A Performance Comparison of Color Vision Tests for Pilots Requirement

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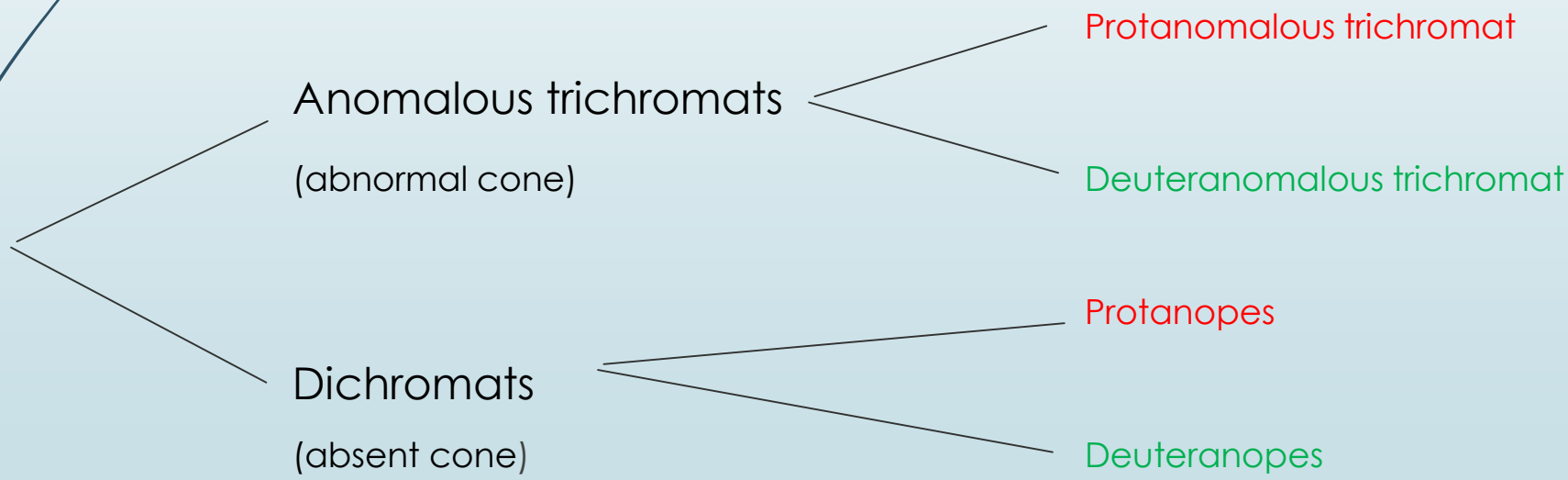
Introduction

- **Color-deficiency**
  - 9 % of men and 0.5 % of women
  - 1.5 to 3% of military pilots candidates (Air Force)

    → 11 to 13% of ophthalmologic incapacity



Maille M, Crepy P. Les nouvelles normes visuelles en aéronautique militaire. Médecine Aéronautique Spatiale. 1990;XXIX:261–2

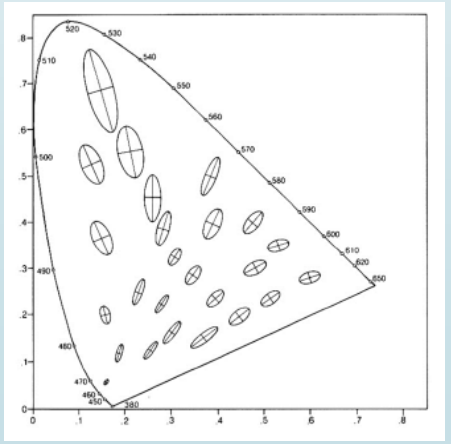
Introduction

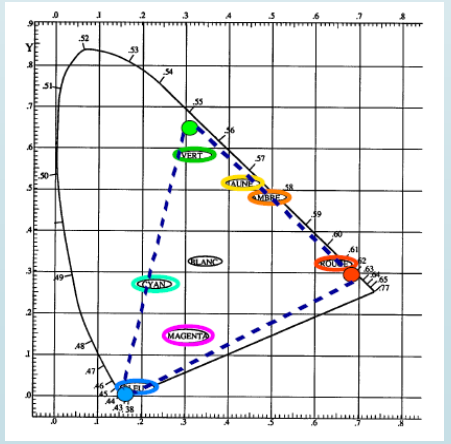
- **Color use in aviation**
  - access to information : first symbol, text, or sound.
  - PAPI (Precision Approach Path Indicator) is the more critical
  - Other are less problematic :
    - Parking lights
    - Taxiways
    - Regulatory lights of airplanes.

