Color vision in civil aviation

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Color vision deficiency (CVD) is a condition that results in individuals being unable to distinguish differences between certain colors. Occupational color vision standards were introduced in aviation in 1919 by The Aeronautical Commission of the International Civil Air Navigation Authority. Concern has been expressed during the last few years that the current color vision standards in aviation may be too stringent and, at the same time, also variable across the world. The tests employed do not always reflect the tasks pilots encounter in today’s aviation environment. This ambiguity leads to the possible exclusion of deserving applicants for selection as aircrew. The compatibility of CVD with aircraft crew is assessed by medical personnel using clinical diagnosis tests on the ground level. These clinical tests were developed specifically to detect the presence, nature, and severity of CVD. No clinical tests yet provide a measure of operational performance in operating an aircraft. Arbitrary pass marks have been assigned to clinical tests such that a failing candidate will either be subject to operational restrictions or excluded completely. The prescribed clinical tests and associated pass marks vary considerably between regulators. While an individual may be subject to no restrictions in one jurisdiction, they may be excluded in another. This article highlights newer diagnostic techniques adopted by different countries for assessing color vision to see for the scope of evidence-based guidelines for minimum color vision requirements for flight crew as well as for civil aviation in India.

Key words: Anomalouscope, civil aviation, color vision, Ishihara chart, Martin Lantern test

Color in aviation is used for decoding signals, taking visual cues from runways, and from gathering information from the visual displays. Hence, it is the main thing in flight safety to set sufficient color vision standards to make sure that the in-flight crew can discriminate and recognize different colors, both on the flight deck as well as an external stimulus. In today’s era of civil aviation which has changed dramatically in terms of lights in visual displays inside the aircraft, night flying concern has been raised all over the world during the recent past that the current color vision standards are not adequate, since most of these tests can screen only for normal red, green color blindness. The prompt and accurate perception of colors is necessary for aviation safety. Although such a general statement is unlikely to be vulnerable to serious disagreement, the issue of color vision deficiency (CVD) and aviation safety, especially the medical assessment of aircrew, is prone to controversy. Many disagreements have been there against the application of CV standards to pilots, and one of the more difficult tasks of the issue is that there is no universally agreed threshold between safe and unsafe degrees of CVD.

At present, color screening methods employed by most authorities of civil aviation does not measure exactly the severity of color vision deficiency, and this makes authorities and examiner difficult to set cutoff values for the pass or fail limits. Barring few exceptions as well as in day to day practice, it has been seen that a normal trichromats applicant will commit some errors in the Ishihara color screening.[4]

Recent advancements in color vision[2] and the development of newer instruments to measure precisely the loss of chromatic sensitivity[3] have prompted research into more accurate methods of measuring color vision sensitivity to establish minimum color vision requirements in aviation. Recent equipment has made a possibility of a new era to define more accurately the population variability or range that exists within the normal color vision and to detect with greater confidence the minute congenital color vision deficiencies that hitherto passed undetected in old color vision tests equipment. These newer tests can quantify the color vision defects better as opposed to occupational tests. The limitations of occupational color vision tests were brought out by Squire et al. in their study comparing various occupational tests in both normal trichromats and a large number of color deficient observers. They have pointed out the need for tests that can reliably measure the range of chromatic sensitivity as well as variability expected to be present in the color normal population.[3]

In India, the Ishihara chart and Martin Lantern test is widely used as a differentiation between trichromats and red-green deficiency. However, currently, in many of the western nations, this is an open access journal, and articles are distributed under the terms of the Creative Commons Attribution-NonCommercial-ShareAlike 4.0 License, which allows others to remix, tweak, and build upon the work non-commercially, as long as appropriate credit is given and the new creations are licensed under the identical terms.

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the lantern tests have been replaced or augmented by newer methods which can to some extent quantify the deficiency.

