Observers with defective color vision confuse colors that to the color-normal observer may appear quite different. Tritan observers are characterized by color confusions, such as green with blue or yellow with violet. König described the tritan defect as characteristic of the normal observer when a small field of view is used. Later, he described similar color-vision defects accompanying eye disease. König apparently did not consider that he had seen the tritan defect as a congenital color defect in persons without ophthalmoscopic abnormality. Waardenburg, however, thought that at least one of König's patients was a congenital tritanope. Similar to protanopia and deuteranopia, tritanopia is usually considered a loss system, affecting the short-wavelength-sensitive (SWS) cones.

Tritan defects were reported rarely and without a hereditary basis until Wright used a magazine article (Picture Post) to attract the attention of possible tritan observers. As a result, Wright confirmed tritanopia in 17 persons and measured 1.2° color-matching characteristics for 7 of them. Kalmus demonstrated an autosomal dominant inheritance in his study of the families of 22 tritans.

The mechanism of tritanomaly, a trichromatic form of tritan defect, is puzzling. Tritanomaly is classified as an alteration system, implying that one or more of the cone visual photopigments differ in their absorption spectra from that of the color-normal observer; an equation for tritanomaly would, as Wright cautioned, be sensitive to interobserver variation in density of macular pigmentation.

The use of blue-green equations for recognition of tritanomaly is therefore not so certain as the use of the Rayleigh equation for recognition of congenital X-linked red-green color-vision defects.

Engelking described the original published case of tritanomaly in his student Hartung. Hartung found the defect in two of his maternal uncles, the more severely affected being described as almost tritanopic. Although initial data suggested X-chromosomal-linked inheritance, subsequent pedigrees stressed phenotypic variation with autosomal dominant inheritance in tritanomaly. Cole et al. suggested that there was no evidence that tritanomaly was transmitted as a separate genetic entity, but they could not distinguish tritanomaly from incomplete tritanopia in their pedigree.

We had the opportunity to study many individuals with an autosomal dominant tritan defect in The Netherlands by using a Moreland anomaloscope. We were interested in two issues. First, we wished to learn if the size of the field of view affected color-matching performance. One of the Wright tritanopes showed dichromacy for a 1.75° parafoveal field. However, larger field sizes were not presented. We thought it possible that phenotypic variation might be different for 1° and 8° fields. Second, we wished to evaluate all affected family members for tritanomaly. For this purpose we used the blue-green equation specifically designed for detection of tritanomaly.

Screening and Criteria for Selection of Tritans

In contrast with tests to screen for red-green defects, there are relatively few tests to screen tritan defects. The tritan tests are unvalidated, having been used on rather few tritan observers. A recently developed test that is a sensitive indicator of tritan defects is the TNO tritan test, in which the observer is required to detect a 0.8°, 456-nm rectangular stimulus that flickers at 0.5 Hz on a 14° 6000-cd-m⁻² yellow-adapting field. A slide with four neutral filters is interposed before the blue test field. The filter densities are calculated so that after chromatic adaptation of 1–2 min to the
Table 1. Summary of Color Matching for Autosomal Dominant Tritan Observers

