of PPP]</td>
</tr>
<tr>
<td>2. Desaturated Plate Color Vision Tests</td>
<td>![Image of D-15]</td>
</tr>
<tr>
<td>3. Hue tests like the D-15</td>
<td>![Image of D-15]</td>
</tr>
<tr>
<td>4. Lantern Color Vision Tests</td>
<td>![Image of Lantern]</td>
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</tbody>
</table>

Different types of color vision tests

1. Pseudoisochromatic Plate Tests (PPP)  
2. Desaturated Plate Color Vision Tests  
3. Hue tests like the D-15  
4. Lantern Color Vision Tests

![Diagram of color vision tests]
Well, there are three important elements when designing such a test.

• You must use the correct confusion colors (hues)

• The colors must be of equal brightness

• The colors must be the correct saturation

Does anyone in the audience know how to design a pseudoisochromatic plate (PIP) color vision test like the Ishirara?

Use the Chromaticity Diagrams for each deficiency to determine which confusion colors to use.

Deutan Confusion Colors

Protan Confusion Colors

Tritan Confusion Colors

Green and brown are common confusion colors, so are yellow, orange, and burgundy. These colors are used to make up the test plate.
Brightness and saturation need to be the same.
Both the green on the right and the brown on the left have 50% Brightness.

Both the green on the left and the brown on the right have 60% brightness

Both the green on the left and brown on the right have 70% brightness
The three greens with different brightness match the three browns. Put them together and you have a color vision test plate. Now we know which colors, brightness and saturation to use, how do we insure the printing process?

You need to utilize a Color Swatch and a Spectrophotometer to profile the printing press. Spectrophotometer used to measure and tell you the name of the color and where it is located on the Chromaticity Diagram.
Heidelberg Printing Press

You print several dozen color swatches

Color swatches being verified with spectrophotometer to profile the printing presses.

Are we ready to print the color vision test book?

Yes!
Computerized Color Vision Testing
"THE NEW PARADIGM"

• All three tests based on cone and contrast sensitivity.
• The color of the target is visible to a single cone type.
• You decrease the target contrast in relationship to the background in steps until target threshold recognition is reached.
• Color deficient subjects reach threshold before color normals.
• The threshold level determines the degree of the deficiency.

Cone Contrast Test (CCT) by Dr. Rabin

Colour Assessment Diagnosis Test (CAD) by Dr. Barbur

Compare Test Results

Settings

- Diagnosis after test
  - Yes
  - No
- Display ICD-9 or ICD-10
  - ICD-9
  - ICD-10
- Upload your logo (recommended 150dpi resolution)

Folder #5

Open
Advantages of Computerized color vision tests

- Detects all three types of color vision deficiencies – protan, deutan, and “tritan”.
- Determines the degree of the color vision deficiency – mild, moderate, severe.
- Tests are self administered and standardized
- Test plates are automatically randomized each time the test begins to prevent memorisation.
- Provides automatic scoring and saves test results on your computer.

Disadvantages of Computerized color vision tests

- Monitors may need to be calibrated.
- More expensive than printed color vision tests

At this time I would like to introduce Lt. Cmdr. Kyle Dohm

- Dr. Dohm is going to talk about performance-based testing of a color deficient helicopter pilot and a cargo plane loadmaster. He will also touch on Navy color vision research and current Navy/Marine Corps color vision standards.
- Dr. Dohm is an active duty Naval Aerospace Optometrist and serves as the Assistant Officer in Charge and Ophthalmology Department Head at the Naval Aerospace Medical Institute (NAMI) in Pensacola, FL. The institute is a center of excellence for aerospace medicine, employing aeromedically trained specialists in a number of fields.
- NAMI’s mission is to maximize performance and survivability of the warfighter by supporting Navy and Marine Corps aviation units through expert aeromedical consultation services as well as development and application of aeromedical standards.
- NAMI serves as an authoritative consultant to a host of other government agencies and NATO allies, including NASA, Home Land Security, and the United State Coast Guard to name a few.

