Sex-related differences in peripheral human color vision: A color matching study

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There has been much controversy as to whether there are sex-related differences in human color vision. While previous work has concentrated on testing the central visual field, this study compares male versus female color vision in the near peripheral retina. Male (n = 19) and female (n = 19) color normal observers who exhibited no significant differences either in the midpoints or the ranges of their Rayleigh matches were tested with a color matching paradigm. They adjusted hue and saturation of a 3° test spot (18° eccentricity) until it matched a 1° probe (1° eccentricity). Both groups demonstrated measurable shifts in the appearance of the peripheral color stimuli similar to those that have been previously reported. However, females showed substantially less saturation loss than males (p < 0.003) in the green–yellow region of color space. No significant differences were found in other regions of color space. This difference in the perceived saturation of color stimuli was minimally affected either by the inclusion or exclusion in the analysis of potential heterozygous female carriers of deutan color vision deficiencies. We speculate that this advantage of female over male color vision is conferred by M-cone polymorphism.

Keywords: color vision, males–females, peripheral retina, sex-related differences


Introduction

The existence of sex-related differences in human visual processing capabilities has been a controversial issue, not only in color vision but also in other aspects of visual function. Even though males are believed to have superior spatial abilities, Silverman and Eals (1992) present evidence to the contrary. Furthermore, it is unclear if the superiority of their female observers in spatial cognitive tests is a physiological phenomenon or due to a task-related feature such as memory. Similar ambiguities apply in color vision where the interplay between the psychology and physiology of color perception makes it difficult to demonstrate the existence of sex differences (Rodriguez-Carmona, Sharpe, Harlow, & Barbur, 2008).

At a psychological level, it is believed that there are a number of higher order cognitive differences between the two sexes. For example, color lexicon studies indicate that females have a larger word repertoire and use more elaborate terms to describe colors (Nowaczyk, 1982; Simpson & Tarrant, 1991) and they are better at matching them from memory (Pérez-Carpinell, Baldovi, de Fez, & Castro, 1998). This ability is spread across languages and cultures (Thomas, Curtis, & Bolton, 1978) and could be attributed to the fact that females follow different patterns of socialization (Bimler, Kirkland, & Jameson, 2003). This notion has resonance with work by Hurlbert and Ling (2007) who found that females showed more of a preference for the red end of the L–M cone opponent axis while males displayed a bias toward the green end of the same axis. They attribute their findings to the evolution of...
the male–female society, where females were the gatherers in a hunter–gatherer society and needed better discrimination to detect reddish fruits against a green foliage (Hurlbert & Ling, 2007).

At a physiological level, differences in color vision between males and females might also arise as a consequence of the way in which color vision deficiencies are inherited in humans. Such defects are sex-linked. They are due to small genetic mutations in either the long-wavelength (L-) or the medium-wavelength (M-) cone photopigment coding genes that are located on the X-chromosome. If the genes in the male X-chromosome are different from the normal, this results in color vision deficiency. If a female inherits one normal X-chromosome and one abnormal X-chromosome, then she becomes a carrier for a color vision defect with a 50% chance of passing this to her sons. The female has the genotype but not the phenotype of the defect because of random X-chromosome inactivation or Lyonization (Lyon, 1972). The normal X-chromosome genes are expressed in some cells but not in others, and the same happens with genes from the abnormal X-chromosome. The result is that some photoreceptors in the female retina will express the normal photopigment while others will express the abnormal one. As a consequence, these so-called heterozygous carrier females have the potential to possess four types of cone, i.e., they may exhibit tetrachromacy (Bimler & Kirkland, 2009; Jameson, Highnote, & Wasserman, 2001; Jordan, Deeb, Bosten, & Mollon, 2010; Jordan & Mollon, 1993).

