

# Novel Classification of the Degree of Color Vision Defects in General Practice: Simulations of Cap Number and Saturation of the Farnsworth Dichotomous Test D-15

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Received date: February 12, 2018; Accepted date: February 28, 2018; Published date: March 05, 2018

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## Abstract

**Objective:** In most eye clinics, while severe to moderate color vision defects are diagnosed with the Farnsworth dichotomous test D-15 (D-15 test), moderate to mild color vision defects are detected with the Farnsworth lantern test. This study aims to propose a new classification of the degree of color vision defects in general practice by simulations of the cap number and saturation of the D-15 test.

**Methods:** We performed the simulation of the modified D-15 tests with a reduced number of test caps (9 and 6 caps) to compress a hue circle based on the color confusion lines for the hypothetical participant. In addition, we performed another simulation of the modified D-15 test with modified chroma test caps (chroma 6 and 2).

**Results:** The color confusion along the confusion lines was more likely to occur as the number of caps decreased in our simulation model. The modified chroma D-15 test did not affect the results of this study.

**Conclusion:** The results of this study reveal that the D-15 test with a reduced number of test caps has possibilities to classify patients with moderate or mild color vision defects.

**Keywords:** D-15 test; Color vision test; Number of caps; Saturation of color caps; Degree of color vision

## Introduction

As Farnsworth described in 1957 [1], it is more important for industries to ascertain the severity levels of color vision defects (CVD) than to classify CVD into protan or deutan. In 1957, Farnsworth developed a method to categorize CVD into four groups, also known as “Farnsworth classification for industrial use”, by combining pseudoisochromatic plates, the lantern test, and the Farnsworth dichotomous test D-15 (D-15 test).

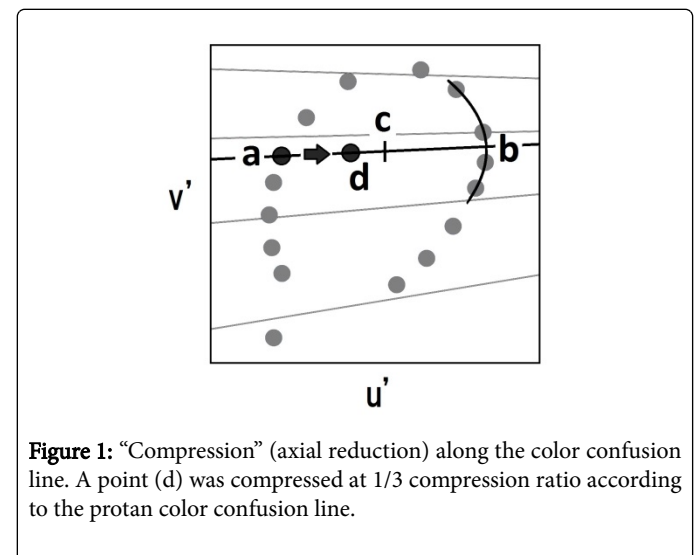
Most eye clinics do not have the Farnsworth lantern test available and hence use the D-15 test alone to classify subjects into two categories based on CVD classification: “moderate or less” and “severe”. This study aims to propose a new classification of the degree of color vision defects in general practice by simulations of the cap number and saturation of the Farnsworth dichotomous test D-15.