Color Vision in Military Aviation

- Required to accurately identify warning lights and color visual displays
  - Airfield and shipboard lighting, colored smoke in combat, ground target identification, aircraft formation lights, etc.
  - Laser eye protection glasses and protective visors may worsen color vision problems
Tests used in US Naval Aviation

- Always use best correction (spectacles or contact lenses) without tints for test administration
- Pseudo-Isochromatic Plates (PIP) = 12/14 pass (given binocularly for aviation)
  - Waggoner® CCVT (www.waggonerdiagnostics.com)
    - normal or mild CVD in red, green or blue is passing (given binocularly for aviation)
  - Rabin® CCT (www.innova.systems/eye-disease-management/rabin-cone-contrast-test-overview)
    - ≥ 55 in all 3 cone types in each eye to pass (monocularly)
- Colour Assessment & Diagnosis (CAD, City University London, www.city-occupational.co.uk/cad)
  - ≤ 6 each cone type in each eye to pass (monocularly)
- FALANT (Farnsworth Lantern) = 9 of 9 or 16 of 18 correct to pass [designed to pass mild CVD]
  - As of 01 January 2017, no longer used for new accessions; grandfather previously designated USN/USMC members who can only pass FALANT

Performance-based Assessment

- Practical test of color vision to demonstrate operational ability
- Administered by flight surgeon, aircraft type instructor, and/or other pertinent experts (i.e. NATOPS officer)
  - Identification of cockpit displays, lighting, gauges, safety indicators, shipboard and landing field lighting, ALIS lights, map markings (hazards, airspace coordination areas, routes)
  - Smoke color identification is also recommended for Marine aviators
  - Control group of at least two like aviators with normal color vision is recommended
  - Commanding Officer endorsement
Performance Based Testing of a Color Deficient UH-1 Helicopter Pilot and a C-40 Loadmaster

- At initial flight physical both failed PIP, but passed FALANT
- At subsequent flight physicals, aviators are still required to pass all vision standards
- Both failed the CV standard for PIP & FALANT
- Waggoner CCVT revealed the pilot had a moderate protan (red) deficiency and the loadmaster had a severe deutan (green) deficiency
- Both were grounded until their functional ability could be determined via a performance-based evaluation

The pilot had to quickly identify and describe various items in two different helicopter simulators (AH-1Z and UH-1Y)

1. External:
   a. ALDIS Lamp Signals
   b. Smoke markers
   c. Ship deck lights
   d. Runway lighting

2. Internal (Cockpit):
   a. System gauges
   b. Warning/caution/advisory indications
   c. Moving maps (terrain banding, overlays, etc.)

3. Classroom (items on paper maps):
   a. Hazards/obstacles
   b. Airspace coordination area
   c. No fire area
   d. Route markings

UH-1Y SIM

- 10 items - red coloration on gauges:
  - Subject: 90% accurate
  - Controls: 100% accurate

- 5 items - red objects on the FLIR imagery:
  - Subject: 20% accurate
  - Controls: 100% accurate

- 5 items - red items on the moving maps:
  - Subject: 10% accurate
  - Controls: 100% accurate
AH-1Z SIM

- 5 colors - various colors of smoke:
  - Subject: 60% accurate
  - Controls: 100% accurate

- 8 items - various runway lights:
  - Subject: 88% accurate
  - Controls: 100% accurate

- 3 items - aircraft lighting:
  - Subject: 33% accurate
  - Controls: 100% accurate

- 10 items - simulated boat environment:
  - Subject: 58% accurate
  - Controls: 100% accurate

F-35 Lightning II

- 6 items - ALDIS lamp signals:
  - Subject: 33% accurate
  - Controls: 100% accurate

- 17 items - map colors and markings:
  - Subject: 82% accurate
  - Controls: 100% accurate

1967 UH-1D Huey

2018 CH-53E Super Stallion
The loadmaster had to quickly identify and describe various items internal and external to a C-40

1. External:
   a. Airfield/Aircraft lighting
   b. ALDIS Lamp Signals

2. Classroom:
   a. Paper charts with color markings

3. Internal:
   a. System gauges
   b. Color radar imagery
   c. Moving-map mechanisms (terrain banding, overlays, etc.)

---

External to C-40:

- 5 items - runway lights:
  - Subject: 60% accurate
  - Controls: 100% accurate

- 6 items - ALDIS Lamp signals:
  - Subject: 50% accurate
  - Controls: 100% accurate

- 5 items - map colors and markings:
  - Subject: 100% accurate
  - Controls: 100% accurate
Internal to C-40:

- 10 items - red coloration on gauges:
  - Subject: 90% accurate
  - Controls: 100% accurate

- 5 items - color radar imagery:
  - Subject: 100% accurate
  - Controls: 100% accurate

- 5 items - colored items on moving map:
  - Subject: 100% accurate
  - Controls: 100% accurate

Compared to the control groups, both the pilot and loadmaster demonstrated frank difficulties with the performance-based assessment:

- Substantially less accurate

  - Slower reaction times were also noted by the observers

Proper color identification is vital aspect of safe flight operations!