Sex differences in color vision may also be generated by another form of heterozygosity caused by L- and M-cone polymorphism (Pardo, Perez, & Suero, 2007). The genes encoding the photosensitive opsins in these two cones are polymorphic with respect to the presence of either alanine or serine at the 180 site of the gene sequence (Neitz & Jacobs, 1986; Neitz, Neitz, & Jacobs, 1993). This results in a slight shift in the peak spectral sensitivity of the cone pigments. Neitz et al. (1993) showed that the polymorphism of the L-cones affects the red–green ratio required for Rayleigh matches. They also demonstrated a bimodality of the red–green Rayleigh matches for the male color normal population, attributing this to the different polymorphic L-cones. Jordan and Mollon (1993) were not able to replicate either of these findings. In males who have only a single X-chromosome, approximately half have the alanine L-cone pigment and the other half have the serine type. In female populations, the prevalence in serine/alanine L-cones is different because they have two X-chromosomes. Around 50% of females possess both L-cone types in their retina while the other 50%, almost equally divided, have only one or the other (Neitz, Kraft, & Neitz, 1998).

There is a long history of testing for hue discrimination and chromatic sensitivity differences between the sexes. Results so far have been inconsistent. Where male–female differences have been identified, the effects have been small. Nichols (1884), for example, showed that males had better hue discrimination for reds and yellows, while females were found to be superior to males in ordering pigments according to their saturation. Hennon (1910) found females to have better hue discrimination in the red and orange regions of the spectrum, while Pickford (1951) concluded that male color vision is the same as that of females. Verriest, Vandevyvere, and Vanderdonck (1962) found no difference in Farnsworth-Munsell 100-Hue test scores between males and females across different age groups but did find an age effect in hue discrimination with young females performing better than young males.

More recently, Kuehni (2001) investigated the appearance of the four unique or focal colors, red, green, blue, and yellow, and found that there is a difference in mean unique hue settings between males and females. Other studies have also reported sex-related differences with unique hues (Cobb, 1975; Kalmus & Case, 1972; Richards, 1967; Volbrecht, Nerger, & Harlow, 1997; Waaler, 1967). Females, particularly color normal carriers of color deficiency, have been shown to exhibit a wider Rayleigh matching range than males (Birch, Young, & David, 1991). In another study, it was shown that females who possess more than three cone pigments in their retina (putative tetrachromats) perceive more chromatic bands in the range of 380 nm to 780 nm than normal male and female trichromats (Jameson et al., 2001). Bimler et al. (2003) found that the only sex-related difference in color vision is that males pay more attention to luminance changes while females place more emphasis on the red–green axis. Pardo et al. (2007) found significant sex-related differences in a modified Rayleigh matching procedure with females requiring more red light in order to obtain a match between the test and reference field. In the most recent study on this topic, Rodriguez-Carmona et al. (2008) found a substantial difference between sexes in red–green chromatic sensitivity, with males being more sensitive than females. However, they argue that this difference is because of the possible presence of female carriers in their population. By excluding these, the sex difference in sensitivity thresholds was reduced and became non-significant. Similarly, Hood, Mollon, Purves, and Jordan (2006) also demonstrated that if color-deficient observers and female carriers are excluded from a population, then no differences along the red–green axis are observed between sexes.

As can be appreciated from the above, there is no clear evidence for either the presence or absence of sex-related differences in color vision. Common to all of the studies discussed above is the fact that they tested central color vision using either spectral or metameric lights. In this study, we were interested in whether the assessment of color vision in more peripheral regions of the visual field might be useful in revealing differences between the perception of color in males and females. In the central visual field, there are major physiological variations between individuals that could mask male–female differences.
Webster and MacLeod (1988) identified various factors that might influence color vision, including variation in macular pigment density, lens pigment density, the position of the cone spectral sensitivity (i.e., cone polymorphism), cone-pigment density, as well as rod intrusion. Macular pigment density, for example, not only differs substantially between observers but also differs between males and females, with males having an average 38% greater macular pigment density than females (Hammond et al., 1996). Macular pigment predominantly affects short-wavelength absorption but may play a more subtle role when metameric colors (i.e., computer screens) are used instead of spectral lights. Color vision in the central visual field is known to operate under the influence not only of cortically based compensatory mechanisms but also of receptoral mechanisms that mediate long-term gain changes (Magnussen, Spellmann, Sturzel, & Werner, 2004; Webster, Halen, Meyers, Winkler, & Werner, 2010). These maintain stable color perception across small eccentricities (<8°) despite the various sources of retinal inhomogeneities described above. In the peripheral retina however, these mechanisms become less effective and can no longer compensate for the processing deficiencies that are faced by color vision in more eccentric retinal locations. For example, as retinal eccentricity increases, L- and M-cone density changes markedly (Curcio, Sloan, Packer, Hendrickson, & Kalina, 1987) and rods make a greater contribution to the perception of color (Buck, Knight, & Bechthold, 2000). As a result, a number of studies have demonstrated that there are measurable changes in the perceived hue and saturation of color stimuli presented in the peripheral visual field compared to when they are viewed centrally (Ayama & Sakurai, 1977; Gordon & Abramov, 1977; McKeefry, Murray, & Parry, 2007; Moreland & Cruz, 1959; Nærger, Volbrecht, & Ayde, 1995; Parry, McKeefry, & Murray, 2006; Stabell & Stabell, 1984). For example, Parry et al. (2006), using an asymmetric matching technique, demonstrated clear changes in the perceived saturation of red-green stimuli in the near peripheral retina in trichromatic human observers. Perceived decreases in saturation for green stimuli were particularly evident across all observers, as has been reported previously (Gordon & Abramov, 1977). Green stimuli also appear to undergo the largest shifts in perceived hue compared to other colors (Nærger et al., 1995). By comparison, blue-yellow color perception appears to be affected to a much lesser degree with increasing retinal eccentricity (Mullen & Kingdom, 1996).

