Color Vision Deficiency Among Doctors: Can We Make Useful Adaptations to the Color Codes Used in the Clinical Environment?

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Abstract: Color vision deficiency (formerly known as color blindness) is common as a congenital and as an acquired condition. Some professions, most famously commercial aviation, require their members to demonstrate normal color vision. In the United States and United Kingdom, no restriction is placed on the ability of the color-deficient doctor to practice medicine, although there is evidence that certain clinical discriminations are harder for such doctors. Generally ignored has been the difficulty and the potential for error that arises from the use of color codes in clinical equipment. In this review, we introduce the basic concepts of color deficiency, summarize evidence for the challenges it poses to the doctor, examine global variation in policy, show the potential for confusion among clinical color codes, and suggest how the current situation could be improved to enhance both patient safety and the well-being of the color-deficient doctor.

Key Words: color deficiency, patient safety, color codes

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Deficiencies of color perception are very common, although they vary in severity: some color-deficient individuals are truly "color blind," unable to discriminate colors that are quite dissimilar to the normal eye, whereas others enjoy near-normal ability to discriminate even similar colors. Whether color-deficiency impairs a doctor's capacity to perform his or her duties safely has often been considered,[1–3] and a recent ruling by the Indian Supreme Court[4,5] directed a medical school to admit applicants who had been rejected solely on the basis of color deficiency. Debate has centered on whether subtle clinical signs will be missed during exam. Generally ignored, however, is a man-made source of danger: The proliferation of color codes that distinguish clinical devices, medications, alerts on electronic systems, and many other objects in the medical environment. Guidance on the safe use of colors in clinical environments is lacking. This poses a particular risk at a time when we are moving critical systems onto computer displays that rely heavily on color codes.

Color Deficiency

Approximately 8% of male staff (and a smaller percentage of female staff) have a congenital form of color deficiency that can cause them professional difficulties.[6] Normal color vision depends on a neural comparison of the amounts of light absorbed in the three different classes of retinal cones. The three types are conventionally termed short-wavelength (S), medium-wavelength (M), and long-wavelength (L) cones. Congenital color deficiency most commonly affects the M or L-cones and is X-linked. Mild "red-green" color deficiency arises when discrimination depends on two variant forms of L pigment or two variant forms of M pigment. These conditions affect approximately 5.7% of males.[7] A more profound loss occurs when either the L- or the M-cone is completely absent (~2.5% of men[7]). The latter observers are "dichromatic" (the level of color vision experienced by many nonprimate mammals), and they will struggle to detect, for example, the presence of fresh blood in feces.[8] Much more rarely, inherited loss of the S-cone (a condition called tritanopia) also leads to dichromatic vision.

Other members of staff will experience impaired color vision due to diseases affecting the retina, visual pathway, or visual cortex.[9] It is hard to quantify how large this group is, because color vision is often only cursorily assessed in the ophthalmology clinic. In particular, acquired tritan defects, caused by S-cone loss, are rarely tested for. However, common diseases such as diabetes and glaucoma are associated with variable loss of color vision, whereas profound loss of color vision is seen in many diseases of the optic nerve (e.g., optic neuritis, optic atrophy, and compression of optic nerve or chiasm). Many of these conditions have an age of onset that will impact the professional career of the doctor.

In the clinic, color vision is most commonly assessed using the Ishihara plates that screen for abnormalities of "red-green" (protan and deutan) color vision. The patient's task is to identify a numeral (or a line in the case of the nonverbal) that is composed of colored circles and is embedded among distractor colored circles. The responses indicate the presence or absence of color deficiency but cannot reliably assess the severity of the deficiency or determine whether the primary abnormality is with the M-cone or L-cone photopigment. There exist many other tests of color vision, some of which measure the severity as well as the nature of color deficiency. The anomaloscope, for example, requires the subject to match a yellow semicircle to a semicircle composed of mixed red and green light by varying the latter's mixture. The balance of red and green in the mixed region indicates the type of color deficiency, whereas the range of mixtures accepted is related to the residual quality of their "red-green" color vision.