An ideal color vision test must (a) provides reliable isolation of different color signals and gives the numerical value of the severity of color vision loss, (b) should be based on population-based data of different races and countries that have statistical limits of color discrimination in “normal” trichromats, so that only those who are outside the range only are deemed anomalous (c) has sensitive enough to detect “minimal” deficiencies and to classify them exactly and (d) can be monitor “significant changes” in color sensitivity with the aging process of humans.

Apart from Pseudo-isochromatic Plate Test (for example, Ishihara plates, Dvorine plate test, AO Hardy-Rand-Rittler, AO Hardy-Rand-Rittler, Tokyo Medical College Colour) and lantern test (examples are—Marin Lantern, Eldridge-Green Lantern, Holmes-Wright Lantern, KBB—Martin Colour Vision Testing Lamp), others methods commonly used across the world are-

1) Farnsworth D-15 Test: The D-15 test is a so-called arrangement test [Fig. 1]. The test objective is to set the colored plates or disc to be arranged correctly. Individuals who are color blind will find it confusing to arrange the given colors in a set pattern and make mistakes. Discs that are placed on the wrong side of the circle are considered a major error. Discs placed in a side to side position on the same side of the circle indicate a minor error or normal confusion. If the individual makes two minor errors that can be taken as within normal limits and 2 or more major errors are considered outside the normal range. Based on mistakes done by the subject and the resultant confusion vector, the type of color blindness, and as well its severity can be calculated.

2) Aviation Light Test (ALT): The Aviation Lights Test is one step-up version of Farnsworth Lantern Test designed to meet the FAA’s (Federal aviation administration) signal color (USDOT-FAA, 1988) and International Civil Aviation Organization (ICAO, 1988) specifications for the red, green, and white signal light colors on aircraft. The instrument has a total of nine vertically separated pairs of colored lights presented to the candidate, who has seated 8 feet away from the lantern [Fig. 2]. The vertical distance between the two apertures is 1.3 cm or 18.3 min of arc. Three basic colors (red, green, white) are projected from the aperture. A total of 27 presentations from the aperture. Before the test begins, basic three test light colors are shown to candidates from the aperture for familiarization. The test requires a very dim room that simulates the light level of the air traffic control (ATC) tower at night.

3) Anomaloscope: The principal of anomaloscope is based on color matching and has turn out to be a standard test for identifying and diagnosing red, green color deficiency in developed countries [Fig. 3]. The instrument produces a disc size stimulus that is divided into two halves of the same area and is viewed in an optical system. The upper half of the disc is illuminated by a mixture of red and green lights, and the lower half of the disc is illuminated by spectrally narrow yellow light. In the base, two control knobs are placed, the upper knob is to change of the red-green color mixture ratio of the top field, and the lower knob is to change the luminance of the yellow lower field. The test has two stages. First, the individual dominant eye is determined and the dominant eye (right, left) is fully tested followed by others. This is to ensure the same deficiency. This also hints that color vision deficiency is congenital or acquired only in one eye due to different retinal pathologies. The test is started after familiarization with the instrument and its controls, then the subject is asked to adjust both the control knobs (present at base) until the two halves of the circle match completely in terms of color and brightness. Examiner has to “spoil” the match after each test. The interval between each match is about ten seconds. The room is dimly illuminated. In between each match, the subject looks away from the instrument into the dimly lit room for a few seconds. This exercise is done to minimize the effect of chromatic after images developed during the mixing of colors. The second stage of the test begins to measure the limits of the matching range of colors. The earlier matches made by the subject taken as reference points. This reference point set the red-green mixture ratio near to the estimated limits of the range. After setting the reference point, the subject is asked to change the luminance of the lower yellow half of the field for exact “match” in color as well as in brightness in the upper half. This gives matching range and limits of subject.

The Heidelberg Multicolour Anomaloscope (HMC) is a new prototype of an anomaloscope that can also diagnose the blue-green disorder. The instrument uses a microprocessor-controlled device for precision diagnosis of color vision in the red, green area (Rayleigh equation) and the blue, green area (Moreland equation) with integrated automatic neutral adaptation. Another added advantage over other anomaloscopes is that it generates results automatically, thus eliminating the need for a skilled technician.

