“I can see clearly now!”
Operational Based Vision Assessment

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USAF School of Aerospace Medicine
Operational Based Vision Assessment (OBVA)

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ICASM
12 November 2018
Operational Based Vision Assessment

The Centennial Anniversary of the USAF School of Aerospace Medicine and the History of 100 years of US Army/Air Corps/USAF Aviation Color Vision Testing

12 Nov 2018

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Disclaimer

• The views expressed are those of the author and do not necessarily reflect the official policy or position of the U.S. Air Force, the Department of Defense, or the U.S. Government
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Introduction to the Operational Based Vision Assessment Laboratory
OBVA Program Purpose

• Are medical vision standards, and test methods, developed in early-mid 1900s applicable today?
  – Initial flying standards developed pre-WWI; most still used today
  – Electronic displays, enhanced vision systems, head-mounted displays, remote vision systems, etc.

• Develop vision standards and tests to support human performance optimization
OBVA Laboratory Research

OBVA Simulated color-coded situation awareness display

OBVA high-bay simulation facility. CAD drawing generated by OBVA personnel.

OBVA KC-46 remote vision system simulation. Photo by USAFSAM media department.

Unmanned aerial vehicle ground control station color displays. Source: DIMOC.
OBVA Collaborative R&D

- International, industry, academic and tri-service collaboration
  - Enhanced mutual reliance, cost sharing, augmented data collection
  - Technology transition and development
Celebrating a 100-Year Legacy
USAF School of Aviation Medicine (USAFSAM)
Celebrating a 100-Year Legacy 1918-2018
USAFSAM

- Established January 1918 as school and laboratory at Hazelhurst Field, New York
- Graduated first Flight Surgeon class – May 1918; also trained Navy FS through 1939

1923 – First international student (Brazil) – now from 133 countries

Moved to Brooks and Randolph Field, San Antonio, Texas, 1926 – 2010

School of Air Evacuation integrated into USAFSAM in 1944

Moved to AFRL and Wright-Patterson AFB, Ohio – 2010

Education – Consultation – Research
USAFSAM Facilities

- **USAFSAM**
  - 3 Buildings
  - 520,000 ft²
  - 55 Laboratories
  - 47 Classrooms
  - 2 Auditoria
  - 1 High bay + outdoor facilities with 7 aircraft trainers

- **Research Altitude Chamber**

- **Occupational & Env. Health**

- **Epi Laboratories**

- **High Bay**

- **Bioenvironmental**

- **3 C-STARS sites, 1 SMART site**

- **Centrifuge**

- **MIST Studio**

- **OBVA**

- **Classroom**

- **Franzello Aeromedical Library**

- **Next-Generation Sequencers**
Celebrating a 100-Year Legacy
USAF Color Vision Testing
The Lagerlunda collision and the introduction of color vision testing

• 15 November 1875, estate of Baron Lagerfelt, Östergötland, Sweden two trains collided head on.
• The northbound train missed “obvious color signals” and proceeded onto the single track with another train inbound on the same track.
• Ophthalmologist Frithiof Holmgren suggested that the engineer of the northbound express, had been color blind.
• The accident undoubtedly had a central role in the introduction of color vision testing by European and North American railroads and the transportation industry.
• Yet, neither train engineer had been tested previously and neither survived to be tested.

Historic color vision transportation mishap

Lagerlund train site a few days after the collision
Color Vision (in the A.E.F.)

“We consider that (color vision) is most important for the aviator to be able to recognize colors rapidly in a reduced light and in a fog.”

Wilmer and Berens
Aviation Medicine in the A.E.F.
“Aviation Medicine in the A.E.F.”

(Wilmer And Behrens, Chap 6, Feb 1920)

• Primary test
  – Jennings Self-Recording Color Test (1896)
    • Modified Holmgren wool test
    • Perforated cardboard score sheet with red (rose) / green confusion colors

• Secondary tests
  – Holmgren wool test (1877)
  – Williams lantern (1892)
  – Stilling plates (1877)
  – Colored lights at 20 feet
Army Air Corps (1935 – 1940)

• Considerable color vision research at Army Air Corps School of Aviation Medicine (SAM)
  – Louise Sloan (Sloan-Rowland)
• Primary and **only** test
  – Ishihara plates, 1st edition (1917)
    • If you failed, you were rejected
Dr Shinobu Ishihara, Japanese medical officer, introduced the world's most well-known color blindness test.