- Compared to the control groups, both the pilot and loadmaster demonstrated frank difficulties with the performance-based assessment:
  - Substantially less accurate

  - Slower reaction times were also noted by the observers

“Color Safe” for Naval Flight Duties

- Normal and Mild CVD perform very similar in terms of reaction time & accuracy
  - Moderate and Severe CVD show drastic decline in both

- Subjects’ moderate protan and severe deutan color vision deficiencies = less accurate and observably slower on certain color-oriented tasks
  - Waiver to continue Naval flight duties was not granted for either case

- Computerized Color Vision Testing correlated well with Performance-based assessment
NAMI is not always the Whammy

- T-44 pilot failed PIP, FALANT, and CCVT tests at intermediate flight training
- Waggoner CCVT and Robin CCT (55 OD, 50 OS) corroborated his moderate deutan CVD
  - A “mild/borderline” moderate CVD
- Able to demonstrate accurate and prompt identification on the various tasks during a performance-based CV assessment, on par with the control group
- Granted a waiver for continued duties as a Naval Aviator

Operational/Clinical Relevance

- Performance-based color vision assessments are a back-up for failed clinical CV tests
- Can be arranged for a variety of aviation tasks as well as other occupations
  - Simulators/Cockpit
  - Ground-based tasks
  - Computer/Classroom
  - Specific tasks at the place of work/job site
- Controls lend credibility
- Allows experienced aviators/workers to demonstrate safety and capability

US Navy Color Vision Research

NAMRU Dayton, OH

and

The Naval Aerospace Medical Institute
Pensacola, FL
Validation Studies by the Naval Aerospace Medical Institute (NAMI) in Pensacola, FL

1. Validated the Waggoner Computerized Color Vision Test

2. Validation of a Tablet-based Waggoner Computerized Color Vision Test

Conclusion: Uncalibrated Surface Pro 3 Tablet and calibrated PC have similar high sensitivity (98%-100%) for detecting red/green CVDs as compared to Nagel Anomalouscope.

NAMRU Dayton study: “Assessment of Color Vision Screening Tests for the U.S. Navy Special Duty Occupations” which tested the reaction time and accuracy of CVD subjects compared to color normal subjects.

PAPI and Missile Targets used in the study:

- PAPI Landing Lights
- F/A-18 Missile Icons
- AIM-9P Landing Lights

The type and degree of CVD was determined using three computerized color vision tests:

1. Waggoner Computerized Color Vision Test (Waggoner CCVT)
2. Cone Contrast Test (Rabin CCT)
3. Colour Assessment & Diagnosis (CAD)

Study Results:

1. Mild CVD subjects performed very similar to those with normal color vision in terms of accuracy and reaction time.
2. Moderate and Severe CVD subjects had a slower reaction time and made significantly more identification mistakes.

There are a multitude of occupations that require normal color vision:

- Electricians
- Firefighter Paramedics
- All Branches of the Military
- Law Enforcement/Police Officers
- Nautical Engineers
- Maritime Industry

Imagine the following situation: A police officerino witnesses a theft and reports it to the police station. "The suspect is about 5' 10" tall, wearing an orange shirt, green or possibly brown pants, and his hair could be blue or dark purple."
Characteristics of congenital versus acquired color vision deficiencies

<table>
<thead>
<tr>
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<td>On set after birth color; vision previously normal</td>
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<tr>
<td>Type and severity remains the same</td>
<td>Type and severity can change with time *Predominantly starts as a tritan</td>
</tr>
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</tr>
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<td>Normally a Healthy individual</td>
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Disease processes associated with “Acquire” Color Vision Deficiencies:

- **Chronic illnesses** like Alzheimer’s disease, diabetes mellitus, glaucoma, leukemia, liver disease, chronic alcoholism, macular degeneration, multiple sclerosis, Parkinson’s disease, sickle cell anemia and retinitis pigmentosa.
- **Accidents** or strokes that damage the retina or affect particular areas of the brain/eye.
- **Medications** such as antibiotics, barbiturates, anti-tuberculosis drugs, high blood pressure medications and several medications to treat nervous disorders.
- **Industrial or environmental chemicals** such as carbon monoxide and lead.
- **Age** — in people over 60 years of age physical changes occur which might affect a person’s capacity to see colors like “cataracts”.

