A New Method
For Testing Color-Defective Vision

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Keywords: color, vision, color physiology, color-defective vision, color-blindness, color vision testing

Abstract:

Since 1999, I have been teaching a course in Color Management and Quality Control as part of the baccalaureate curriculum in Graphic Communication at Cal Poly, San Luis Obispo. In the years that I have taught the course, I have had nearly 1,000 students, and I have required every one of them to take the Ishihara color-blindness test as well as the Farnsworth-Munsell color discrimination test (See my paper, *An Analysis of Color Discrimination of University Students in the Graphic Arts* from the TAGA 2009 Proceedings on the Farnsworth-Munsell test results).

Shinobu Ishihara (1879-1963) was a Japanese ophthalmologist who developed the most commonly used test for color-blindness. His test is used worldwide, and is the basis of both medical and workplace vision testing for people in all walks of life.

The Ishihara test is administered to both children and adults, and is valuable in determining if a subject has one of the two most common color defects, which are called *protanopia* and *deuteranopia*. Both are forms of *red-green color-blindness,* and they affect a small percentage of the general population.

Ishihara's test, however, does not test for a rarer form of color-defective vision, that called *tritanopia.* Tritanopia is a blue-green color-

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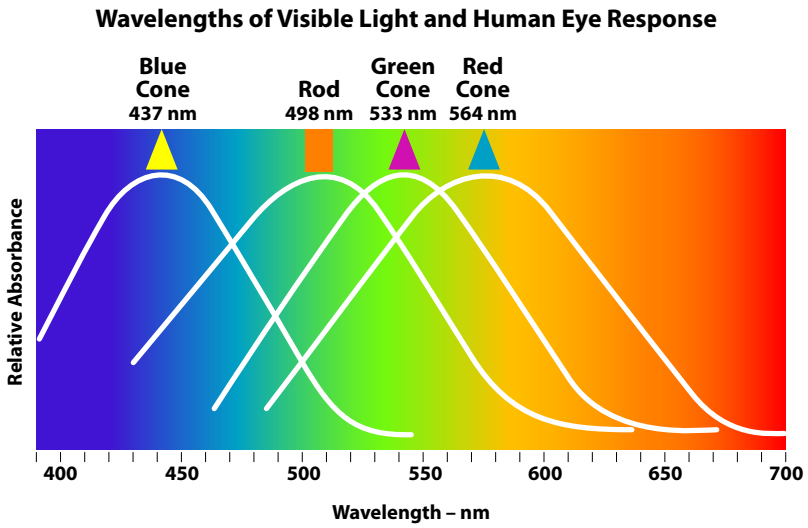
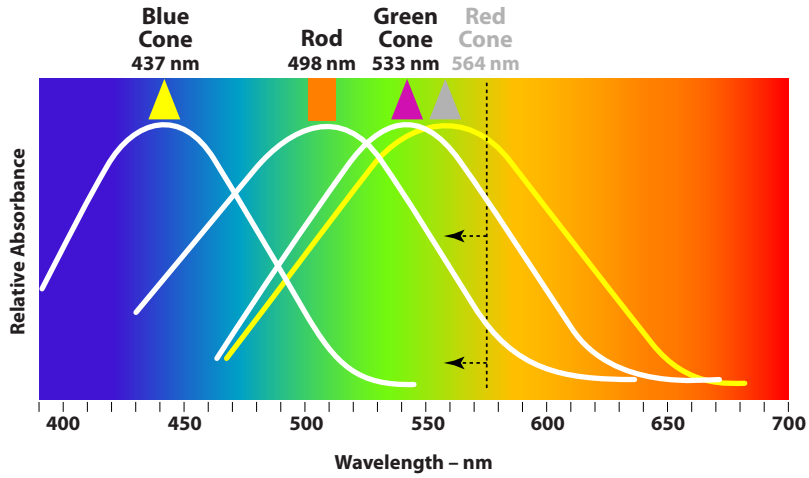


Normal cone responses of human vision have their peaks in separate ranges of the electromagnetic spectrum. The rods, which most people assume to be monochromatic, are actually sensitive to green light centering on 498 nm, which explains, in part, why the chromaticity of the human eye so strongly favors green.

blindness which affects a tiny percentage of the population (less than 0.01 percent). Dr. Ishihara clearly never encountered a person with tritanopic vision, though he does acknowledge the possibility of its existence in the booklet that accompanies his test plates.