Introduction

Color is more and more present in cockpits,

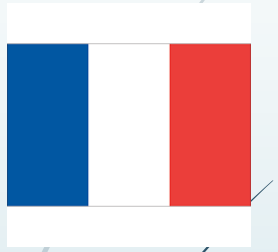
- "glass cockpits“ : LCD screens with electronic process of many instruments of flights, whose display is multicolored.
- Colors choice : free to the manufacturer
- Located in different areas of confusion according to MacAdam ellipses





Introduction - rules

- In France : Decree of 27 January 2005 and follow the regulations of EASA



- pass the **Ishihara** 24 plate test
(first 15 plates identified without error or hesitation)
- 'normal trichromat' at the **Nagel anomaloscope**

Normal Color vision

- identification without mistake or hesitation of colored lights in **Beyne lantern**
(presented at 5 meters for 1 second with 3 minutes of arc aperture)
- matching range is 4 scale units or less to the **Nagel anomaloscope**

Color vision Safe

Introduction - rules

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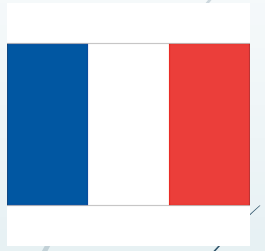

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} **Color vision Safe**

- Secondary tests in other countries


In UK : Holmes-Wright lantern or CAD test


In Germany : Anomaloscope


In USA : Farnsworth and Optec lanterns or Titmus vision test


In Canada : lantern test or Farnsworth D15


In New Zeland : Farnsworth and Holmes-Wright lanterns, Farnsworth D15 or CAD test

Introduction

- **Lanterns :** no more commercialized (only Fletcher-Evans CAM lantern)

- **Aim of the study**

To assess the abilities of 8 color vision tests

for screening, qualification and quantification of red / green hereditary deficiency,

to improve and to adapt the current color selection protocols.

Methods

- Prospective study
  September 2016 to May 2017
  CPEMPN of Percy hospital, in Clamart (France).

- INCLUSION
  - **Color-deficient subjects**: addressed for a failure in reading the Ishihara plates by
    - military selection center
    - or Aviation Medical Examiner.
  - **Color vision normal subjects** : healthy volunteers.

- EXCLUSION
  - BCVA less than 6/10.
  - Sunglasses or tinted contact lenses.
  - Ophthalmologic pathology (evolutionary or sequelar).

Methods - color vision test

Ishihara

Beyne lantern

Fletcher lantern

Arrangements test

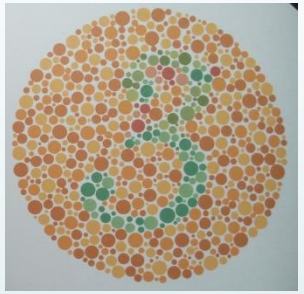
- Farnsworth D15
- Lanthony 15 Hue
- Munsell 100 Hue

CAD (Colour Assessment and Diagnosis) test

Anomaloscope Nagel type

Methods - color vision test

Ishihara 38 plates



- Out of order
- at 70 cm of distance, at 45°
- 3 seconds for each plate

→ successful if the first 17 plates were viewed without error or hesitation.