<table>
<thead>
<tr>
<th>Pedigree 1</th>
<th>Family Information</th>
<th>Age</th>
<th>Sex</th>
<th>Defect</th>
<th>Red-Green Coefficient ( \theta )</th>
<th>Moreland Equation ( \theta )</th>
</tr>
</thead>
<tbody>
<tr>
<td>III-1</td>
<td>children of II-1</td>
<td>47</td>
<td>M</td>
<td></td>
<td>( X ) ( X ) ( X ) S</td>
<td>S</td>
</tr>
<tr>
<td>III-5</td>
<td></td>
<td>39</td>
<td>F</td>
<td></td>
<td>( X(\text{RE}) ) ( \text{LE; S; RE; N?} )</td>
<td>( \text{LE; S; RE; N?} )</td>
</tr>
<tr>
<td>III-6</td>
<td></td>
<td>38</td>
<td>M</td>
<td></td>
<td>U U U U</td>
<td>U N?</td>
</tr>
<tr>
<td>III-18</td>
<td>children of II-5</td>
<td>23</td>
<td>F</td>
<td></td>
<td>( \sqrt{0} ) ( \sqrt{0} ) ( X ) X S</td>
<td>N</td>
</tr>
<tr>
<td>III-19</td>
<td></td>
<td>21</td>
<td>F</td>
<td></td>
<td>X - - -</td>
<td>F N</td>
</tr>
<tr>
<td>III-20</td>
<td></td>
<td>20</td>
<td>F</td>
<td></td>
<td>( \sqrt{0} ) ( X) - -</td>
<td>F N</td>
</tr>
<tr>
<td>III-29</td>
<td>children of II-10</td>
<td>33</td>
<td>M</td>
<td>DA</td>
<td>X - - -</td>
<td>F N</td>
</tr>
<tr>
<td>III-30</td>
<td></td>
<td>31</td>
<td>M</td>
<td></td>
<td>( \sqrt{0} ) ( \sqrt{0} ) ( \sqrt{0} )</td>
<td>F W</td>
</tr>
<tr>
<td>III-34</td>
<td></td>
<td>20</td>
<td>M</td>
<td>DA</td>
<td>X - - -</td>
<td>F N</td>
</tr>
<tr>
<td>III-36</td>
<td>children of II-13</td>
<td>32</td>
<td>F</td>
<td></td>
<td>X(OU) ( \text{LE; S; RE; N?} )</td>
<td>( \text{LE; S; RE; N?} )</td>
</tr>
<tr>
<td>III-38</td>
<td>(deceased)</td>
<td>28</td>
<td>M</td>
<td></td>
<td>X - - -</td>
<td>W N</td>
</tr>
<tr>
<td>III-40</td>
<td></td>
<td>23</td>
<td>F</td>
<td></td>
<td>X - - -</td>
<td>S N</td>
</tr>
<tr>
<td>III-43</td>
<td>children of II-15</td>
<td>24</td>
<td>F</td>
<td></td>
<td>( \sqrt{0} ) ( \sqrt{0} ) ( X) - -</td>
<td>F N</td>
</tr>
<tr>
<td>IV-2</td>
<td>child of III-1</td>
<td>11</td>
<td>M</td>
<td></td>
<td>X - - -</td>
<td>S N</td>
</tr>
<tr>
<td>IV-15</td>
<td>child of III-5</td>
<td>9</td>
<td>F</td>
<td></td>
<td>U U U U</td>
<td>S U</td>
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<table>
<thead>
<tr>
<th>Pedigree 2</th>
<th>Family Information</th>
<th>Age</th>
<th>Sex</th>
<th>Defect</th>
<th>Red-Green Coefficient ( \theta )</th>
<th>Moreland Equation ( \theta )</th>
</tr>
</thead>
<tbody>
<tr>
<td>II-1</td>
<td>siblings</td>
<td>47</td>
<td>F</td>
<td></td>
<td>( \sqrt{0} ) ( \sqrt{0} ) ( \sqrt{0} ) ( \sqrt{0} )</td>
<td>F W</td>
</tr>
<tr>
<td>II-3</td>
<td></td>
<td>46</td>
<td>M</td>
<td>DA</td>
<td>( \sqrt{0} ) ( \sqrt{0} ) ( X) X F</td>
<td>W W</td>
</tr>
<tr>
<td>II-4</td>
<td></td>
<td>35</td>
<td>M</td>
<td></td>
<td>( \sqrt{0} ) ( \sqrt{0} ) ( X) X F</td>
<td>W W</td>
</tr>
<tr>
<td>II-5</td>
<td></td>
<td>32</td>
<td>M</td>
<td>DA</td>
<td>X - - -</td>
<td>W N</td>
</tr>
<tr>
<td>III-1</td>
<td>child of II-1</td>
<td>11</td>
<td>M</td>
<td></td>
<td>X X - -</td>
<td>W N</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Pedigree 3</th>
<th>Family Information</th>
<th>Age</th>
<th>Sex</th>
<th>Defect</th>
<th>Red-Green Coefficient ( \theta )</th>
<th>Moreland Equation ( \theta )</th>
</tr>
</thead>
<tbody>
<tr>
<td>II-2</td>
<td>siblings</td>
<td>54</td>
<td>M</td>
<td></td>
<td>X - - -</td>
<td>W N</td>
</tr>
<tr>
<td>II-3</td>
<td></td>
<td>49</td>
<td>F</td>
<td></td>
<td>( \sqrt{0} ) ( \sqrt{0} ) ( X) X F</td>
<td>W W</td>
</tr>
<tr>
<td>II-5</td>
<td></td>
<td>47</td>
<td>F</td>
<td></td>
<td>X X - -</td>
<td>F W</td>
</tr>
<tr>
<td>II-7</td>
<td></td>
<td>45</td>
<td>M</td>
<td></td>
<td>( \sqrt{0} ) ( \sqrt{0} ) ( X) X F</td>
<td>F F</td>
</tr>
<tr>
<td>III-9</td>
<td>children of II-4</td>
<td>22</td>
<td>M</td>
<td>DA</td>
<td>( \sqrt{0} ) ( \sqrt{0} ) ( X) X W</td>
<td>N N</td>
</tr>
<tr>
<td>III-11</td>
<td></td>
<td>17</td>
<td>F</td>
<td></td>
<td>X X - -</td>
<td>F F</td>
</tr>
<tr>
<td>III-12</td>
<td></td>
<td>11</td>
<td>M</td>
<td></td>
<td>X X - -</td>
<td>F F</td>
</tr>
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</table>