Problems Faced by Color Deficient Doctors

Several doctors have written personal accounts of the subjective troubles they have encountered as a result of color deficiency[6] and offered imaginative advice on how to overcome challenges they face.[10] Questionnaire-based surveys have sampled a larger population of doctors and suggest some consistency in the situations where difficulty was experienced by

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color deficiency clinicians: exam of skin and rashes, of eyes, and of body products (urine, vomit, feces etc.), as well as judgments of charts, of histological slides, and of test strips for urine.[8]

Although the literature is very incomplete, and it is unclear whether specialists eventually find ways to fully compensate for their deficiencies, there is evidence that defective color vision could affect clinical judgments in a way that could compromise patient safety. Objective evidence has been presented of reduced performance on interpreting some clinical tests, such as blood glucose strips.[11] Reduced performance in interpretation of stained slides has been shown among color-deficient histopathologists and histopathology laboratory technicians,[12] and the reduction in performance correlated with the severity of the color deficiency. Nevertheless, there are known to be color-deficient histopathologists,[13] not all of them are aware of their deficiency. A recent study from India investigated the ability of 30 color-deficient medical students to perform clinical discriminations and showed reduced performance on several objective tasks.[2] Some of the largest effects were seen on interpreting Ziehl-Neelson staining, distinguishing green from orange tablets, marking the borders of a bruise, describing pigmented lesions of the retina, and identifying a jaundiced chest and cyanotic fingernails. Interestingly, the errors in this study were accompanied by high levels of self-reported confidence. The authors suggest that deficiencies of color vision might have a greater impact on those practicing histology, pediatrics, pathology, hematology, microbiology, dermatology, and ophthalmology. However, it is important to note that no applied research has been undertaken that supports a relationship between color deficiency and clinical errors in these or any other specialties.

Clinical Color Codes and Color Deficiency

The manmade color codes used in hospitals and clinics (except for blood and urine strips and some tablet colorings in the studies previously mentioned) have not yet been carefully examined as a source of confusion for color-deficient doctors. Unlike colors encountered on clinical exam (which are immutable), clinical color codes can be changed by better design.

Color codes are ubiquitous in the hospital environment. They have been shown to have a beneficial effect on the safe prescription of medication,[14] adherence to patient isolation protocols,[15] safe administration of intravenous fluids,[16] avoidance of incorrect blood sampling,[17] identification of staff groups,[18] flagging patient alerts using wristbands,[19] resuscitation protocols,[20] and patient flow.[21] The result of their success is that we rely heavily on color codes at the expense of other forms of identification. Many doctors will know that a purple blood tube is used to collect specimens for erythrocyte sedimentation rate. Fewer would know to seek out a tube containing ethylenediaminetetraacetic acid to perform the same test.

Although color may seem a subjective matter, there are standard procedures for quantifying color and what is relevant here is that it is possible to predict what color labels or markers would be confusable by a doctor who lacked a given type of retinal cones. This can be done in a "chromaticity diagram" such as that of Figure 1. Here, we plot the colors used in four different color-coding systems that are used in a clinical setting: Venturi adapters, blood sampling tubes, eye drop packaging, and anesthetic labels. We also show (dotted lines) sets of colors that would be confused in a particular type of dichromatic vision. The bottom right panel of Figure 1 shows our earlier analysis of color codes used in anesthetic agent labeling[22]—an analysis revealing that there are pairs of colors signifying different drug classes that become indistinguishable to the color-deficient observer. Moreover, there is such variation between standards that the confusable combinations of labels differ between countries.

Because color confusions can be predicted quantitatively, any image can be transformed so as to represent for the normal observer the gamut of color variation available to one of the three types of dichromat, and algorithms have been published for performing such transformations.[23,24] The color code most familiar to many doctors is that used to differentiate between the various blood sample tubes. As an educational aid, Figure 2 shows how these tubes seem to several types of color-deficient observer.