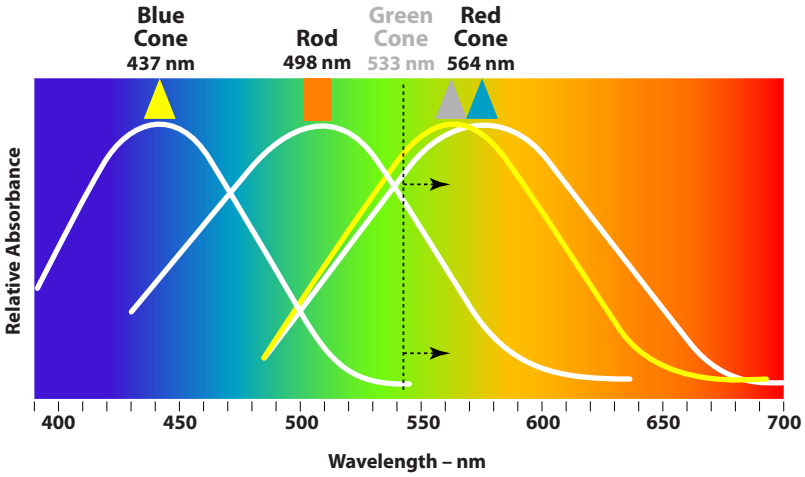
The Ishihara test uses Arabic numerals as the symbols in its charts, a number system *that is not used* by over 1.5 billion people in the world (The Chinese, who do not use the Arabic number system, represent approximately 25 percent of the world's population). The use of Arabic numerals also *presumes literacy* of the subject, something that cannot be assumed of very young children, people with mental deficiencies, and people who cannot read the numbers due to an inability to read – illiteracy. These factors make the Ishihara test less than ideal in the modern world.

My new method for testing for color-defective vision uses color plates similar to those used by Dr. Ishihara, and supplements those colors with several tests that are effective for detecting tritanopia.



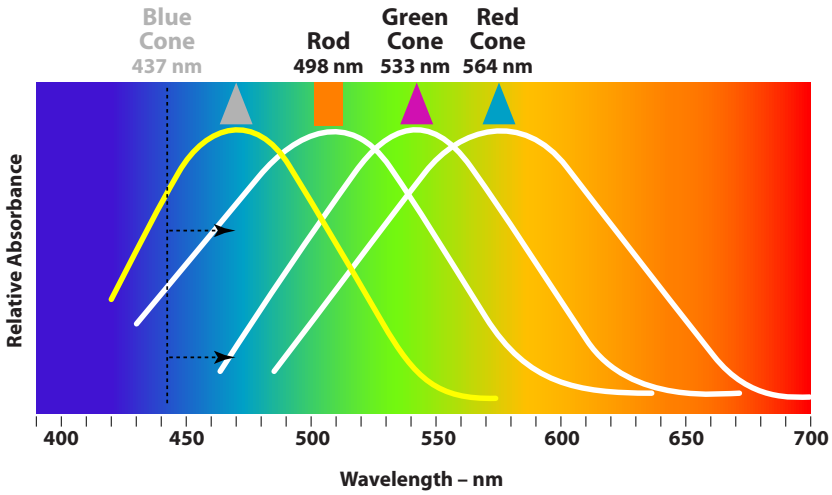
A person with a Deuteranopic color defect has red cones which have a sensitivity closer to the peak of green (shown here as a yellow sinusoidal line). As a result, subjects that would be seen as red by people with normal color vision appear green to the Deuteranope.

A *Deuteranope* sees reds with green sensitivity. The photo on the left is "normal" while the image on the right simulates the view of a Deuteranope. Note the bight reds at the top-left and the lower-center of the balloon are green instead of being bright red.



Protanopia is characterized by a shift in the sensitivity of the green cones toward the peak of red sensors. This is quite rare, affecting only about 2.5 percent of men, and less than one percent of women. The shift, indicated by the yellow sine wave above, is closer to 560 nm, where it normally falls at about 533 nm.

A *Protanope* sees greens with red sensitivity. The photo on the left is "normal" while the image on the right simulates the view of a Protanope. It's much more difficult to understand the effect of shifting green sensitivity toward red; the result is very similar to Deuteranopia, but colors that are created by a mix of green and red are lost to the green area of the spectrum.