Methods - color vision test

Ishihara

Beyne lantern

Fletcher lantern

Arrangements test

- Farnsworth D15
- Lanthony 15 Hue
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CAD (Colour Assessment and Diagnosis) test

Anomaloscope Nagel type

Methods - color vision test

Beyne lantern type aviation

simple colored lights, in random order

low mesopic conditions, at 5 meters

any hesitation or false answer = an error

military

2 protocols without cited colors

- 1 s / 4' : presentation 1 second with 4 minutes of arc aperture
- 1/25th s / 2 : presentation 1/25th second with 2 minutes of arc aperture

civilian

2 protocols with colors cited (red, green, blue, yellow-orange and off-white)

- 1 s / 3' : presentation 1 second with 3 minutes of arc aperture
- 1 s / 3' x 3 presentations (pass if no error on 2 of 3 presentation)

Methods - color vision test

Ishihara

Beyne lantern

Fletcher lantern

Arrangements test

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- Munsell 100 Hue

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Methods - color vision test

Fletcher-Evans CAM lantern

two lights, vertically

6 meters

5 colors : 2 Red, 2 Green, 1 White

9 combinations

- Informative phase : colors presented and cited 'red', 'green' and 'white '.
- test phase : 0.9 minute of arc , 2 seconds

First round : pass if no error

Two more rounds if errors

Methods - color vision test

Ishihara

Beyne lantern

Fletcher lantern

Arrangements test

Farnsworth D15

Lanthony 15 Hue

Munsell 100 Hue

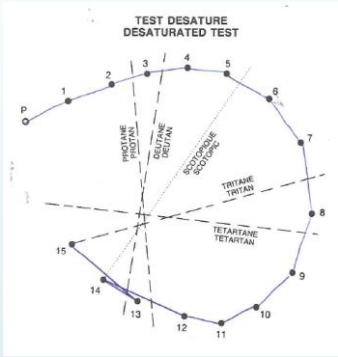
CAD (Colour Assessment and Diagnosis) test

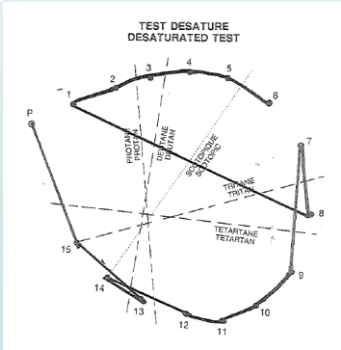
Anomaloscope Nagel type

Methods - color vision test

Arrangement tests

- **Farnsworth D15**
  - to classify the 16 pawns in a time of 3 minutes.
  - successful if no confusion right (circular scheme)
    a straight between the pawns 7 and 15,
    a simple pawns inversions.





- **Desaturated Lanthony 15 Hue**
  - successful if less than 2 lines of confusion

- **Farnsworth-Munsell 100 Hue**
  - 2 minutes /box x 4
  - axis of the deficiency
  - severity score

Methods - color vision test

Ishihara

Beyne lantern

Fletcher lantern

Arrangements test

- Farnsworth D15
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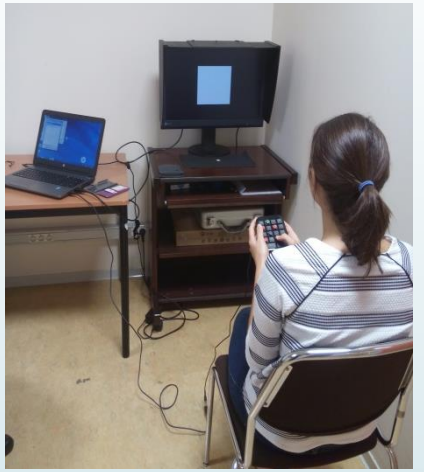
CAD (Colour Assessment and Diagnosis) test

Anomaloscope Nagel type

Methods - color vision test

The CAD Test (Colour Assessment and Diagnosis)

Mesopic condition
at 1.40 meter in front of the viewing screen,



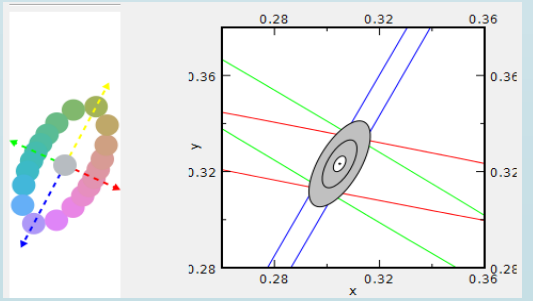
3 steps

- *'learning mode'* : check the test understanding.
- *'fast screening'* : identify a large part of the healthy subjects.
- '*definitive CAD*' : determine the chromatic sensitivity of the subject present for each wavelength stimuli of varying intensity.