Sometimes, ill-judged color coding presents problems even for those with perfect color vision. S-cones are entirely absent from the very center of the normal foveola and are sparse[26] throughout the remaining retina. Thus, vision relying on them is of low spatial resolution.[27] This renders us all "small field tritanopes": we struggle to distinguish small targets from their surround when that discrimination relies on the S-cone signal alone. Figure 3 shows a good example of this effect: the pink and orange regions of a Modified Early Warning Score (MEWS) chart from the United Kingdom are clearly discriminable when the color blocks are large, but hard to distinguish when small. We should expect this effect to be increased in those experiencing acquired tritan deficiencies, which are common in diabetes and glaucoma.

As hospitals become paperless, developers naturally seek to produce software that displays information in the most efficient manner, and color coding is one of their basic tools. Ensuring that clinical color codes can be discriminated by color-deficient doctors would be a clear example of a workplace adaptation. Hospital computer systems display information critical to patient safety, so it is troubling that there is no specific guidance on how color should be used. By contrast, there are examples in the broader technology industry where this issue is understood, and some commercial Web sites,[28] software companies,[29] and governmental bodies[30] comment on good design.

Reducing the Risk Posed by Color Deficiency

There are two ways in which any risk posed by color deficiency can be ameliorated: Access to the profession or particular specialties could be contingent on good color vision (because it is for certain types of aviation); alternatively, workplace modifications could be made to reduce the risk of clinically significant confusions arising from color deficiency.

Solution 1 – Restrictions on Professional Practice

In many countries, there exist restrictions that prevent the color deficient from entering certain professions, most notably aviation and areas of the emergency services. Firefighting is an interesting example: color is used in the coding of equipment but also provides useful information about the temperature and constituent materials of a fire. Many American fire departments require that applicants pass the Ishihara test, and failure can lead to rejection.[31] In aviation, color vision requirements are usually administered centrally, for example, by the Federal Aviation Administration in the United Kingdom[32] and the Civil Aviation Authority in the United Kingdom.[33] Typically, assessment of color vision is performed using a screening test such as the Ishihara plates, with those failing able to proceed to more specialized tests such as anomaloscopy.

In medicine, there is variation in global practice, but deficiencies of color vision are not in general seen as an impediment to entering medical training. It is likely, therefore, that the proportion of color-deficient doctors reflects the base rate among the general population, although some may choose to avoid medicine if they know they have problems with color vision. Entrance to medical