<table>
<thead>
<tr>
<th>Pedigree 4</th>
<th>Family Information</th>
<th>Age</th>
<th>Sex</th>
<th>Defect</th>
<th>Red-Green Coefficient ( \theta )</th>
<th>Moreland Equation ( \theta )</th>
</tr>
</thead>
<tbody>
<tr>
<td>III-17</td>
<td></td>
<td>55</td>
<td>F</td>
<td></td>
<td>X X - -</td>
<td>F N</td>
</tr>
<tr>
<td>IV-15</td>
<td>children of III-17</td>
<td>29</td>
<td>F</td>
<td></td>
<td>X - - -</td>
<td>F N</td>
</tr>
<tr>
<td>IV-20</td>
<td></td>
<td>25</td>
<td>F</td>
<td></td>
<td>( \sqrt{0} ) ( \sqrt{0} ) ( X) X F</td>
<td>W W</td>
</tr>
<tr>
<td>IV-22</td>
<td></td>
<td>20</td>
<td>F</td>
<td></td>
<td>X - - -</td>
<td>S N</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Pedigree 5</th>
<th>Family Information</th>
<th>Age</th>
<th>Sex</th>
<th>Defect</th>
<th>Red-Green Coefficient ( \theta )</th>
<th>Moreland Equation ( \theta )</th>
</tr>
</thead>
<tbody>
<tr>
<td>II-1</td>
<td></td>
<td>39</td>
<td>F</td>
<td></td>
<td>( \sqrt{0} ) ( \sqrt{0} ) ( X) X F</td>
<td>W W</td>
</tr>
</tbody>
</table>

\* \( \sqrt{0} \), accepts; X, refuses; - , not tested; U, untestable.
\* \( N\), normal; S, shift; W, wide; F, full; U, untestable.

yellow field, detection of the test field should be mediated by SWS cones for slide positions 1 and 2 and by SWS, MWS, or LWS cones for slide positions 3 and 4. The observer with normal color vision or an X-linked red-green defect should detect the test field for all four slide positions. The observer with a functional reduction in SWS sensitivity may detect the test field only at slide position 3 or 4.

It was anticipated that elderly observers or observers with acquired color-vision defects would also fail the TNO tritan test. We therefore adopted the following as minimal criteria for diagnosis of autosomal dominant tritan defects:

(1) The individual should fail the TNO tritan test.
(2) Positive family history. One parent should also fail...
the TNO tritan test, or family study should reveal an autosomal dominant mode of inheritance.