## Methods

### Simulating the D-15 test with “compressed” colors

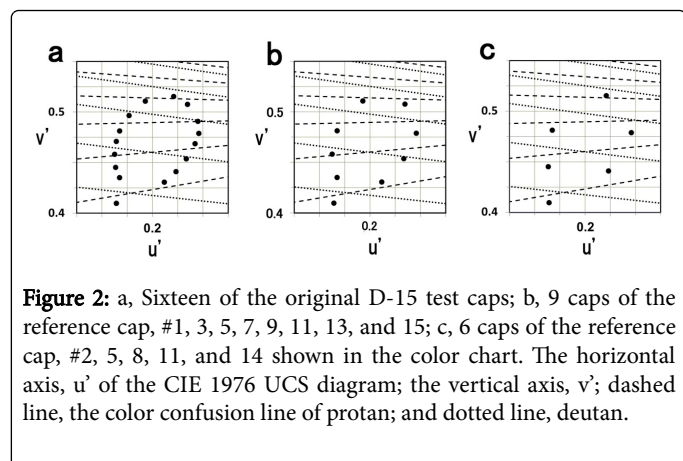
Simulation of the D-15 test with axial reduction (“compressed” colors) warrants using a uniform chromaticity scale (UCS) diagram wherein the distance between two coordinate points correlates with the color difference between them. Because the perfect UCS diagram has not been established yet, we used the Commission Internationale de

l'éclairage (CIE) 1976 UCS Diagram that was adopted by the International Commission on Illumination in 1976.



We plotted the color chart of the D-15 test on the CIE 1976 UCS diagram and moved these points along the confusion color lines at a constant ratio toward the center of the color circle. We determined the point (b) at which the confusion color line passes through a coordinate test cap (a) of the D-15 test on the chromaticity diagram, and set the middle point of the line (ab) as (c) (Figure 1). Then, the color indicated by the coordinate point (d) for dividing the straight line (ac) at a

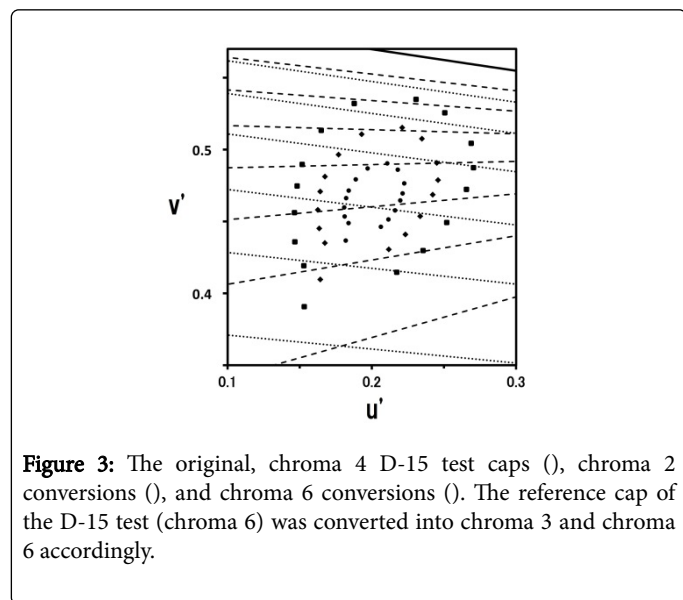
constant ratio (dc divided by ac; “compression ratio”) was defined as a newly manufactured cap of the D-15 test that we used for our simulation. We performed this operation for all 16 color caps of the D-15 test. Assuming a strong correlation between the distance on the CIE 1976 UCS diagram and the color difference, we simulated the color alignment test results by calculating the distance between the two newly determined coordinate points of 16 color caps which were newly manufactured by the method explained above and connecting the closest distance coordinate points.



**Figure 2:** a, Sixteen of the original D-15 test caps; b, 9 caps of the reference cap, #1, 3, 5, 7, 9, 11, 13, and 15; c, 6 caps of the reference cap, #2, 5, 8, 11, and 14 shown in the color chart. The horizontal axis,  $u'$  of the CIE 1976 UCS diagram; the vertical axis,  $v'$ ; dashed line, the color confusion line of protan; and dotted line, deutan.

### Simulating the D-15 test with reduced number of caps

Among the caps used in the D-15 test, we selected 9 caps (reference cap, #1, 3, 5, 7, 9, 11, 13 and 15) or 6 caps (reference cap, # 2, 5, 8, 11 and 14) to perform the simulation. Figure 2 shows the coordinate points indicating the newly determined color caps.