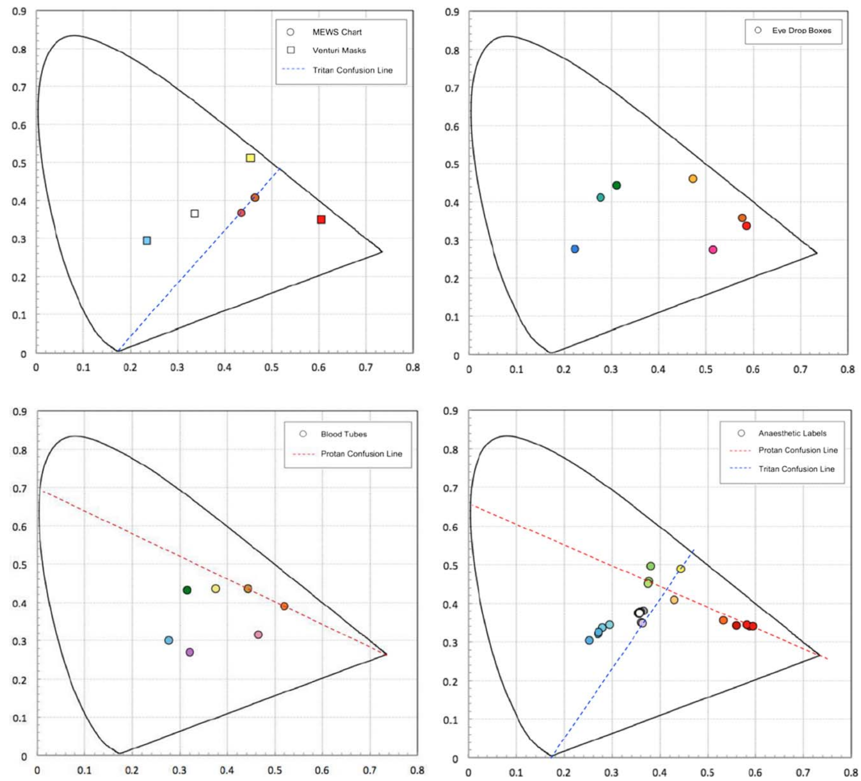

FIGURE 1. The CIE diagrams above, such as alternative chromaticity diagrams, allow quantitative description of colors. Here, we plot the colors comprising several common clinical color codes. Dotted lines are "confusion lines" and are plotted when two members of a color code are confusable to one group of dichromats (protanope, deuteranopes, or tritanopes). Top left, Colors on a MEWS chart and Venturi masks; top right, colors on eye drop boxes (no confusions found); bottom left, colors on blood tubes; bottom right, colors on anesthetic labels. Measurements were made by the authors with a PhotoResearch 650 spectroradiometer, which had been calibrated with its close-up lens (Rainbow S7.5mm) in place. The surfaces were measured under a fluorescent illumination (F58W/865) of color temperature 6500K (equivalent to daylight).

school is typically the point at which health restrictions are formally applied, although there is substantial variation in the standards applied and the willingness to make workplace adaptations to accommodate disabilities.

Historically, Japan had the most restrictive policies on entry to medical school, with half of national universities and 56% of medical schools excluding individuals with deficient color vision in 1986.[34] Because of concerted action by the Japanese Ophthalmologists Association, this rate fell to 2.3% by 1992. Outside of medicine, color-deficient Japanese also faced restrictions on their ability to work in computer, automotive, and other industries and could even be prevented from getting married.[34] In recent years, mandatory school testing of color vision[35] and most professional restrictions have been dropped.

In the United States, medical school technical standards set out essential abilities and characteristics required for completion of medical training (MD). These often contain vague reference to "skills (that) require the use of vision, hearing, and touch *or* the functional equivalent."[36] Some contain more specific statements, such as "Observation necessitates the functional use of the senses of vision, touch, hearing, and somatic sensation. It is enhanced by the functional use of the sense of smell and by color vision (Students who are color blind may require special accommodation in Histology)."[37] However, there are no formal restrictions on color-deficient doctors. In the United Kingdom, applicants to medical school are not routinely screened for color deficiencies,[8] although self-reporting is sometimes encouraged on preacceptance health information forms.[38] When the information is collected, it is not used to select candidates. Nor is it widely used as an opportunity to give the candidate guidance or support: that role has fallen to external agents.[3]

In India, students are routinely screened before entry to medical school, although in many instances no action is taken if a deficiency is found.[2] In the absence of formal guidance, however, some Indian institutions have excluded color-deficient candidates from medical training. In 2017, two students who performed well in entrance exams were excluded from the Tripura Medical College because of color vision deficiency.[5] A ruling from the Supreme Court later ordered their admission[4] and should have the effect of standardizing practice.

Within a few years of completing medical school, doctors will typically apply to enter specialty training. We could find no instances of bodies governing individual medical specialties recommending color vision testing for applicants. At this point in his or her career, a doctor's performance is monitored via a structured training program or a governing body (such as the General Medical Council in the United Kingdom). In the United Kingdom, doctors are required to declare health conditions that require modification of practice. Deficiencies of color vision are not considered such a condition.