(3) There should be no indication of optic atrophy or other ophthalmologic disease.

We tested 39 observers with an autosomal dominant tritan defect who met these criteria.

Observers
The tritan observers came from five families (Table 1).

Pedigree 1
This was a large pedigree in which we tested 22 tritan members. The index case (III-19) was found in a screening of 400 students by using the TNO tritan test. Subsequently, other family members representing three generations were tested. We evaluated by anomaloscope 22 of the 26 who failed the TNO tritan test as well as 7 other family members.

Pedigree 2
The index case of this family was found in a screening at a medical instrument convention by using the TNO tritan test. A tritan defect was subsequently established in three siblings and a nephew of the index case, all of whom we tested.

Pedigree 3
This family was described as family B by van de Merendonk and Went. The index case (III-10), a deuteranomalous trichromat, was found in a school screening for red-green defects by using pseudoisochromatic plates as screening devices. An autosomal dominant tritan defect was subsequently discovered in eight family members, of whom we tested seven.

Pedigree 4
This family was described by Went et al. who identified eleven tritan members, of whom we have tested four.

Pedigree 5
The index case of Hungarian origin was found in the same screening as Pedigree 1. Subsequently, the mother was examined and found to have a tritan defect.

Methods

Equipment
A Moreland universal anomaloscope was used. Modification of this interference-filter anomaloscope has been described. The instrument permits a circular bipartite field of variable extent to be used, with the left half-field giving the test field and the right half-field giving the matching field. We used stops yielding field sizes between 1° and 8° visual angle. Three-cavity interference filters (Ditric) were used for this study. Wavelengths of peak transmission and half-height bandwidth were measured in the anomaloscope with a calibrated laboratory-constructed spectroradiometer. Half-height bandwidths ranged from 7 to 14 nm.

Procedure
The majority of observers were tested in their homes. The anomaloscope was used in a manner essentially identical with that of the Nagel anomaloscope. The spectral test field was variable in luminance; the primary mixture field was variable from instrument unit 0 at primary 1 to instrument unit 424 at primary 2. The field was freely viewed; each observer used his preferred eye. The observers adapted to the ambient field illumination. Observers were cautioned not to stare continuously at the field but rather to use a glance technique in which they looked away every 10–12 sec. This technique was used to minimize the changes in color appearance that occur with continuous viewing of blue–green test fields.

Experiment 1: Evaluation of Dichromacy in 39 Observers with an Autosomal Dominant Tritan Defect
We evaluated two equations. First, we checked each observer's Rayleigh equation to establish whether red–green vision was normal or showed evidence of X-chromosome-linked red–green color defect. We then presented a dichromatic match to evaluate the presence of tritanopia.

Procedure

1. The Rayleigh Match. The test-field wavelength was 589 nm; the mixture field primaries were 545 and 670 nm. The field size was 2°; the field luminance was approximately 5 cd m⁻². For those observers over 16 years of age for whom preliminary screening indicated normal red–green vision, a self-adjustment technique was used. The observer controlled the test-field luminance knob and the primary ratio control. The observer who asked to adjust the test-field luminance and primary ratio to achieve a color match. The majority of observers were able to do this without difficulty. For younger observers and for those for whom we suspected a red–green color defect, the primary ratio adjustments were made by the experimenter; the observer reported whether the circular field appeared to be of uniform color.

2. Dichromatic Coefficients. The test-field wavelength was 589 nm; the mixture-field primaries as used by Wright were 650 and 480 nm. The mixture-field luminance varied with the primary ratio. At the characteristic tritanopic match, the field luminance was 15 cd m⁻². The field size was 1°, 2°, 4°, or 8°. A self-adjustment technique was used. For younger observers, matches characteristic of tritanopes were presented. A 1° or 2° field was presented initially; if a 1° match could not be made the procedure was discontinued. If 1° and 2° matches were accepted, the procedure was repeated for the 4° and 8° fields.