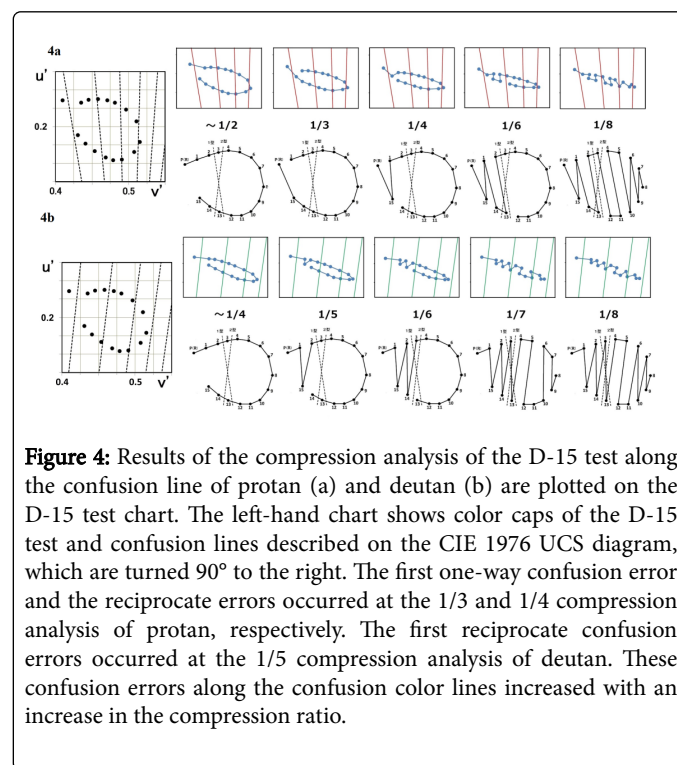


**Figure 3:** The original, chroma 4 D-15 test caps ( $\circ$ ), chroma 2 conversions ( $\square$ ), and chroma 6 conversions ( $\triangle$ ). The reference cap of the D-15 test (chroma 6) was converted into chroma 3 and chroma 6 accordingly.

### Simulating the modified saturation of the D-15 test

While the reference cap of the D-15 test was chroma 6, remaining test caps were chroma 4. In the present study, we performed simulation by changing the reference cap to chroma 8 and the test caps of the D-15 test to chroma 6 and by changing the reference cap to chroma 3

and the test caps to chroma 2. Figure 3 shows the newly determined color caps.



**Figure 4:** Results of the compression analysis of the D-15 test along the confusion line of protan (a) and deutan (b) are plotted on the D-15 test chart. The left-hand chart shows color caps of the D-15 test and confusion lines described on the CIE 1976 UCS diagram, which are turned 90° to the right. The first one-way confusion error and the reciprocal errors occurred at the  $1/3$  and  $1/4$  compression analysis of protan, respectively. The first reciprocal confusion errors occurred at the  $1/5$  compression analysis of deutan. These confusion errors along the confusion color lines increased with an increase in the compression ratio.

## Results

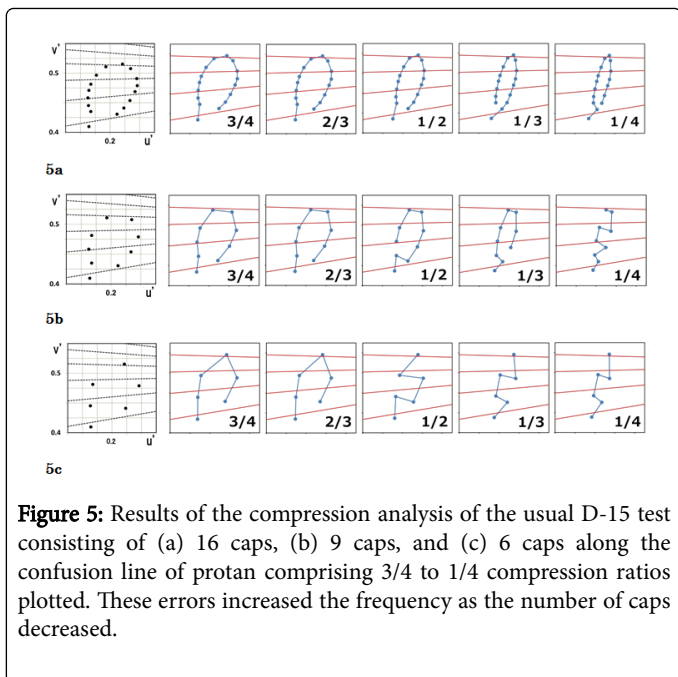
### Simulation of the compressed D-15 test