Color Vision Test Results

**CASE #1**

1. **Computerized Color Vision Testing (CCVT)**
   - Rt Eye: Normal Color Vision
   - Lt Eye: Abnormal Color Vision- severe deutan & severe tritan

2. **Ishihara**
   - Rt Eye: Normal Color Vision
   - Lt Eye: Abnormal Color Vision, 2/14 correct

3. **Nagel Anomaloscope**
   - Rt Eye: Normal Color Vision +/− 6 from 46.5
Suspected Hemangioma of left optic nerve

VOTE

Acquired
Or
Congenital
Color Vision
Deficiency?
### Characteristics of congenital versus acquired color vision deficiencies

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### Color Vision Test Results

1. **Computerized Color Vision Testing (CCVT)**
   Binocular results – moderate deutan and severe tritan.

2. **Ishihara**
   Binocular – Red/green color deficient 10 out of 14

3. **D-15**
   Monocular Tritan CVD
VOTE
Acquired
Or
Congenital
Color Vision
Deficiency?

Reference: A Family with Congenital Deutan and Tritan Defects by P.R. Kinnear

Characteristics of congenital versus acquired color vision deficiencies

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CASE #3

1. Computerized Color Vision Testing (CCVT)

Rt Eye: Mild deutan and moderate tritan

Lt Eye: Normal color vision
Acquired Or Congenital Color Vision Deficiency?

Characteristics of congenital versus acquired color vision deficiencies

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**Last Case # 4**

The CCVT recorded a moderate deutan and mild tritan CVD in 2014. In 2016 it recorded only a moderate deutan CVD – no mild tritan CVD.

1. 2007 - A blister of subretinal fluid (SRF) formed causing a neurosensory retina detachment (NSD) in the macula of the right eye, just inferior of fovea. It resolved over a 3 months period. BCVA improved from 20/30 to 20/20.

2. In 2011 CSR recurred. This time there was no blister and the neurosensory retinal detachment was temporal to the optic nerve head which is “atypical”. BCVA 20/20

3. The 2014 Photo is similar to the 2011 drawing. BCVA 20/20

4. The 2016 Photo indicates overall improved state of healing/location. BCVA 20/20*

In 2011, 2014, & 2016 the optical coherence tomography (OCT) images remained constant over a 5 year period. All three displayed a very thin area of subretinal fluid (indicated by the three red arrows) adjacent to the optic nerve head. The fovea was “not” a bullous blister.*
Metamorphopsia was measured using the Blind Spot Amsler Grid in 2014 and 2016. No change was noted.*

Visual field testing using the Humphrey Visual Field Analyzer in 2011, 2014, 2016 indicated there was no change in the relative scotoma.*

VOTE

Acquired
Or
Congenital
Color Vision Deficiency?
Characteristics of congenital versus acquired color vision deficiencies

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REIMBURSEMENT FOR COLOR VISION TESTING

- The reimbursement CPT Code for extended color vision testing 92283 - Medicare Physician Fee 2015 Schedule allowable is $56.49. Medicare allowable amounts are adjusted in each area by local wage indices; other payers set their own rates.

- You must provide good documentation that supports reimbursement for color vision testing.
  a. Physician’s order – Extended color vision testing to support diagnosis of central serous retinopathy (CSR) – estimate extent of vision loss.
  b. Findings – acquired tritan CVD.
  c. Assessment, diagnosis – new onset of CVD associated with CSR.
  d. Impact on treatment prognosis – monitor changes/return of color vision indicates CSR resolution, letter to family physician.
  e. Doctors signature – Terrance Waggoner O.D.

So, how can we help or aid those who are color vision deficient?
There are dozens of helpful Colorblind Apps – Simply Google “Color Vision Apps”

Say Color  Color Reader  ColorBlind Assistant  Spectrum Assistant

Take colors from the world

Color Blind Pal
Windows 10 Home has a setting that will change the color of the screen to help those who are colorblind. Go to Settings; Search “color filter”; then select the type of color vision deficiency you have. Colorblind individuals see things more clearly by pressing the Windows Logo key+Control+C which will toggle the color filter.

EnChroma glasses
How well do EnChroma glasses work?
Some other misc helpful resources available online

- www.colorvisiontesting.com/online-test
- www.waggonerdiagnostics.com (free demo download of WCCVT for 30 days)
- www.testingcolorvision.com/index.php
- www.color-blindness.com (free eBook, color blindness simulator, app, FAQs, etc.)
- www.cvdpa.com (Color Vision Defective Pilots Association)