In the light of the fact that color vision in the peripheral visual field is more susceptible to perceptual shifts, we wanted to assess the possibility that male–female differences in color vision might be more effectively revealed in more eccentric retinal locations. We have tested this idea by examining the hue and saturation shifts in different regions of color space in the peripheral retina of males and females, all of whom have normal color vision according to conventional color vision tests.

Materials and methods

Observers

Thirty-eight male and female observers participated in the study. All were tested for color vision deficiency using the Farnsworth-Munsell 100-Hue test, Ishihara plates (38-plate edition, 1979), and a Nagel anomaloscope (Model I). The participants performed the 100-Hue test twice, read the first 24 Ishihara plates once, and did 10 matches with the anomaloscope using the test (right) eye only. Subjects who exhibited Farnsworth-Munsell error scores greater than 50 (after the second trial) or more than 4 errors in Ishihara plates or made abnormal matches on the anomaloscope were excluded from the main experiment. All the observers who failed in one or more color vision tests were males. A total of 19 male (29 ± 10 years; mean ± 1 SD) and 19 female (24 ± 6 years) color normals participated in the main asymmetric matching experiment. Written informed consent was obtained from all subjects and the study was approved by the Ethics of Research on Human Beings Committee of the University of Manchester (Ref. No. 09169).

Color matching paradigm

The task for the observers was to match a peripheral 3° spot at 18° eccentricity in the nasal visual field with a parafoveal 1° probe spot (1° eccentricity, nasal visual field) in hue and saturation. These eccentricities and sizes were chosen according to the cortical magnification factor and to match our previous work that we describe in detail elsewhere (Parry et al., 2006). The stimuli were defined in a two-dimensional CIE 1931 color space. It is 2-dimensional as the stimulus luminance (12.5 cd/m²) was kept constant during the experimental procedure. The 0°–180° and 90°–270° axes used in these experiments coincide with the cardinal L–M and S–(L + M) axes, respectively (Derrington, Krauskopf, & Lennie, 1984). Chromatic axis, which is the physical equivalent of hue, is defined as the rotation of a vector (spanning 360°) that originates from the background illuminant C (x = 0.31, y = 0.316 at 12.5 cd/m²). Purity, the physical equivalent of saturation, is the length of that vector. Since there is no absolute value for purity, we defined a vector of length 0.0739 as having purity of 1, following the work of De Valois, De Valois, Switkes, and Mahon (1997). The parafoveal spot was always displayed with purity equal to 0.5. The two spots were presented simultaneously for 380 ms following which the observer had unlimited time to adjust either purity or chromatic axis in increments of 5° (axis) or 0.1 (purity). After the observer’s response, the two stimuli were presented again and a new match was required. Hence, the ISI depended on the observer’s response time.
The background subtended 37.2° × 29.3° and the stimuli were generated on a high-resolution SONY Trinitron MultiScan color monitor driven by a ViSaGe graphic card (Cambridge Research Systems, Rochester, UK). A calibration procedure was carried out before the experiments to ensure that the display presented the colors accurately. Details of the experimental setup and the calibration procedure can be found in Parry et al. (2006).