Figure 4 represents the simulation results of the modified D-15 test that was transferred to the D-15 test chart. While Figure 4a shows the simulated results of protan, those of deutan are shown in Figure 4b. In addition, the simulation results on the CIE 1976 UCS diagram were shown by turning approximately 90° in the clockwise direction to make the simulation results compatible with the D-15 test chart.

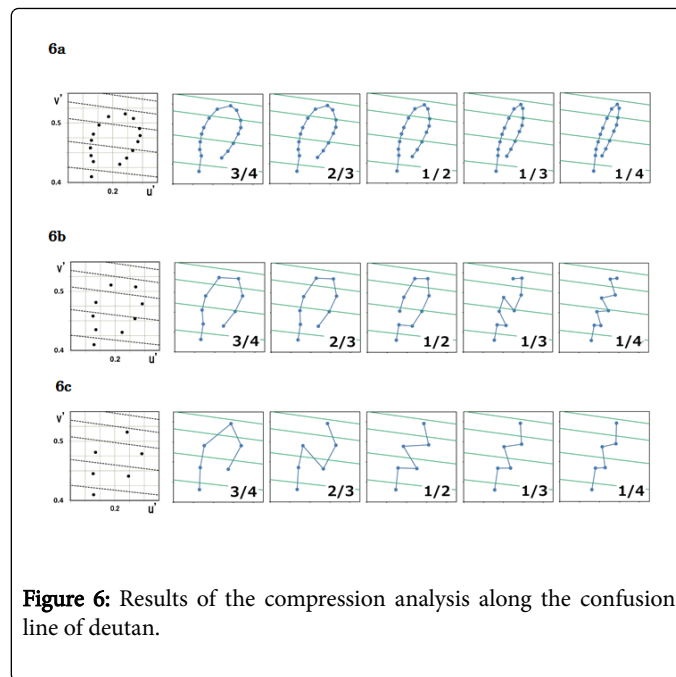
The color confusion along the confusion color lines increased with an increase in the compression ratio. In addition, the results of protan and deutan revealed one reciprocal crossover along the confusion color line at  $1/4$  and  $1/5$  compression ratios, respectively, suggesting that the D-15 test failure started at  $1/4$  and  $1/5$  compression ratios, respectively. The results that the color confusion errors started at the left side area of the index lines are compatible with the diagnosis of the D-15 test that is routinely performed for the confusion errors at the near point of the index lines in the chart. These results indicate that our simulation model could coincide with the results of the original D-15 test for CVD.

### Simulation of the D-15 test with reduced number of caps

Figures 5 and 6 present the simulation results of protan and deutan obtained by decreasing the number of D-15 test caps, respectively. While Figures 5a and 6a reveal the simulation results of the original D-15 test, Figures 5b and 6b and Figures 5c and 6c present the simulation results of modified D-15 tests with 9 and 6 caps, respectively.



**Figure 5:** Results of the compression analysis of the usual D-15 test consisting of (a) 16 caps, (b) 9 caps, and (c) 6 caps along the confusion line of protan comprising 3/4 to 1/4 compression ratios plotted. These errors increased the frequency as the number of caps decreased.