4) Color Assessment and Diagnosis (CAD) Test-The CAD test has been recommended in an earlier CAA record of the USA. It has a calibrated visual monitor display. It projects colored stimuli of precise chromaticity and saturation. This colored stimulus presented moves along each of the diagonal directions of visual display [Fig. 4]. The subject seats have four buttons. The main objective of the subject is to report the direction of motion of the color-defined stimulus by pressing buttons at a measured distance. Randomly staircase procedures are used to adjust the intensity of the color signals. The intensity of the color is automatically adjusted by computer-controlled software according to the subject’s responses. This determines thresholds for the color detection of red-green and yellow-blue colors. The CAD test has several advantages over the conventional test. This test can isolate the intensity of color signals more accurately.

5) Precision Approach Path Indicator (PAPI) Simulator Test: The PAPI is probably the most important and safety-critical task in aviation that relies mostly on color vision. The PAPI system has four lights arranged horizontally and installed at 90° to the runway. The nearest light some 15 m away from the edge. Each light is 30 cm in diameter with an inter-separation between light is 9 m. The unit is divided into two halves, red in the lower half and white in the upper half. The aircraft approach on the runway gives different elevation angles with a combination of red and white lights. On a particular slope, all lights visible as red if the aircraft is too low, and all-white if it is too high [Fig. 5]. PAPI simulator test is a
specific task test for the subject that is aimed to quantify the severity of a pilot’s color vision deficiency which is still safe to fly. This simulator uses controlled laboratory environments. A simplified laboratory setup was developed to reproduce the actual environment of the PAPI tests [Fig. 6]. PAPI simulator test simulates the photometric as well as the angular subtense of the red and white lights under demanding viewing conditions. A dark background is created for this purpose. The aim of this simulator test to make a real-time scenario and to identify the type and severity of color blindness. Simulator test has four horizontal lights that are presented for 3 s and the subject’s job is to simply report the number of red lights in the display. There are five possible combinations of red and white lights that are presented randomly [Fig. 7]. When carrying out the PAPI simulator test, observers were required to report the number.
of red lights using the following names: one, two, three, four, or zero (to avoid confusing “none” with “one”). Before the test, observers were dark-adapted to the low mesopic surround and then presented with a practice run before starting the test.

6) Rabin Cone Contrast Test (RCCT): The RCCT is a unique test designed to diagnose rapidly as well as to see the severity of congenital CVD and is the only color vision test adopted by the US Air Force.[9] The test is sensitive enough to detect the severity of cone deficiency. RCCT uses a randomized red, green, and blue color letters visible to a single cone type (long [L], medium [M], short [S]). Contrast is decreased in reducing steps to measure the final threshold for letter recognition. Hence, this is a very specific color vision test designed to diagnose rapidly and easily to identify the type and severity of congenital CVD too.[10] However, CCT scores in the elderly could be affected by normal age-related changes including senile miosis, ganglion cell loss, any slight misalignment of cones, and cognitive decline.[11] A score of 75 or greater was defined as normal in the RCCT. RCCT begins with one eye in a dark room with a distance of 1 m with corrective glasses to be worn. After giving a demonstration of L, M, and S letter appearance on the central location on the display to the subject, the test starts with a random series of 20 red letters (L), followed by green letters (M), and then violet letters (S) progressing from most visible down to least visible [Fig. 8]. The program randomly uses letters from Bailey-Lovio Early Treatment Diabetic Retinopathy Study (ETDRS) visual acuity chart[12] (H, N, V, R, U, E, D, F, P, Z) The font of the letter is Arial bold. On each trial, the program presents a colored letter centered within a crosshair on a grey background. The time interval between the appearance of the letter is 1.0 to 1.6 s (duration increases as contrast decreases), followed by an equal duration of the grey field. During this grey field duration, the subject is required to read the letter and then the program goes to the next stage. The technician records the letters that have been read correctly and those missed. For each testing color, the number of errors done in projected 20 letters is entered into the in-built software which calculates and gives a printout for the L, M, and S cone scores. Time taken to complete this test is 3 min per eye.