Results
The majority of the tritan observers had normal red–green color vision. X-chromosomal-linked defects occurred in three pedigrees. Protanomaly and deuteranomaly occurred in Pedigree 1, protanopia and deuteranomaly in Pedigree 2, and deuteranomaly in Pedigree 3. Five of the tritan observers, two in Pedigree 1 (III-29, III-34), two in Pedigree 2 (II-2, II-4), and one in Pedigree 3 (III-9), showed a combination of a tritan defect with deuteranomaly. Segregation of X-chromosomal and autosomal dominant genes was observed in Pedigrees 1 and 3.

We tested 37 tritans (20 in Pedigree 1 and all in Pedigrees 2-5): 25 refused the dichromatic match with a 1° field, 11 accepted the 1° match, and one who was not tested with the 1° field accepted the 2° field match (Table 1). Fewer tritans...
accepted the dichromatic match as the field size increased, and only two observers showed tritanopia for an 8° field. Among the five deuteranomalous tritans, two accepted a 1° dichromatic match and none accepted the 8° dichromatic match.

Our data indicate that dichromacy is not typical in autosomal dominant tritan defect. The majority of the tritans were trichromats even with a 1° field. In our test families we note that observers with congenital deuteranomaly do not have a more severe tritan defect than observers with normal red–green vision.

**Experiment 2: The Moreland Equation**

The Moreland equation is a blue–green equation optimized by Moreland and Kerr\(^1\),\(^2\),\(^21\),\(^22\) to minimize the effect of interobserver macular pigment variation. It is similar to the equation previously derived by Speranskaya.\(^23\) The equation is affected by the age of the observer, but norms are available.\(^24\)

We used 430 nm for the blue primary rather than the 440 nm used by Moreland and Kerr\(^21\),\(^22\) because pilot data indicated that color-normal observers showed less match-midpoint variation when 1° and 8° matches were compared. Since 450 nm nearly coincides with the tritan confusion wavelength for 500 nm, we hoped to obtain good correlation between full-range Moreland equations and acceptance of dichromatic coefficients.

**Procedure**

We used primaries of 500 and 430 nm in the mixture field and 480 nm with a small amount of 580-nm desaturation in the test field.\(^21\),\(^22\) The mixture-field luminance varied with the mixture ratio and was 5 cd m\(^{-2}\) at the normal match for a young observer. A fixed mixture ratio was presented, and the observer was instructed to adjust the luminance of the test field and report if an exact color match occurred. After each setting, the mixture ratio was reset and the full matching range for the equation was established. For the majority of observers the desaturant was fixed.\(^21\),\(^22\) If an observer refused the normal match, we varied the desaturant to check that the normal blue–green ratio was refused at all desaturant levels. Field sizes of 1°, 2°, 4°, and 8° were used; in some observers, all four were evaluated; in others, only the 1° and 8° fields were evaluated. We tested the preferred eye; if time (and patience) permitted we checked the fellow eye.

Normal data were obtained from 10 observers who worked in the laboratories. All were under 45 years of age; six had normal color vision; four had congenital X-linked deutan defects. The Moreland equation does not distinguish between normal and deutan observers. We also noted that rod intrusion does not affect 8° Moreland matches. All observers could make acceptable 8° matches without reporting annoying desaturant effects. The 8° matches were anything easier to make than the 1° matches. In addition, we tested seven members of Pedigree 1 who passed the TNO tritan test to verify the Moreland equation in the field-testing situation. These observers included one deuteranomalous trichromat. All gave normal Moreland equations.

**Results**

We classified the data according to four groups (Table 1): (1) Normal: A normal match showed normal midmatching position for age and a narrow matching range (fewer than 20 instrument units). (2) Shifted: A shifted match showed a midmatching position and range that did not fall within the normal position for age. Matching ranges of shifted matches were usually narrow. In no case did variation of the desaturant change the match location. (3) Wide: A wide match included the normal match and showed a matching range that was 6–18 times wider than normal (i.e., 120–350 instrument units). (4) Full: a full matching range including either primary (425 instrument units) or an extremely wide matching range excluding only one or another primary (over 400 instrument units).