There is no active move toward restriction of medical training to those with normal color vision. Relaxation of restrictions in India[4] and Japan[34] suggest an international trend in the other direction. Importantly, although deficiencies of color vision may make some specific clinical tasks harder to perform,[2] there is no evidence that this impacts clinical performance—color-deficient clinicians might use other contextual information to avoid errors. Interestingly, some existing publications support the routine screening of

FIGURE 2. Reproductions of the normal (N), protanopic (P), deuteranopic (D), and tritanopic (T) percept of blood tubes. Dichromatic simulations were created using the Chromatic Vision Simulator,[25] which is based on a validated algorithm.[23]

medical students[6] not to restrict access, but to help them avoid inappropriate specialties and to be self-aware of potential sources of error.[2] This is particularly important because color-deficient doctors can be highly confident about tasks on which they perform poorly.[2]

Solution 2 – Workplace Adaptations

The Americans with Disabilities Act (ADA 1990, amended 2008) requires that "any program or activity receiving federal funds" (which would include medical schools) avoids discrimination against an "otherwise qualified person with a disability." However, there is variation in how this legislation is applied. A national study found that most medical schools "do not support provision of reasonable accommodations for students with disabilities as intended by the ADA."[39] This leads to a situation in which some medical schools will make appropriate adaptations to enable a blind student to successfully pursue an MD,[39] whereas other medical schools have actively resisted

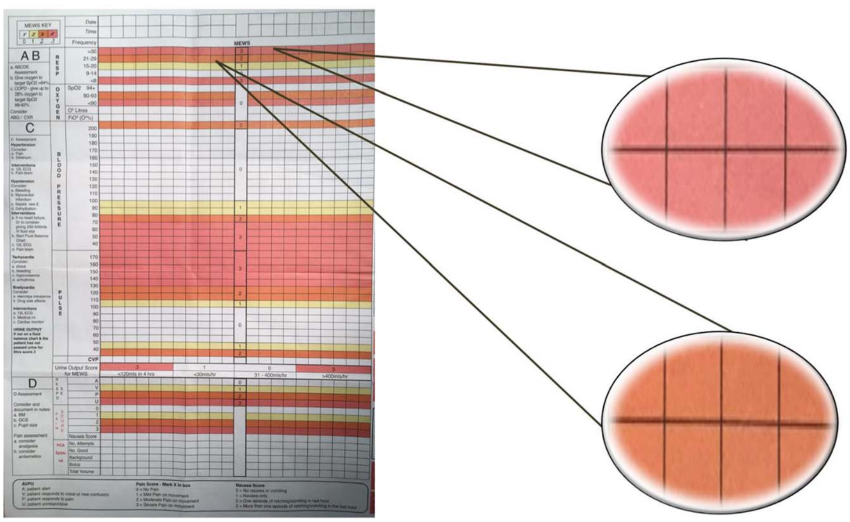

FIGURE 3. An example of a MEWS chart from a UK hospital. Large blocks of the orange and pink colors used to denote scores of 2 and 3 are easy to distinguish (right of figure). However, when they are presented as small blocks (e.g., a single line on the chart), they appear similar.

adaptations to accommodate deaf students under the ADA.[40] Because color deficiency is not considered a disability under the ADA, there is no process by which workplace adaptations can be mandated for a color-deficient doctor. This contrasts with the situation for a blind doctor, where the ADA could require suitable accommodations to be made.

In the United Kingdom, the General Medical Council is currently consulting on improvements to the way that medical education providers can support students with disabilities and long-term health problems. Employers and education providers are required under the UK Equality Act (2010) to make reasonable adjustments to workplace and working practices to accommodate those with long-term health problems. Employers are required to consider all requests for adjustments but are not obligated to make these if they are considered unreasonable. Color blindness, however, has already been shown not to constitute a disability under this law.[41]

In the United States and United Kingdom, therefore, the laws that can require workplace adaptations to be made do not apply to color deficiency. Medicine lags behind other professions in advice on workplace and graded working practice accommodations that can be made for the color deficient. In aviation, a graded approach to working practice is often taken: daytime flying,[32] for example, is allowed for those with color deficiency in the United Kingdom. The U.S. Department of Health and Human Services' Office of the Assistant Secretary for Public Affairs (Digital Communications Division) issues advice for the design of digital media to accommodate the color-deficient user.[30] There is no analogous guidance or code on how to approach workplace or working practice adaptation in medicine.