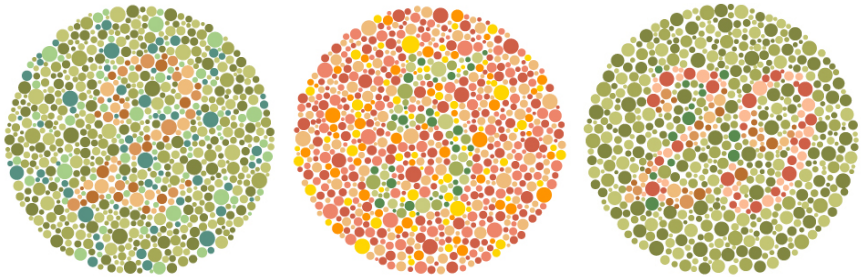
Tritanopia is a color defect where the cones that normally see blue have a sensitivity closer to green. This is a very rare form of color-defective vision, affecting only a fraction of a percentage of men – 0.5 percent, and almost no females. As shown in the diagram above, the sensitivity of cones that would normally see blue has shifted to the right, making it difficult for the person with this defect to differentiate between blues and greens.

A *Tritanope* sees color in a way that is very different than those with normal vision. The cones that normally see blue are shifted to the right, their sensitivity more like that of green, and because the eye mixes colors from the neural signals of red, green, and blue, the mixture is distorted toward the red end of the spectrum, resulting in more colors that appear pink, and no colors that could be called "green."

The tests will also isolate the two common red-green color defects more effectively so that a test administrator can determine if the subject has protanopia or deuteranopia.

In the graphic arts industry we rely on color to make our living. In the commercial work environment we rely on employees who can see and judge color effectively. Both the Ishihara test and the more complex *Farnsworth-Munsell* test are commonly used in our industry, and are commonly used as factors in testing new employees and employees for color-critical positions. We can do better as an industry by employing more modern color vision testing methods and systems.

Dr. Ishihara's test, though very common, is not as effective as it could be in setting a standard for the measurement of color vision

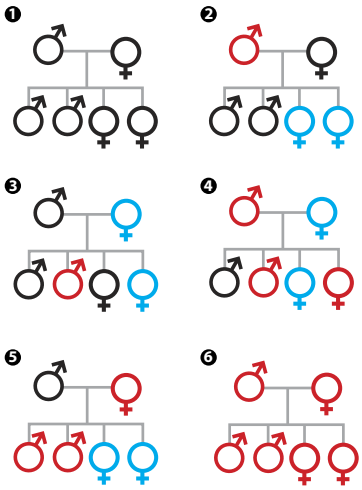


Three sample plates from the Ishihara Color-Blindness Test, published in 1963. Note that all are red-green-centric. In fact there is only one blue-gray plate in the book, and it is ineffective for testing for Tritanopic color defects. Note also that most of the plates feature an Arabic numeral. (Due to reproduction techniques, these plates cannot be considered color-accurate.)

in both clinical and industrial settings. I believe that my method is better suited to the modern world and the use of color on computers, printers, and in the creative arts.

Genetics and color-defective vision

A small percentage of the population has some form of color-defective vision. Often called *color-blindness,* color-defective vision is a result of inheritance (there are also some diseases and medications



The genetic possibilities of color-defective vision: Number 1: A "normal" pair of parents, both of whom have no color defects (and the mother does not carry the recessive color-defective chromosome). All of their children, regardless of gender, will have normal color vision. Number 2 is the another common combination, where the mother is not a carrier of the color-defective chromosome but the father has color-defective vision. The father passes his color-defective Y chromosome to both daughters in this example, and his two normal-vision sons. The daughters become carriers of two copies of the X chromosome; the sons do not. All of the children have normal vision, but the daughters then become recessiver carriers of the color-defective chromosome.

At 3, one of the daughters mates with a man with normal vision. The result in case No. 3 is one male child with color-defective vision and three children with normal vision (and one of the daughters is a carrier of the color-defective gene). The other genetic permutations are shown in examples 4 through 6. Blue indicates the carrier of the color-defective chromosome; red indicates a person with color-defective vision.

that can cause color vision damage). The X chromosome for color-defective vision is carried by the mother. The mother carries two copies of the X chromosome, it is recessive, and can be inherited by, or carried by her female children. Male children inherit color-defective genes from their parents in a pattern as described on the previous page. The chances of a male inheriting color-defective vision are approximately one in 20, or about 5%. The chances of a female inheriting color-defective vision are much lower – about one in 128, or 0.75%.