7) Operational Color Vision Analysis (OCVA): This test has two components: ground and flight assessment. Each assessment is carried out initially by day and maybe repeated at night for those subjects who wish to remove the limitation of night flying. It is a two steps process: a) single light test—it is administered on the ground at an airport ATC tower. It’s a live test where red, green, and white colors of 12 light signals are projected from an air traffic tower (six from 1000 feet and six from 1500 feet). The signal would be shown for 5 s and after that candidates are allowed to answer in 5 s. b) Chart reading: aeronautical charts are displayed in the table and candidates have to read and correctly interpret various sizes, terrain colors in a time-bound manner.

Discussion

The lack of uniformity in testing color vision across the world continues to be a cause for confusion and dispute. It is not uncommon for a subject to fail the color vision assessment by one testing method in one country and to pass in another by a different testing method. However, this is not completely unexpected if we take intersubject variability, the different factors (environment, lighting condition of the same test, contrast, and hue of testing instruments that can contribute to loss of chromatic sensitivity), and other characteristics of the various color vision tests. This also aids confusion among applicants and allows them to attempt several tests to pass one of the many color vision standards. Different countries have adopted peculiar methods for testing color vision.[13,14] In India, currently, pseudoisochromatic plates (Ishihara) and the Martin Lantern test (MLT) are the most common color vision testing methods used by both military and civil aviation.[15] As pointed out, these are not error-free, even in the normal individuals going for color vision test by these methods.[11] In fact, the International Civil Aviation Organization (ICAO) manual clearly states that color plates can be too discriminating.[16] MLT is a very old device and commercially not available. The unique lantern design and form have not changed very much since their origin in the early 20th century.[17] To overcome this problem, computerized testing of color vision was innovated and it was found that the computer made software able to reproduce results comparable with the existing MLT.[18] As
far as newer equipment is concerned, the anomaloscope is considered as the gold standard for color vision testing in clinical research.\textsuperscript{[19,20]} The Nagel anomaloscope test is excellent at distinguishing between red, green deficiencies, but fails to quantify reliably the amount of color vision loss, and does not test for yellow, blue deficiency.\textsuperscript{[20]} In India, Khan et al. compared four different methods of color assessment on military as civil pilots aspirants. The author pointed out that the results of MLT are questionable when testing is being done at 1.5 m compared to other instruments. Authors have also suggested that MLT should not be used as the sole criterion for distinguishing severe color deficiency. The results of MLT should be read very carefully and should use other diagnostic tests for color vision such as the anomaloscope before declaring MLT results.\textsuperscript{[20]}

On the contrary, studies also have shown that different types of lanterns have many disparities and conflicting results.\textsuperscript{[23]}

Passing the Lantern test itself may not be a good idea for acceptance in civil aviation and night flying. In another study conducted by Cole et al., more than 80% of errors were found in the PAPI signal test in deficient color vision (DCV) who had passed the Farnsworth lantern test during initial entry.\textsuperscript{[24]}

New Zealand aviation had adopted a new approach to color vision. It has three stages: stage 1—color vision test by Ishihara plates. If the subject clears the Ishihara chart, then no restrictions on their medical certificate. Stage 2—if the subject is unsuccessful in stage 1, he can opt for the Holmes-Wright lantern test, Farnsworth lantern and Anomaloscope, CAD test, or Farnsworth D15 tests. If he passes in any one opted vision test, he will have no restrictions, if found unsuccessful they will have restrictions on their certificate. Stage 3—this stage is for unsuccessful candidates in stage 2. The last option is to take the operational color vision assessment (OCVA). The OCVA allows subjects to be assessed in daytime or day and night time both for night flying clearance on the ground and in the air.\textsuperscript{[25]}