→ determines the axis and severity according to a score (RG for the Red-Green axis and YB for blue-yellow axis)

→ Ability according to UK threshold :
RG < 6 SN for protans and RG< 12 SN for deutans

→ Healthy subjects : score < 2 SN



Methods - color vision test

Ishihara

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Anomaloscope Nagel type

Methods - color vision test

The anomaloscope IF2, Tomey

Rayleigh equation,
on the dominant eye in mesopic conditions

- 2 modes : Automatic or Manual
- identifies the deficiency axis, differentiates anomalous trichromats from dichromats, or class the subject in normal color vision

- matching range ⇔ severity
- Safe : if matching range less than 4 units at the Nagel anomaloscope

Methods

➔2 groups : CVD : color vision deficient
CVN : color vision normal

For each test, evaluation of :

- Sensibility, Specificity, Positive and negative predictive values
- Application to aeronautic : Total number and success ratio for class 1 ability
- Severity assessing : ROC curves for dichromatism diagnosis
  for CAD test and 100 Hue

Results

- 55 subjects
  - 32 color vision deficient subjects (CVD). 3 were excluded (missing results)
  - 23 color vision normal subjects (CVN).

29 VCD	23 VCN	p
23 years ± 6.09	26 ± 6.1 years	p = 0.075
0 woman	9 women	p = 0.015
- 11 deuteranomalous trichromats (37.9%) - 7 protanomalous trichromats (24.1%) - 6 protanopes (20.69%) - 5 deuteranopes (17.24%)		

Results

- ***Detection of color-deficiency tests power***

		Se	Sp	PPV	NPV
ISHIHARA		0.97	1.00	1.00	0.96
FARNSWORTH D15		0.58	1.00	1.00	0.64
LANTHONY HUE	desaturated	0.79	1.00	1.00	0.79
MUNSELL 100 HUE		0.79	0.96	0.96	0.79
BEYNE Lantern	1s / 4'	0.79	0.96	0.96	0.79
	1/25th s 2'	0.97	0.57	0.76	0.93
	1s / 3'	0.76	0.96	0.96	0.76
	1 s/3' x 3 series	0.69	1.00	1.00	0.72
FLETCHER Lantern	1 presentation	1.00	0.78	0.85	1.00
	2 retests	0.97	1.00	1.00	0.96
CAD test		1.00	1.00	1.00	1.00
ANOMALOSCOPE	Automatic	0.97	0.96	0.97	0.96
	Manual	1.00	1.00	1.00	1.00

Results

- ***Total number and success ratio for a class 1 ability for CVD***

Test		Deuteranomalous trichromats		Deuteranopes		Protanomalous trichromats		Protanopes		All	
		n = 11	in %	n = 5	in %	n = 7	in %	n = 6	in %	n=29	in %
ISHIHARA		1	9.09	0	0.00	0	0.00	0	0.00	1	3.44
FARSNWORTH	D15	5	45.45	0	0.00	5	71.42	2	33.33	12	41.38
LANTHONY	D15	4	36.36	0	0.00	2	28.57	0	0.00	6	20.69
MUNSELL	100HUE	3	27.27	0	0.00	2	28.57	1	16.67	6	20.69
Beyne lantern	1s / 4'	5	45.45	0	0.00	1	14.29	0	0.00	6	20.69
	$1/25^{th}$ s / 2'	1	9.09	0	0.00	0	0.00	0	0.00	1	3.44
	1s / 3'	3	27.27	1	20.00	2	28.57	1	16.67	7	24.14
	1s / 3' x 3	6	50.00	0	0.00	2	28.57	1	16.67	9	31.03
Fletcher lantern	1 present.	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
	2 retests	1	9.09	0	0.00	0	0.00	0	0.00	1	3.44
CAD test		2	18.18	0	0.00	1	14.29	0	0.00	3	10.34
ANOMALOSCOPE		4	36.36	0	0.00	2	28.57	0	0.00	6	20.69