Color defects come in various types

Inheriting a color-defective vision gene will cause one of several types of color-defective vision:

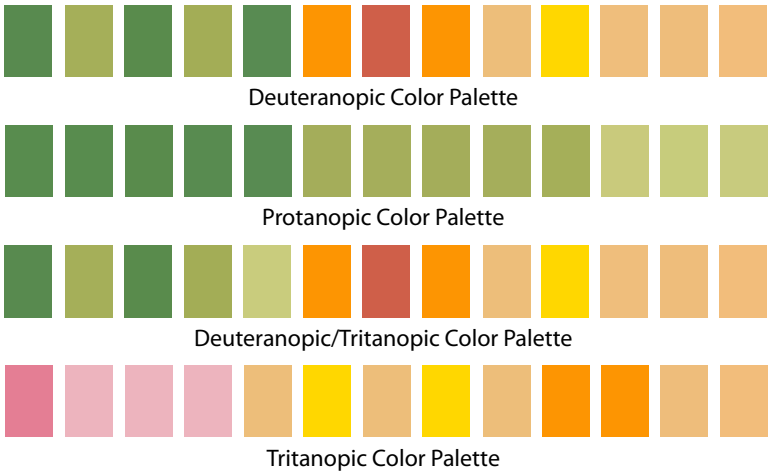
1. *Deuteranopia* – a red-green defect that affects a small percentage number of men and women

2. *Protanopia* – a red-green defect that affects a very small number of men and women

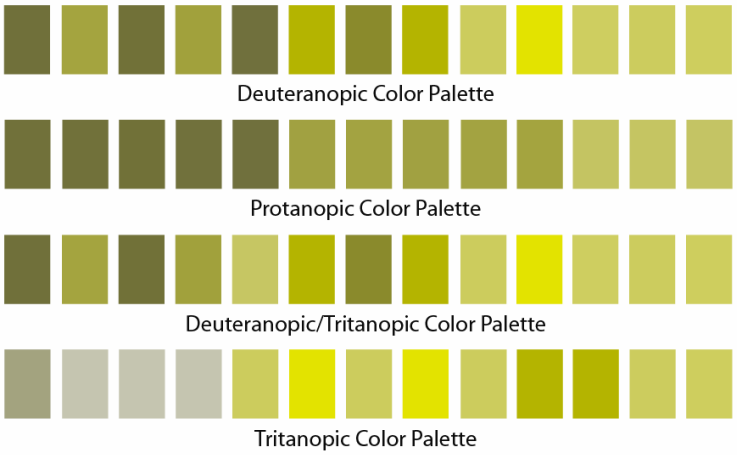
3. *Tritanopia* – a blue-green defect that affects a fractional percentage of the population

Deuteranopia is a red cone defect, where the sensitivity of the red sensors in the retina has shifted toward the green cone sensitivity, making the differentiation of red and green difficult for people with this type of color defect. Geneticists explain the prominence of this type of color-defect, which affects about five percent of men and less than one percent of women, as an anomalous development of cells which stand head-to-toe in the DNA chain. Because the pairs of color-defective genes are adjacent to each other, it is apparently easy for these genes to copy incorrectly, causing the red color-defective gene to predominate.

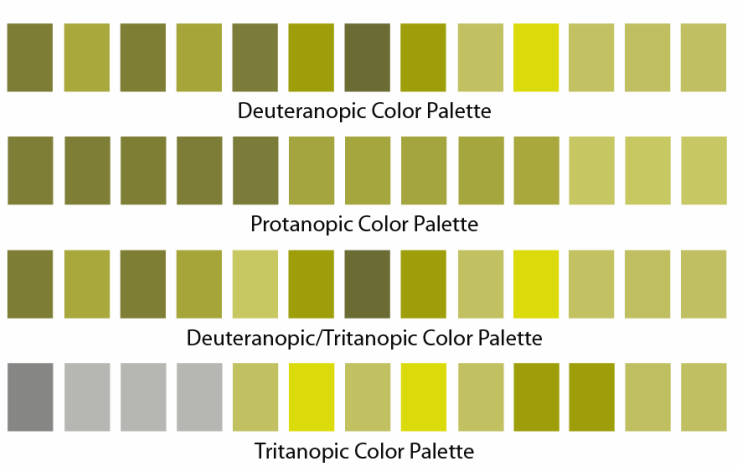
People with red-green color-defective vision of the deuteranopic type see things that are normally red as greens due to a shift in the sensitivity of the cones that would normally see red.