Existing Guidance on Clinical Color Coding

The most striking feature of the guidance on clinical color coding is its paucity. In the United Kingdom, the Food and Drug Administration publish regulations concerning the use of color additives and dyes in clinical equipment.[42] However, these regulations are concerned only with the physical safety of the dye. In the United Kingdom, the National Health Service issues formal guidance on the color coding of hospital cleaning materials.[43] The National Patient Safety Agency comment on the use of color in the graphic design of medication packaging to make important features stand out (e.g., dosage).[44] They make the sensible point that overreliance on color coding could lead to errors if clinicians stop reading the text, and they encourage "an awareness of users with limited color perception".

Color coding is uniquely well developed in the labeling of drugs in the anesthetic and critical care environments. International standards[45] have been published specifying the colors to be used to encode different drug classes. National advice has also been published in the United States[46] and United Kingdom[47] (many other countries have abandoned national advice in favor of the international standard). These national and international standards are similar, specifying most of the same colors, agreeing on the need for written drug names to appear on the labels, and using a hatched section to signify important antagonist drugs.

Current Shortcomings in Guidance and Areas for Improvement

There is a clear absence of guidance and career support for color-deficient individuals entering medicine. This absence has been explicitly noted for some time[6] and contributes to uncertainty among color-deficient doctors who might be inclined to hide their condition in the belief that it might affect career progression. Previous work suggests that some specialties will be particularly challenging for the color-deficient doctor: Histopathology, microbiology, dermatology, and ophthalmology are obvious candidates. The severity of color vision deficiency will also determine the scale of the challenge. Among the common variants, it is the dichromats (protanopes and deuteranopes) who will be most severely affected, whereas anomalous trichromats (deuteranomalous and protanomalous) might have near normal color discrimination. Again, lack of engagement with the issue means that tailored guidance cannot be offered contingent on the severity of color deficiency.

There is also a striking lack of guidance on the use of colors in designing the hospital environment and clinical equipment. A formal vetting process to examine every design would be excessive. Nevertheless, there is a need for clear guidance on good design principles, especially with regard to sets of colors that are least likely to confuse a color-deficient observer. Color Universal Design in Japan offer recommendations on suitable palettes,[48] and adoption of similar recommendations in other countries would promote safe design. Inclusion of secondary cues (such as the use of hatched areas on anesthetic labels) helps those who cannot decipher the color code. Designers can also be aided by algorithms that allow simulation of their products as they would appear to a color-deficient observer.[23] These have been incorporated into smartphone apps[25] that show on screen in real time how the world would appear to different types of severely color-deficient observers. Formal guidelines on the use of color in healthcare design would provide a single source that summarizes the available tools and best practice recommendations that are currently scattered across many sources and multiple languages.

Recommendations

1) Guidance from appropriate regional or national regulatory bodies should be made available to designers involved in product, medication, and packaging development. Recommended color palettes that can be used to minimize the chance of color confusions should be provided. Methodologies to assess the discriminability of products should also be described in the guidance. These would include formal colorimetry and the use of software that can simulate the dichromatic percept.
2) Designers should also be encouraged to consider the inclusion of nonchromatic codes (e.g., patterns in a colored background) to allow rapid identification of products where the user is unable to use the color code.
3) Organizations governing the medical professions (e.g., the General Medical Council in the United Kingdom) should develop advice for color-deficient doctors to support them in their career choice. Where there is evidence of specialty-specific problems (e.g., in histopathology), the governing bodies for such specialties should issue advice on how working practices can be modified to reduce any risk.
4) Further investigation should be undertaken to identify situations in which color deficiency might put the doctor at a disadvantage and ways to mitigate these risks identified. This will allow appropriate device and workplace modifications to be made that can support safe practice.

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