In the UK, those failing the Ishihara test will need to take the CAD test and to pass as “normal trichromats” to gain a class 3 certificate. In other European countries, those that fail the Ishihara test can be examined on the anomaloscope (Nagel or equivalent). The UK CAA does not trust in lantern testing as evidence of being color-safe.\textsuperscript{[26]}

Whereas US FAA does not accept the D15 test for ATCs and airmen but FAA seems to more liberal as it allows to get a pass from any one of the 14 kinds of instruments from different manufacturers and, as a result, more color defective applicants pass.\textsuperscript{[27]} If we analyze large data, 84% of states use Ishihara plates as the first choice but the number of plates required to be passed widely varies in the different regions.\textsuperscript{[28]}

In secondary methods, 47% uses different types of lanterns whereas 31% uses anomaloscopes.\textsuperscript{[29]}

In India, the DGCA manual uses Ishihara as a first screening method followed by MLT as a second screening procedure as per Indian Air Force guidelines.\textsuperscript{[15,29]}

This seems in line with the International Civil Aviation Organization (ICAO) recommendations.\textsuperscript{[30]} However, MLT is only available in the armed forces clinics and very few private hospitals. In scrutiny carried out at one of the aviation centers of Air Forces of India, of 69 flight crew for appeal medical board at the highest echelon in India, three cases were found to be color defective.\textsuperscript{[31]} There have been several reports of color vision deficiency contributing to air incidents and air infringements. In a famous FedEx crash incident, a color vision deficient (CVD) first officer pilot was named as a potential contributory factor.\textsuperscript{[22]}

In this incident, three pilots were on the flight deck. One, the first officer, was color vision deficient though he had passed the necessary clinical lantern test to be issued an unrestricted license. The remaining two pilots had a normal color vision. The aircraft was on a visual approach at night and descended in a nonstabilized approach to descend shortly of the runway. The investigation by the National Transportation Safety Board (NTSB) listed CVD as a contributory factor beyond crew fatigue. From 2004 to 2008 in the United States, there were only two occasions on which it was reported that CVD pilots entered controlled or restricted air space without the necessary clearance.\textsuperscript{[33]}

The above incidents do not mean that every color vision deficient should be barred from flying but only emphasize the need to establish standards that can be considered safe to fly. Multiple reviews by the Administrative Appeals Tribunal of Australia, and further supported by relevant research from the United Kingdom CAA and the United States FAA and others, have consistently demonstrated that certain CVD aircrew can perform operational tasks as competently as those with normal color vision individuals. North Atlantic Treaty Organization (NATO) recommends that CVD assessments should evaluate the capacity or competency of an individual to crew aircraft and not their ability to complete clinical diagnostic tests.\textsuperscript{[36]}

In 2001, NATO has made special software (PROFOCAT), which assesses the candidate’s color vision based on a combination of colored puzzles, colored mazes, and aeronautical images. The relevance of the colored puzzles and mazes to aviation is however not clear and therefore this system does not appear to have been adopted by many nations.\textsuperscript{[33]}

Conclusion

This review article aims to stimulate policymakers to adopt new methods for accurate assessment of color vision in India at par with world standards and to see for a scope of evidence-based guidelines for minimum color vision requirements for flight crew in civil aviation. In the Indian context, MLT is sparingly available commercially and older models have not been under service maintenance for years. This makes MLT even more questionable. Many countries have done away with MLT and adopted other alternative lanterns or instruments. The present discrepancy in color vision testing methods and standards demonstrates the need of the hour to adopt more objective assessment techniques at par with developed countries and to set minimum color vision requirements that are both safe and fair to the civil aviation applicants. Therefore, in the Indian context, this requires evaluation of newer tests to augment occupational tests with quantitative tests as well as designing algorithms for assessment on color-coded tasks relevant to the aviation environment.

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