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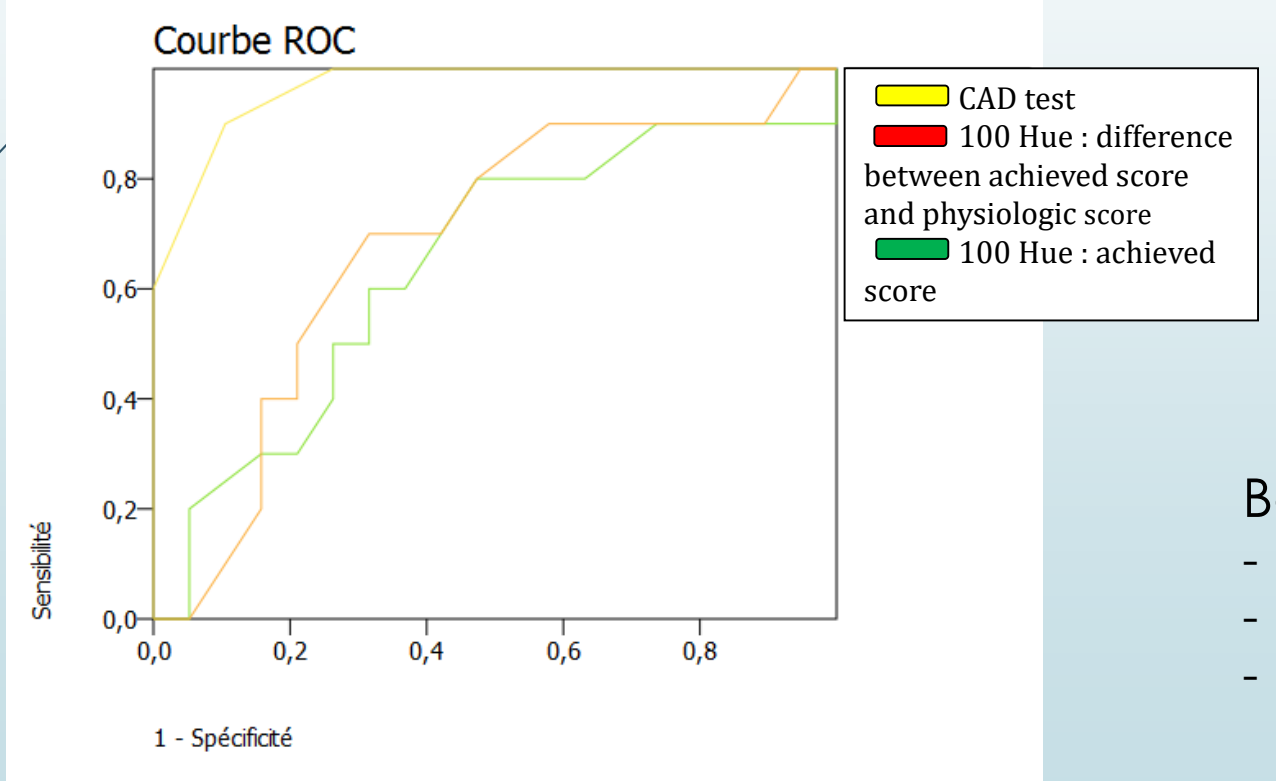
CVD	Ishihara	D15	15HUE Lanthony.	100 HUE	BEYNE lantern				FLETCHER lantern		CAD test	Anomal.
					1/4	1/25th 2	1/3	3 tests	1 test	2 retests		
1	fail	fail	fail	fail	fail	fail	fail	PASS	fail	fail	fail	fail
2	fail	PASS	PASS	fail	fail	fail	fail	Fail	fail	fail	PASS	PASS
4	fail	PASS	PASS	fail	fail	fail	PASS	PASS	fail	fail	fail	PASS
5	fail	PASS	fail	fail	fail	fail	fail	fail	fail	fail	fail	fail
6	fail	PASS	fail	fail	fail	fail	fail	fail	fail	fail	fail	fail
7	fail	fail	fail	fail	fail	fail	PASS	PASS	fail	fail	fail	fail
11	fail	fail	fail	fail	fail	fail	PASS	fail	fail	fail	fail	fail
14	fail	fail	fail	fail	PASS	fail	fail	fail	fail	fail	fail	PASS
15	fail	PASS	fail	fail	PASS	fail	fail	fail	fail	fail	fail	fail
16	fail	fail	fail	fail	fail	fail	fail	PASS	fail	fail	fail	fail
17	fail	PASS	fail	fail	fail	fail	fail	fail	fail	fail	fail	fail
20	fail	PASS	PASS	fail	fail	fail	fail	PASS	fail	fail	PASS	fail
22	fail	fail	fail	PASS	fail	fail	fail	fail	fail	fail	fail	fail
24	fail	PASS	PASS	fail	PASS	PASS	PASS	PASS	fail	fail	fail	PASS
25	fail	fail	fail	fail	fail	fail	PASS	PASS	fail	fail	fail	fail
26	fail	PASS	fail	PASS	fail	fail	PASS	PASS	fail	fail	fail	fail
27	fail	fail	fail	fail	PASS	fail	fail	fail	fail	fail	fail	fail
29	fail	PASS	fail	PASS	PASS	fail	fail	fail	fail	fail	fail	PASS
30	fail	PASS	PASS	PASS	fail	fail	fail	PASS	fail	PASS	PASS	PASS
31	fail	fail	PASS	PASS	fail	fail	fail	fail	fail	fail	fail	fail