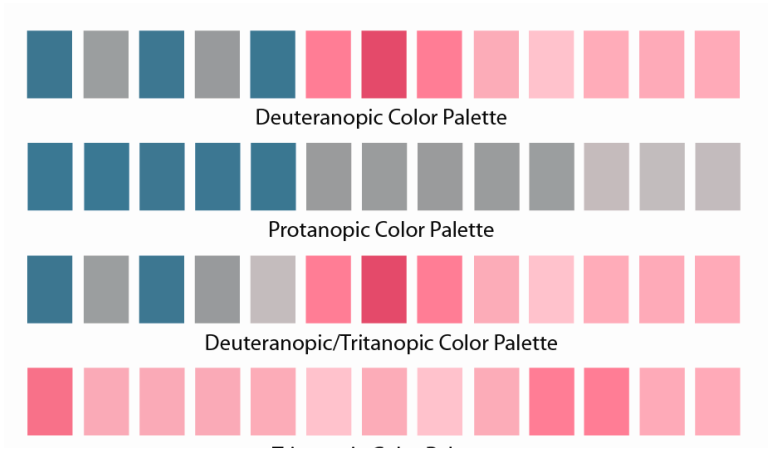
These are the color palettes with which I created my color test plates. I have many more colors than those in the Ishihara test plates. Printing these test plates with any conventional process color system (with halftone dot patterns) would render the test ineffective because of the presence of solid colors of magenta, cyan, or yellow. The colorants used to print the test plates must use non-halftone patterns for the plates to be effective or must be done with spot colors.



This is the appearance of the same color palette as above, but filters to show what a person with Deuteranopic color-defective vision sees. This is very telling, and it reveals the difficulty that these people have in seeing colors in the red-pink-orange part of the spectrum.



This is the Protanopic view of the same palette of colors. The difficulty in making a test that can help to differentiate between the two types of red-green color-defectives is that most of these colors are common to both groups. It is only by careful examination of the green shades that I was able to make a set of plates that the two groups can see or not see, exclusively.



Tritanopes see a very different range of colors in the palette I used for my test plates, and it was relatively easy to make a series of plates that can identify a tritanopic person. Unfortunately, I have never met such a person!

Protanopia is another form of red-green color vision defect, but in protanopia, the green sensors have a sensitivity with its peak closer to that of the red cones in a non-color-defective eye.

The *Tritanopic* genetic defect is believed by geneticists to be a random mutation of the blue sensor gene, which lies alone, as compared to the more common head-to-toe confusion of the red and green genetic markers. As a result, tritanopia is dramatically less common in humans than the other two types of color defects.

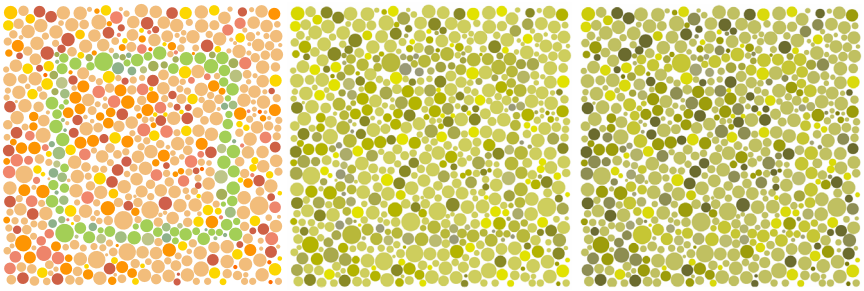
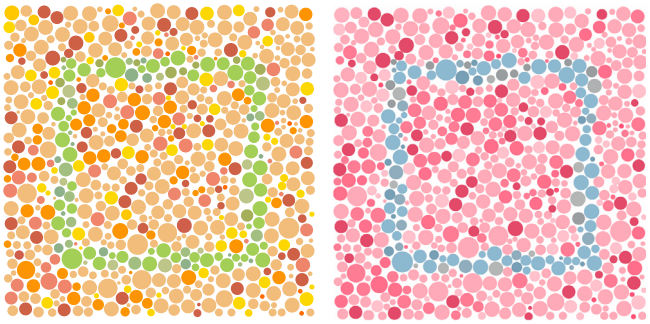


Plate One from my test booklet shows how a person with normal vision would see the square (Ishihara used numerals) on the left; in the center is the view of a deuteranope; on the right is the view of a protanope. With careful study, the deuteranope can see a very subtle square, while the protanope sees no pattern at all. These two examples of red-green color-defective vision show how difficult it is to differentiate between the Deuteranopic and protanopic view of the plates. Below are the "normal" and the tritanopic view of Plate One. The extremely rare Tritanope will see the square clearly, unlike those with a red-green color defect.