- Later became a General Officer
- Principles similar to Stilling plates

**Ishihara Plates (1917)**

Normal

Deuteranope
Published “No Cures for Color Blindness”

• No “Cures” for color blindness, including
  – Colored lights / colored filters

• Noted improved scores with practice
  – PIP plates are “obviously not suitable for repeated use…”

• Standardized illuminant (true “daylight”)

• Dispelled myth that vitamin A improved color vision

• Lack of understanding of important precautions concerning PIP use and interpretations

Problem with PIP Plates

• Pseudoisochromatic (PIP) tests (Linksz)
  – “…not meant to be a scoring device, [they were intended ] to be a separator of wheat from chaff, of color normal from color defectives.”
  – “Test improvements [were] meant to improve diagnostic facility [not scoring of different types of color defectives]”

Arthur Linksz, MD
“An Essay on Color Vision”
WWII Color Vision Testing Strategy:

Employ two types of color vision tests

- Basic screening test
  - Simple, rapid, reliable separation of color normal and color defective: PIP test

- Secondary test (if fail basic screening test)
  - Reliable and valid estimate of degree of defects
    - Anomaloscope is best

- Reserve test (to counter PIP memorization)
  - Sole use of Armed Forces
American Optical (AO) Plates (1940)

46-plate AO test compiled for U.S. Armed Services (1st ed)

- Plates “stolen” from Stillings-Hertel and Ishihara
  - “It was wartime and both tests were alien property”
  - Some optotypes were “Japanese or German looking“ so suspect
  - Ishihara/Stillings hard to obtain in the vast numbers needed
  - No authors names; no credits given

- Comprehensive test instructions
  - Backlighting with true daylight
  - 2-3 feet testing distance
  - Prompt response (2 sec)
    - “‘Tarrying’ indicates certain amount of color deficiency”
  - Never allow to hold or touch plates
  - Errors never revealed

[Image of test book cover]
American Optical (AO) Plates

• 46-plate AO set (First Edition)
  – “Too long”
  – Failed some normals
  – Not much in the way of diagnostics

• Shortened versions produced
  – 1942: 19-plate “first abridged” version (L. Sloan)
    • 4 or more errors = color defective
  – 1945: 36-plate “second edition” (D. Farnsworth)
    • Germanic optotypes (letters) changed to block letters
    • Uniform background used
    • Removed “white rivers”
    • Improved colorimetrics
  – 1946: 20-plate Navy version
SAM-CTT (1943)

• School of Aviation Medicine Color Threshold Test (SAM-CTT)

• Devised to measure ability to distinguish colored signal lights existing at the time
  
  – 8 different colored lights (2 reds, 2 yellows, 2 greens, 1 blue, 1 white)

  • Provided color “close to limiting” standards of Bureau of Standards for Aviation Colors
Additional Developments (1942 – 1947)

- 1942: Holmgren wool test discontinued
- 1944: 46 plate version of AO discontinued
- 1944: Abridged version of AO developed by Sloan discontinued
- 1944: 1st edition of Dvorine PIP printed
- 1945: Abridged 38 plate version of AO developed by Farnsworth
- 1946: 20 plate version of Farnsworth adopted by US Navy
- 1946: Original Farnsworth Lantern (FALANT) developed for Navy signalman
- 1947: Birth of the USAF
USAF (1947 – 1952)

• Primary Tests
  – Ishihara PIP (8th edition)
  – Original American Optical Company PIP
    (19 plate “2nd abridged” version)

• Adjunct Tests (“color safe”)  
  – SAM-CTT
Developments (1953 – 1959)

- **1953:** 2nd edition of Dvorine printed
  - 15 plates (1 demo plate)
- **1953:** Armed Forces - National Research Council’s Vision Committee
  - Adopts Sloan, Judd, and Farnsworth’s 15 plate AOC as the “official” USAF test (AF-CVT)
- **1954:** FALANT adopted for Navy aviation
- **1954:** Dvorine (2nd edition) approved by A.M.A.
- **1959:** 2nd edition Dvorine approved by military
“In this country there was one test published that is worth serious consideration, the Dvorine Test.”

Arthur Linksz, MD

“An Essay on Color Vision”
**USAF (1959 – 1995)**

- **Primary tests (standard color vision tests: VTS-CV)**
  - AO
  - Dvorine (2\textsuperscript{nd} edition)
  - Both had 15 plates (1 demo plate)
    - Passing criteria: 10 or more correct out of 14

- **Secondary tests (if failed PIP)**
  - Farnsworth lantern (FALANT)
    - Applicants rejected if failed
    - SAM-CTT could be used only for trained aircrew and flight surgeons
  - 1989: SAM-CTT discontinued due to faded and irreplaceable filters
  - 1991: Routine FALANT production stopped
  - 1993: USAF dropped test as a qualifying test: Unavailability and undependable results
Color Vision Caper – 1994

Memorization of PIPs or “SCAMMING the PIPs”
### PIP I Sensitivity

**Percent of Color Defectives That Fail Test**

**PIP I Passing Criterion:** 12 of 14 correct

**USAF Pilots & Aircrew (n=1329)**

<table>
<thead>
<tr>
<th></th>
<th>PIP I</th>
<th>PIP II</th>
<th>PIP III</th>
<th>F2</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>96%</strong></td>
<td>78%</td>
<td>65%</td>
<td>88%</td>
<td></td>
</tr>
</tbody>
</table>