Results

- ***Deficit quantification***



AUC:

- 0,98 [0,94 ; 1,01] for CAD test
- 0,65 [0,47 ; 0,83] for score difference
- 0,69 [0,52 ; 0,86]for 100 Hue

Best cut-off:

- RG > 18,5 for CAD test
- Score difference > 22
- Score > 112 for 100 Hue

Discussion

Walsh in 2016 , USA

- 65 CVD subjects and 68 CVN subjects of US Army.
- Our results :
  similar except a better diagnostic efficiency of the CAD test.

Test	Sensitivity	Specificity
CAD test	0.86	0.85 to 1.00
Farnsworth D15	0.35	1.00
FALANT	0.92 to 0.86	0.96
3 presentations	0.83 to 0.85	0.97 to 0.99
PIPIC	0.98	0.96 to 1.0

→ good efficiency of the computerized tests CCT and CAD

operator-independent and randomized patterns

Walsh DV, Robinson J, Jurek GM, Capó-Aponte JE, Riggs DW, Temme LA. A Performance Comparison of Color Vision Tests for Military Screening. Aerosp Med Hum Perform. 2016 Apr;87(4):382–7.

Discussion

Squire et al. in 2005, UK

- 3 lanterns (Beyne, Spectrolux, and Holmes-Wright) and Nagel anomaloscope.
- 55 CVD subjects and 24 CVN subjects.
- all dichromats failed the 4 tests.

- pass one secondary test : not guaranteed to pass the other tests
  → Tests authorized by the EASA standards : high variability and inconsistency of their results.

Squire TJ, Rodriguez-Carmona M, Evans ADB, Barbur JL. Color vision tests for aviation: comparison of the anomaloscope and three lantern types. Aviat Space Environ Med. 2005 May;76(5):421–9.

Discussion

British CAA, 2006

- 117 CVD
- Ability of PAPI lights recognition and CAD test results

- No subject who pass CAD test failed to PAPI simulator.
  (pass : RG < 6 SN for protan or RG < 12 SN for deutan)

- CAD test : pass in 36.1 % of deuteranomalous trichromats
  29.8% of protanomalous trichromats

  In our study : only 18.2% deuteranomalous trichromats
  14.3% protanomalous trichromats

Barbur JL, Rodriguez-Carmona M, Evans S, Milburn N. Minimum Colour Vision Requirements for Professionnal Flight Crew. Recommendations for a new colour vision standards. Safety Regulation Group. Civil Aviation Authority; 2009.

Discussion

Fletcher in 2005

- Similar to Holmes-Wright lantern : 2 lights with a 0.9 minute arc aperture. Colors used : slight differences in the CIE diagram.
- 9 / 71 normal trichromats : mistakes in first pass.
- 18 color-deficient subjects : all failed.

➨ Fletcher-Evans CAM lantern : very sensitive.
→ good test for clinical diagnosis, not for chromatic selection.