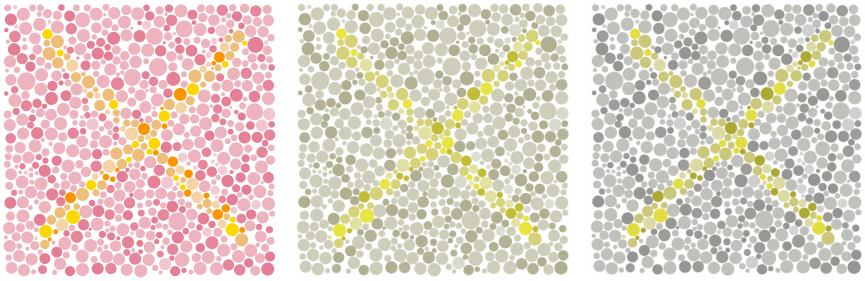
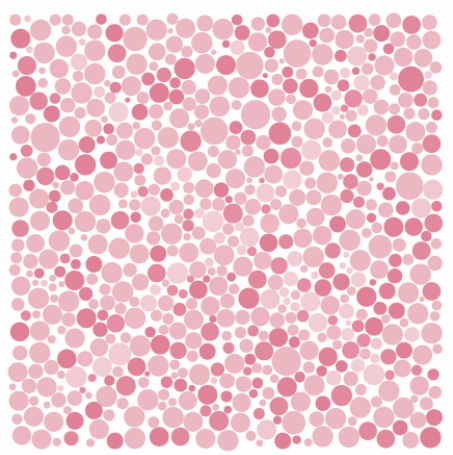


Plate Ten from my test is designed to identify the tritanope. On the left is the view for a person with normal vision. In the center is the view of a deuteranope; on the right is the view of a protanope. Both of the red-green color-defective types can see the X clearly in the plate. The tritanope, whose view is shown below, sees nothing in the plate except red and pink spots.



A fourth type of color-defective vision is *achromatopsia*, a profound color-blindness where the sensors in the eyes have no coloration, and thus the person cannot see color at all. Achromatopsia affects 0.003 percent of the population or less. It is so rare that most ophthalmic researchers go a lifetime without ever coming in contact with a person with this defect.

Testing for color-defective vision

The Ishihara *Test for Colour-Blindness* is handsomely printed, and seems to hold up well to the ravages of time. My copy was printed

in 1963, and it compares nicely (almost precisely) to a more recently-printed edition of the same book.

Shinobu Ishihara's tests for color-blindness are effective in determining if a person has one of the two red-green color defects, but the book plates are mostly ineffective in assigning one of the two. And, the Ishihara test plates do not test for, nor identify tritanopia.

The guidebook that accompanies the Ishihara plates is quite clear in the author's intentions. Though he acknowledges tritanomaly and tritanopia, he discounts this rare form of color-defective vision in his book, saying, "…a failure in the appreciation of blue and yellow may be termed *tritanomalia* if partial, and *tritanopia* if absolute, but even if such cases do exist, they are extraordinarily rare. The plates in this book are not designed for the diagnosis of such cases."

Ishihara also has included seven "winding line" tests to help define color-defective vision in people who cannot read Arabic numerals. These plates are supposed to be used by such people by having them trace a line from one side to the other, following a serpentine trail of colors. Ishihara's plates can be effective for non-readers who have one of the two common red-green color defects.

Developing a new test for color-defective vision

After using, studying and analyzing the Ishihara test plates for years, I came to the conclusion that the tests, though well-regarded, are simply out of date. We need a different type of test that affords diagnosticians and laymen the ability to test for color defective vision, to identify it correctly, and to be able to find the rare Tritanope.

I believe that the use of Arabic numerals is unfair to a large number of people in the world, so decided that my test should use symbols instead of numerals. As a result, I use a square, a circle and a triangle as my symbols, objects that can be identified by almost anyone from any culture.