**USAF Pilots Applicants (n=1279)**

<table>
<thead>
<tr>
<th></th>
<th>PIP I</th>
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<th>F2</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>78%</strong></td>
<td>47%</td>
<td>53%</td>
<td>76%</td>
<td></td>
</tr>
</tbody>
</table>

Fail to detect 22%!
1998-2018: all USAF pilot applicants required normal color vision

- MFS centers at (Brooks AFB and USAF Academy)
- Must pass 4-test screening battery (1998-2011)
- No waivers granted
Pilot applicants

- Screened in field by PIP I
  - Ishihara, Dvorine, or original AO
- If pass PIP I, Applicant goes to Medical Flight Screening (MFS)
  - PIP I  (R/G; congenital)
  - PIP II  (B/Y; some R/G; acquired)
  - PIP III (R/G + B/Y; mixture)
  - F2     (R/G + B/Y)
- Color vision test took over 20 min to perform
Pilot applicant

- If fail any of the 4 tests
  - Complete color vision evaluation (CAD, D15, FM 100 hue)
  - Anomaloscope is final determining test

No waivers allowed for entry
USAF (2011 – present)

• 2011, the USAF introduced a new computer-based color vision screening test - the Rabin cone contrast test (RCCT)
  – Replace pseudoisochromatic plate (PIP) tests
  – Demonstrated to very reliably screen for color deficiency (Rabin et al, 2011; Hovis, 2016)
## Cone Contrast Test (CCT Staircase)

### Colour Assessment and Diagnosis (CAD)

### Computerized Color Vision Test (CCVT)

### Oculus Anomaloscope

<table>
<thead>
<tr>
<th>Subjects evaluated</th>
<th>Cone Contrast Test (CCT Staircase)</th>
<th>Colour Assessment and Diagnosis (CAD)</th>
<th>Computerized Color Vision Test (CCVT)</th>
<th>Oculus Anomaloscope</th>
</tr>
</thead>
<tbody>
<tr>
<td>98 Total Subjects</td>
<td>48 Color Normal, 50 Color Deficient (based on test battery)*</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sensitivity (Color deficiency correctly diagnosed)</td>
<td>100.0% (50/50)</td>
<td>100.0% (50/50)</td>
<td>96.0% (48/50)</td>
<td>96.0% (48/50)</td>
</tr>
<tr>
<td>Specificity (Normal color vision correctly diagnosed)</td>
<td>100.0% (50/50)</td>
<td>100.0% (50/50)</td>
<td>96.0% (48/50)</td>
<td>98.0% (49/50)</td>
</tr>
<tr>
<td>Nature of deficiency correctly diagnosed (i.e. deutan vs. protan)</td>
<td>100.0% (50/50)</td>
<td>94.0% (47/50)</td>
<td>78.0% (39/50)</td>
<td>96.0% (48/50)</td>
</tr>
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*Based on test battery.
USAF High Precision Color Testing

• USAF Academy identified the current Rabin color test as:
  – “better than any previous color test”
  – “but the most significant reason the cadets don’t trust cadet standards”
    Lt Col Ruth German, DO, Mar 2015

• OBVA developed a new high fidelity color test 2014-2016
• Partnered with industry on CRADA (Konan medical) 2016-2018
• Validated on >2000 USAF pilot applicants compared to Rabin CCT, UK CAD, anomaloscope
• Six peer review presentations/publications
• USAFSAM ACS perfected interface/algorithm
• Adjusting for mild CVD (2018)
Konan CCT-HD

New USAF Color test

AVT research – Konan Medical CCT-HD CRADA
Photo provided by Konan Medical, used with permission
Rabin CCT Distribution (OD, OS)

- RCCT distribution
  - Monocular scores (0 – 100)
- L-cone: 2,182 eyes tested
- M-cone: 2,168 eyes tested
- CVN Mean, SD
  - L: 97.2, 4.2
  - M: 97.7, 3.8
- Protans: 0.92%
- Deutans: 3.8%
- Ceiling effect: >80% of USAF pilot applicants score 100
- Floor effect: All scores below 40 unreliable
- Arbitrary score of 55 includes significant number of moderate color deficient
Benefits of CCT-HD -- *No Ceiling Effect; No Floor Effect*

- M cone (green) test results distribution
- The bottom horizontal axis identifies contrast sensitivity and the top horizontal axis shows the equivalent CCT scores.
  - The normal pass/fail criterion (1.65 logCS, 75 CCT score) is shown by the solid line.
  - The maximum measurable contrast sensitivity in for the RCCT (1.9 logCS, 100 CCT score) is shown using the dotted line.
- Contrast Sensitivity values to the right of the dotted line (~86% of normal observers (90% male, 95% female) cannot be measured using the RCCT.

RCCT scores all these results at 100% due to ceiling effect.
USAF Color Tests Summary
Digital Color Tests

Waggoner CCTV

Konan CCT-HD

Colour Assessment and Diagnosis (CAD)
“I can see clearly now!”
Questions?