**Figure 6:** Results of the compression analysis along the confusion line of deutan.

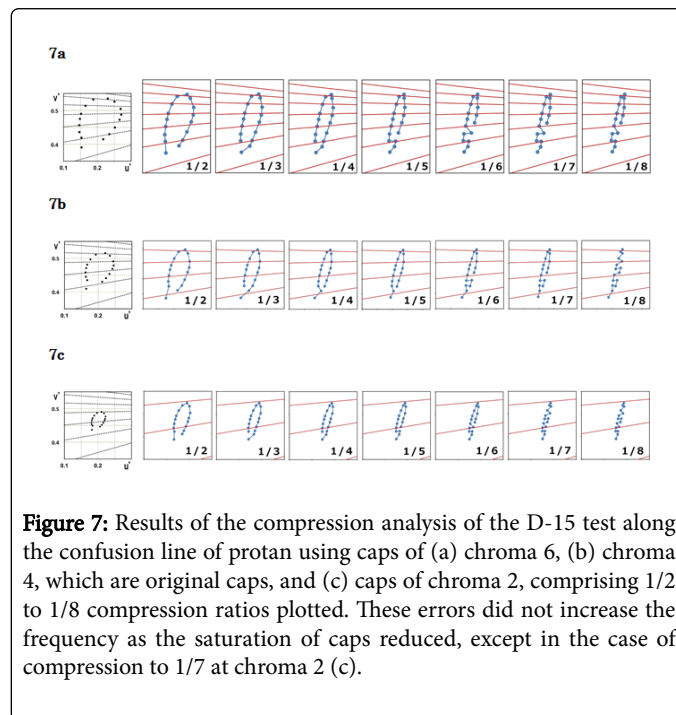
The color difference between adjacent caps increased as the number of caps decreased, and the color confusion along the confusion line was more likely to occur; this tendency was more pronounced when the simulation was performed with 6 caps than 9 caps. In the simulation performed with 9 caps, the color confusion started from 1/2 compression ratio in both protan and deutan (Figures 5b and 6b), and the compression ratio of 1/4 caused complete color confusion. In contrast, in the simulation using 6 caps, complete color confusion occurred at 1/2 compression ratio for both protan and deutan (Figures 5c and 6c).

### Simulation of the modified saturation of the D-15 test

Figures 7 and 8 present the simulation results by modifying the saturation of the D-15 test of protan and deutan, respectively. When increasing the saturation of test caps of the D15 test with chroma 4 to 6 (Figures 7a and 8a), the simulation result was almost similar to the result of the original chroma 4 ((Figures 7b and 8b). Lowering the saturation to chroma 2 revealed that only in the case of compression to 1/7 in protan (Figures 7c) and 1/6 in deutan (Figures 8c), a little more color confusion occurred compared to the result of saturation at chroma 4, but other cases of compression revealed almost similar results compared with those of chroma 4. Overall, the change in chroma had little impact on the likelihood of color confusion.

### Discussion

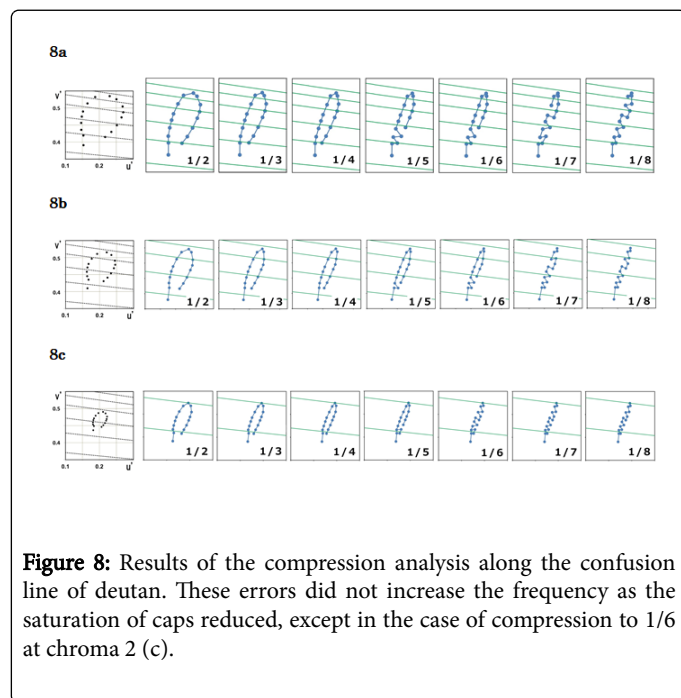
Since Farnsworth announced the Farnsworth–Munsell 100 hue test and dichotomous test B-20 in 1943 [2], several trials of CVD judgment using the color alignment tests have been reported. While the Farnsworth–Munsell 100 hue test is a quantitative test to determine the total number of misalignments, the dichotomous test B-20, assessing whether color confusion of the cap on the hue circle with the one on the opposite side, is a qualitative test that divides subjects into “pass” or “fail.” The D-15 test has been derived from the dichotomous test B-20.