Birch in 2008

- Holmes-Wright lantern type A
- 125 color-deficient subjects: 10 subjects (9%) were able to pilot

➨ Nevertheless, Fletcher lantern not comparable to the Holmes-Wright lantern (passing 9 to 30% of CVD)

- Fletcher R. The Fletcher CAM lantern colour vision test. Optom Today. 2005 Jul;(29):24–6.
- Birch J. Performance of colour-deficient people on the Holmes-Wright lantern (type A): consistency of occupational colour vision standards in aviation. Ophthalmic Physiol Opt. 2008 May;28(3):253–8.

Discussion

Professional selection specificity

- Candidates try to minimize their color-vision deficit / learn Ishihara → consider any hesitation / mistake as failure.

- testing protocol should be strictly respected and examiners must be trained,
  - that can be an impediment to the use of anomaloscope
  - In some cases, automatic mode may fail to categorize the candidate.

Discussion

Test duration is to take in account in a screening context.

- **Ishihara** album : **2 minutes**
- **Beyne** lantern : **1 mn**, and **Fletcher-Evans** CAM lantern : **5 mn**
- Both test of **D15 : 2 - 3 mn**, **100 Hue : 15 mn**
- **Anomaloscope** with both automatic and manual mode : **20 mn**
- **CAD test : < 5 mn** if "Fast screening" is successful.
  In our study, 6 CVN (26%) had "**Definitive CAD" : 8 mn** for red/green (3-4 mn for blue / yellow if necessary).

Discussion

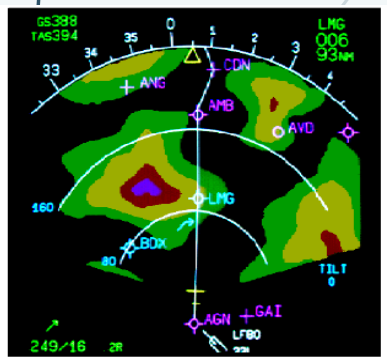
CAD test

- Advantages
  - Can't be learn
  - Reproducible
  - Red / green and yellow / blue axis
  - 16 colors
  - Quantitative test

Lanterns

- Advantages
  - Quick
  - Easy
  - Less expensive
  - Ergonomic test

Conclusion



- Many tests are used for pilots ability. Their results are discordant
- lanterns are no more commercialized.
  CAD test and anomaloscope : most accurate in our study
- Recent increase of colored signals in new generation cockpits.
  Multitude of color amount.
- The acceptable color-deficiency for a pilot to be safe is difficult to determine, as well as the risk of not detected blue-yellow deficiency.

Thank you for your attention

Discussion

- In conclusion

  - Ishihara plates : excellent screening test for red / green deficiency.
  - Farnsworth D15 : quick and easy but some dichromats subjects can pass this test.
  - Lanthony 15 Hue test : ability of 20% and seems suitable for use in professional selection.
  - Munsell 100 Hue : too long
  - Fletcher-Evans CAM lantern : too restrictive
  - Beyne lantern : simple and quick to use, but some dichromats pass.
  - Anomaloscope : qualify and quantify the deficiency
    requires a strong experience of the examiner.
  - CAD test : quantitative test , yellow/blue and red/green
    thresholds used by the British CAA seem to be more restrictive
    More expensive

Results

- ***Assessment of the axis of the color-deficiency***

ANOMALOSCOPE	Diagnosis	ISHIHARA	D15	LANTHONY 15HUE	LANTHONY 100 HUE	CAD
	deutan	15	11	9	12	16
all CVD	protan	9	6	12	6	13
n = 29	not defined	5	12	8	11	0
Deuteranomalous	deutan	10	6	5	6	11
Trichromats	protan	0	0	2	0	0
n = 11	not defined	1	5	4	5	0
	deutan	5	5	4	5	5
Deuteranopes	protan	0	0	0	0	0
n = 5	not defined	0	0	1	0	0
Protanomalous	deutan	0	0	0	1	0
Trichromats	protan	4	2	4	2	7
n = 7	not defined	3	5	3	4	0
	deutan	0	0	0	1	0
Protanopes	Protan	5	4	6	4	6
n = 6	not defined	1	2	0	2	0