With a 1° field, 19 observers showed a full range match, 2 showed a widened matching range, and 11 showed a shifted match. We could not establish a match for two observers (Pedigree 1, II-8 and III-6). One observer (Pedigree 1, III-5) had a shifted match with one eye while the other eye matched approximately normally; yet another observer (Pedigree 1, III-36) showed a shifted match in one eye and a wide match in the other. For the 8° field, twenty-four observers gave a normal match; eight gave a wide match; one gave a full match; five gave shifted matches. One (Pedigree 1, IV-15) was impossible to test. For the 1° field, a shifted match was seen in five persons over 64 years of age and in six observers (excluding III-5) ranging in age between 9 and 47 years. For the 8° field, the shifted match occurred only in the five observers aged over 64 years of age. Five younger observers who had a shifted match for the 1° field had a normal match for the 8° field.

The brightness matches for the various ratios in the matching range were plotted for the five tritans with shifted 1° and normal 8° matches (Fig. 1). The figure shows 8° matches in filled symbols and 1° matches in open symbols. The arrows show average midmatching points and flux settings of our 10 control observers. The heavy solid line shows the 1° brightness matches of one of the 1° tritanopes (Pedigree 1, III-20). This line intersects the normal matches and agrees with the 8° matches of the five tritans.
The 1° shifted matches require a high proportion of 430-nm primary and are made with low 480-nm flux. The matches do lie on the 1° dichromat's match, i.e., the 1° dichromat is a reduction system of both 1° and 8° tritan matches. A shifted match may be indicative of an alteration system, which could occur if a photopigment other than SWS cones mediated the match, or of an absorption system, which could occur if an abnormal spectrally selective filter attenuated light before the retina. The acceptance of the shifted 1° matches by 1° dichromats suggests an alteration rather than an absorption system. In a study of incomplete achromatopsia, we found an incomplete achromat who had a similarly shifted 8° Moreland equation. This suggested that rods might be the receptor system mediating the shifted 1° matches. The dashed line in Fig. 1 shows 8° matches made by a complete achromat. The 1°-shifted matches occur near the intersection of the achromatic and tritanopic matches. It is, therefore, possible that the matches are rod mediated. In order to investigate this possibility, we decided to test other wavelengths.

**Experiment 3: Extended Match Series for the Moreland Equation**

According to von Kries, an alteration system can be differentiated from an absorption system when a series of test wavelengths is used. In an absorption system the normal and abnormal matches remain in constant proportion, i.e., the amount of shift is independent of test wavelength. The algebraic basis is shown by Alpern et al. In contrast, in an alteration system the normal and abnormal matches change in proportion, i.e., the amount of shift varies with test wavelength.

**Procedure**

Following the example of the extended Rayleigh series, we used the same primaries, 500 and 430 nm, and desaturant, 580 nm, as for the Moreland equation. We used test wavelengths 440, 450, 460, 470, and 490 nm. For each of these test wavelengths, two of the authors (JP and VS) made a large-field (8°) match, varying the amount of desaturant for a best color match. The desaturant was then fixed at that level. A 1° tritanope (Pedigree 1, III-20) made 1° brightness matches, and a complete achromat made 8° brightness matches for the five test wavelengths. Two of the tritans with shifted 1° matches (Pedigree 1, III-18 and Pedigree 4, IV-22) performed the full series of 1° and 8° matches. A third tritan (Pedigree 1, III-40) was available only for a limited time and was tested at 460, 470, and 490 nm.

The procedure was as before. The test wavelength with fixed desaturant was chosen. For various ratios of primary ratio, the tritans adjusted the flux of the test field and reported when a color match was obtained.

**Results**

The logarithm of the midpoint and range was calculated; the data for a test wavelength of 480 nm were included in the calculation. The logarithmic differences between 8° and 1° as a function of test wavelength (Fig. 2) are shown. In this plot, an absorption system should give data that show no dependence on wavelength. Despite rather large error bounds, data for the three observers show a systematic decrease as test wavelength increases. The solid line is an estimation of the differences expected if rods were active in the 1° matches and SWS cones were active in the 8° matches. For the analysis, the CIE 1964 1° observer 2 was taken as representing the SWS cone spectral sensitivity, and the CIE 1951 V’ represented the rod spectral sensitivity. These data are consistent with an alteration system.