**Figure 7:** Results of the compression analysis of the D-15 test along the confusion line of protan using caps of (a) chroma 6, (b) chroma 4, which are original caps, and (c) caps of chroma 2, comprising 1/2 to 1/8 compression ratios plotted. These errors did not increase the frequency as the saturation of caps reduced, except in the case of compression to 1/7 at chroma 2 (c).

The Lanthony desaturated 15 hue test [3] and the Lanthony New Color Test [4] are other tests that use different chroma from the D-15 test and specialize in testing acquired CVD. However, based on our simulation results, these tests were not appropriate to determine the severity of congenital CVD, because the change in chroma had little impact on the likelihood of color confusion. The Lanthony 40 hue test [5] and Roth 28 hue test [6] are color tests in which the number of test caps varies from that in the D-15 test. Although these tests are a good compromise between the D-15 test and the Farnsworth–Munsell 100 hue test, these are not suitable for moderate CVD who can pass the D-15 test, because the number of caps in these tests greater than that in

the D-15 test. Principles of color association accompanying axial reduction for various axial ratios along the confusion lines have been well understood [2]; however, we could not find any study on detailed simulation of the D-15 test with respect to the number and saturation of caps for CVD.



**Figure 8:** Results of the compression analysis along the confusion line of deutan. These errors did not increase the frequency as the saturation of caps reduced, except in the case of compression to 1/6 at chroma 2 (c).

In this study, we performed compression simulation assuming that all points on the chromaticity diagrams comprise confusion color bands in anomalous trichromats of the same width along the confusion color line; however, there is a possibility that these were not of the same width in anomalous trichromats. Assumedly, the slope of the confusion color line of anomalous trichromats is slightly different from that of protan or deutan because the wavelength absorption characteristics of the opsin derived from the hybrid opsin gene are slightly different depending on the type of the gene [7-9]. However, our simulation was based on the premise that confusion color lines of protan and deutan on the CIE 1976 UCS diagram apply to all types of CVD.

In the compression simulation performed by reducing the number of test caps to 9 (reference-1-3-5-7-9-11-13-15) or 6 (reference-2-5-8-11-14), the color difference between the cap and the one on the opposite side of the color circle was smaller than the adjacent one, enabling easy drawing of the crossing line despite the low compression ratio. Possibly, the reduced-number D-15 test we developed in the present study has ability to categorize patients with moderate or less CVD into one of three categories: (a) “moderate” CVD, those who pass the D-15 test but fail the 9 cap test; (b) “mild” CVD, those who pass the 9 cap test but fail the 6 cap test; and (c) “very mild” CVD, those who pass the 6 cap test.

In addition, the order to conduct the D-15 test series is considered as a factor that might affect the results. If the original D-15 test is performed first, patients who pass it will memorize the order of the colors of test caps and enhance the probability of passing the next test with reduced caps. Hence, it is essential to conduct the modified D-15 test with 6 caps first, followed by 9 caps, and the original D-15 test with 16 caps. Overall, the D-15 test with a reduced number of test caps has possibilities to classify patients with moderate or mild color vision defects.

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