The tests were performed in a darkened room. The observer had full control of the chromaticity of the peripheral spot, within the color gamut of the display, and used the method of adjustment to match the two spots while fixating on a cross. Prior to the experiment, about 10 min were given to the observer to familiarize him/herself with the equipment and to adapt to the background. Chin and forehead rests were used to minimize head movements. The first probe axis presented was always 0° and the other axes appeared in numerical sequence. Preliminary experiments showed that changing the order of appearance does not affect the matching results. The observer changed the chromatic axis and the purity of the peripheral spot until they found a satisfactory match with the parafoveal spot. When the match was obtained, chromatic axis was changed by 15° and the participant again matched the probe chromaticity. In one trial, 25 matches were obtained in total. After a break of about 10 min, the procedure was repeated.

**Results**

Figure 1 shows the results of the asymmetric task. In this figure, the average of 19 males (left panel) and 19 females (right panel) are shown. The black dots are the probe chromaticities and the open symbols (squares for males and circles for females) are the matches. The dark gray curves depict ±1 SD and the light gray lines are the cardinal axes.

Both groups show a saturation loss mainly around the 0° and 180° axes, but there is a difference in the peak saturation loss between males and females of approximately 30°. Note that when an observer matches the peripheral spot using a higher saturation this is effectively compensating for a saturation loss. For example, matching the probe at saturation 0.5 with the peripheral spot at saturation 1 means that the observer needs to double the saturation of the peripheral spot so that it appears the same saturation as the probe. From Figure 1, it is obvious that there is substantial interindividual variability. Males show greater matching variability than females, especially in the green–yellow region of the color space. As we are interested in detecting sex differences in either hue or saturation, the two attributes are considered separately in Figures 2 and 3.

**Figure 1.** (Left) Male and (right) female color matches in CIE 1931 xy color space. The black spots are the probe chromaticities and the open symbols (squares for males and circles for females) are the averaged matched chromaticities. The dark gray curves and the gray shaded areas are ±1 SD. The light gray lines are the cardinal axes. The open star is the background (illuminant C).

**Hue rotation difference**

Figure 2 shows the hue rotation results for the two groups (upper panel for males (a) and lower panel for females (b)). The black lines with the open symbols are best-fitted Fourier functions. An 8th degree Fourier function of the form

\[
f(x) = a_0 + a_1 \cos(x) + b_1 \sin(x) + a_2 \cos(2x) + b_2 \sin(2x) + \ldots + a_8 \cos(8x) + b_8 \sin(8x),
\]

was found to give the best fit \((R^2)\) to the data. For the number of data points \((N = 950)\), \(R^2 = 0.696\) (males) and \(R^2 = 0.725\) (females) are high, revealing a high level of association \((p < 0.0001\) for both graphs). Both groups show the same pattern of hue rotation. As has been
reported previously (Parry et al., 2006), some hues are remarkably stable while others undergo obvious and systematic shifts. These major hue shifts occur especially around the 90° and 270° cardinal axes. For other hues, there is no hue distortion (rotation = 0), that is, observers do not need to change the hue of the peripheral spot to match it with the probe spot. These are what Parry et al. (2006) referred to as peripherally invariant hues. Males have a slightly greater interindividual variability compared with the females, according to the confidence bounds. As it is not possible to compare these two graphs quantitatively by eye, the following statistical analysis was conducted.

Hue, by definition, is a vector, rotating around a white point. The difficulty here is that hue has to be treated as circular data and there are no suitable conventional statistical tests that can be applied to such data sets. To perform a parametric test on linear data, these data should be drawn from a normal distribution, thus they should be tested for normality. The equivalent of normality for circular data is that they should be drawn from a von Mises distribution, which is described by mean angle θ and a concentration parameter k (θ and k are analogous to the mean and variance of a linear normal distribution).

The hue rotation data shown in Figure 2 failed the test for "circular normality" and so parametric tests are not applicable. The Wilcoxon–Mann–Whitney rank sum test was, therefore, applied (Batschelet, 1981). This showed no statistically significant difference in the hue rotation between the two groups for any chromatic axis. The

Figure 2. Hue rotation for (upper) male and (lower) female observers. The graphs depict the hue rotation that both groups exhibited as a function of chromatic axis. The dashed lines are the 95% confidence bounds of the fitted functions. The small black data points are the raw data for all the observers.