Identifying the narrow range of colors specific to red-green color-defective vision

One of the weaknesses in the Ishihara test plates is the difficulty of identifying which of the two common red-green color defects is present. I set my first criterion as identifying colors that are unique to the weaknesses of both deuteranopia and protanopia. Since both types of red-green color defectives seem to see things similarly, I had to identify a method for isolating the defect of one type of color anomaly from the other.

With these colors identified, I could build a test plate that a deuteranope would fail and a protanope would pass. This turns out to be exceedingly difficult because of the cross-over of colors (one could call this a *bi-stimulus*) in the range of reds and greens in the human-visible spectrum.

I began by making spectral readings of the Ishihara test pages, and building a palette of colors based on the solids in the Ishihara plates. Then I began a process of building my ten plates with similar colors. I started with a deuteranopic color palette, distributing dots of random size in a large square. For this I used Adobe Illustrator to create the color plates. The distribution of the colors was done by hand, being careful not to cluster too many of the same color spots together, as some color-defective people are extraordinarily good at seeing tonal values, and one of the objectives of any test of color-defective vision is to prevent the "gleaning" of a tonal pattern in the plates. I carefully added adjacent colors to my palette to add randomness to the color plates, and make the differentiation of colors more difficult to the deuteranopic person.

Deuteranopic and Protanopic test plates

To test my plates, I used the (new) *Deuteranopic* filter in Adobe Photoshop CS4, and a display simulation application called *Color Oracle,* written by Bernhard Jenny of the Swiss Institute of Cartography in Zurich. In essence this was a process of adjust-and-test, with very subtle color adjustments to make the colors invisible to

the Deuteranope while keeping them visible to the Protanope.

Once I had the Deuteranopic plates complete, I did the same thing again with a different palette of colors fine-tuned to "favor" the color defects of protanopes while allowing deuteranopes to see the patterns in the color plates. This allows the person administering the test to differentiate between the two common red-green color-defective vision types.

Tritanopic test plates

For the tritanopic plates, of which there are five, I built a color palette that is uniquely difficult for a tritanope to distinguish, but which is clearly visible to red-green color defectives and people with normal vision. The colors in the tritanopic palette are red, pink, yellow and orange.

The test booklet

On the reverse of each page of my test are four example images with labels showing what is seen by a person with normal vision, a person with deuteranopic vision, a person with protanopic vision, and a person with tritanopic vision. Test administrators with normal color vision will see what the person being tested is seeing, and will be able to determine their particular type of color defect according to their response to the test plates.

Decoding the two red-green color-defective types is very difficult, and my plates must be studied carefully to see the subtle differences between the sensitivities of the deuteranopics and the protanopics. To the person taking the test, the ability to discern a pattern, or not discern a pattern, may be the only hint that they fall into one category or the other. However, the inability to see reds will immediately segregate the two red-green classes from those with normal vision, and those with tritanopic vision.

Just as Dr. Ishihara never encountered a tritanope in his career, I have never encountered a tritanope on whom to test my plates. I am working entirely from existing research on the tritanopic col-

or-defect. As a result, my plates have never been tested on such a subject. I am currently in search of a tritanope on whom to test the plates.

Red-green color-defective persons are quite common, and I am acquainted with several who have shared their perspectives on my new test plates. For deuteranopics my test is very effective; so far I have not identified a protanopic person, though I am sure I will with time and additional searching.

Since I have access to about 50 students per year who are required to take these tests as a part of their course work, I have a good test group on whom to test my plates. Beginning this fall, I will test each student with the Ishihara, with my new test, and with the Farnsworth-Munsell color discrimination test.

After a suitable test period, during which I plan to engage the assistance of several ophthalmologists and researchers nationwide, I will adjust the test booklet as necessary and then make it available to the public.

References:

Color Plates from Ishihara test book: Ishihara, Shinobu – *Tests for Colour-Blindness*, Kanehara Shuppan Co., Ltd. Tokyo, 1963

Electromagnetic spectrum illustration derived from information by Dowling, John E. – *The Retina, An Approachable Part of the Brain, Belknap Press, 1987*

Genetic chart is based on statistical information from various authors in *Causes of Color,* WebExhibits, Institute for Dynamic Educational Advancement, U.S. Dept. of Education (not dated)

Simulated color-defective images made with *Color Oracle,* a computer application written by Bernhard Jenny, Institute of Cartography, Zurich, Switzerland, Copyright 2006-2009.

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