Using the same data format as for Fig. 1, the mixture ratios and brightness settings were plotted (Fig. 3). The normal matches and tritan matches fall on the tritanope's brightness matches. The 8° matches of the tritans fall near the 8° matches of the normal observers. The 1° matches are shifted toward the 430-nm primary and occur near the complete achromat's brightness matches. The two independent analyses of the data are consistent with the hypothesis that the shifted 1° matches are mediated by activity of a rhodopsin photopigment with peak sensitivity near 490–500 nm and that 8° matches are mediated by SWS cones.

**Discussion**

All the tritans had an abnormal Moreland equation with a 1° field. The 1° Moreland match therefore agreed with the TNO
tritan test in establishing functional SWS cone abnormality.

The color matches showed interfamilial and intrafamilial variation, just as has been reported previously for screening and discrimination tests. The dichromatic coefficients and Moreland equations showed some variability: not all dichromats had full-range Moreland matches; conversely, many tritans with full-range 1° Moreland matches were not 1° dichromats. There was also some indication of intereye variability. Observer III-36 gave a shifted 1° Moreland match in one eye but a wide match in the other. Unfortunately, time constraints and general difficulties of field testing made it impossible for us to obtain full data on both eyes from all observers. Observer III-5 showed a shifted match in one eye and a normal match in the other eye. There was a mild visual-acuity deficit in the color-normal eye, but ophthalmoscopic examination was not revealing. We thought that eccentric fixation in that eye might explain the normal color match since the majority of tritan observers made normal matches with 8° fields; we have no other explanation of the result. The data from the 22 observers of Pedigree 1 showed some differences from the data of the 17 observers from Pedigrees 2-5. Some of these differences may be ascribed to age. Six of the seven Generation II members in Pedigree I were 19-20 years older than any of the tritans in Pedigrees 2-5. If these Generation II members were omitted, the differences between Pedigree 1 and Pedigrees 2-5 for the 8° test field would be reduced. Nevertheless, we found only four 1° dichromats of 16 Generation III-IV tritans in Pedigree 1, compared with eight 1° dichromats of 17 tritans in Pedigrees 2-5.
whereas we noted a shifted 1° Moreland match in six young members of Pedigree 1 and in only one member of Pedigrees 2–5.

Finally, we did find evidence of an alteration system in some of the observers. We suggested that the shifted matches reflect rod activity. We have previously noted that rods may be active in color matching of color-defective observers. Of note in this study was rod activity in a 1° colorimetric field. We suppose that certain observers have small or nonexistent rod-free zones or are able to use stray light in making 1° discriminations. Provided that rods are active, their signals may give information to those observers whose color vision has been compromised by hereditary or acquired defects. Among tritan observers over 64 years of age, a shifted blue–green equation was seen even with an 8° field. The shift was larger than would be expected on the basis of age-related changes in ocular media transmission and may reflect a variation of a normal retinal aging phenomenon. We hypothesize that if SWS function diminishes, rods may become an active color receptor. Some clinical Moreland equation data may be interpreted in this way: Moreland et al. noted a shifted blue–green equation in one eye of a 55-year-old patient with maculopathy (visual acuity, 0.7) similar to the shifted blue–green matches that we observed in young and old tritan observers. Further, Moreland has reported shifted small-field matches in some diabetic patients.

We found that most tritans made a completely normal blue–green color match using an 8° field. Some continue to show chromatic discrimination loss, but only 2 of 39 tritans showed an 8° dichromacy. We infer that the normal 8° Moreland equations indicate that the majority of tritans have SWS cones in their retinas. Our studies do not indicate the cause of the tritan defect. The tritan defect might reflect an abnormal number or distribution pattern of SWS cones or a neural defect.

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