Figure 3. Saturation match for (upper) male and (middle) female observers. The graphs depict the matched saturation that both groups exhibited as a function of chromatic axis (data from males are shown on the upper panel (a) and female data on the middle panel (b)). The dashed lines are the 95% confidence bounds of the fitted function. The small black data points are the raw data for all the observers. Panel (c) (lower panel) depicts the differences between (a) and (b) as a function of chromatic axis (see text for details). The black solid line is the mean of the differences and the black dashed lines are the mean ± 1.96 SD. The arrow shows the area where there is a statistically significant difference between males and females in saturation match.
statistical p-value ranges between 0.175 and 0.965 (α = 0.05) for the 24 chromatic axes.

**Saturation difference**

Figure 3 depicts the results for saturation only. As previously, the two upper panels are the male (upper, a) and female (middle, b) saturation matches as a function of chromatic axis. The lower panel (c) shows the difference in saturation match between the two groups as a function of chromatic axis. For both groups, there is again substantial interindividual variability, with that of males being slightly higher. Both groups show the same pattern of saturation match to differing extents. For both males and females, there is greater saturation loss in the green region with males exhibiting higher loss. Females show a slightly greater saturation loss in the red region of the color space. The same fitting function, as in hue graphs, is used for saturation giving $R^2 = 0.196$ and $R^2 = 0.161$ for males and females, respectively ($p < 0.0001$ for both graphs).

As saturation is an axial measure and because we are not interested in interactions between different axes but instead on absolute differences between the same axes, a different approach can be followed compared to hue. For every axis, the difference in saturation between males and females was calculated. Then, the differences were plotted as a function of the chromatic axis as in Figure 3c. The black line is the mean of all the differences and the dashed lines are the mean ± 1.96 SD (95% confidence interval). Thus, the points that lie outside the dashed lines differ significantly from the others. Hence, these data suggest that there is a statistically significant difference between males and females in saturation match in the green–yellow region of the color space between 225° and 240° axes. The saturation of only these two axes between males and females is compared with an independent sample t-test, having first checked for normality using the Kolmogorov–Smirnov non-parametric test ($p = 0.433$ for males and $p = 0.0913$ for females). This statistical analysis confirms the analysis performed on the data shown in Figure 3. The t-test shows a statistically significant difference in saturation match between males and females in the region of 221°–244° with $p = 0.003$ and post hoc power of 85%. The mean ± 1 SD saturation match of males is 0.82 ± 0.32 and that of females is 0.63 ± 0.19. These numbers give a mean saturation loss of 64% for males and 26% for females with the difference between the two groups being 38%.

**Female observers with wide anomaloscope matching range**

Several studies have shown that Nagel anomaloscope data could provide an insight as to whether a female observer is a carrier for color deficiency (Jordan & Mollon, 1993) or whether, in a group of male observers, there are more than one L- or M-cone pigments present (Neitz & Jacobs, 1986; Neitz et al., 1993). Figure 4 illustrates the midpoints and matching ranges of our 19 male and 19 female color normal observers.

The data show no statistically significant difference in the means of the midpoints between males and females ($p = 0.519$, $α = 0.05$, independent sample t-test) and no statistically significant difference in their matching ranges, which, according to Pokorny, Smith, Verriest, and Pinckers (1979), is a measure of hue discrimination ($p = 0.465$, $α = 0.05$, independent sample t-test). Jordan and Mollon (1993) found that the matching range of the female carriers was significantly greater than that of color normal females. Hood et al. (2006) found that, if heterozygous females and any clearly color-deficient subjects are removed from a sample, any differences in color perception between males and females disappear. We wanted to ascertain whether similar exclusions from our analysis had any effect on the differences in perceived saturation changes that were measured here. In Figure 4, one can see that there are a number of female observers with wider matching ranges than the rest (see arrows in Figure 4). The prevalence of total carriers in the color normal population is approximately 15% (Jordan & Mollon, 1993; Sharpe, Stockman, Jagle, & Nathans, 1999), which in our group of 19 females is equivalent to 3 observers. So three female observers with the widest matching range can be excluded because of the possibility of their being carriers of a color defect. A similar
approach was adopted by Rodriguez-Carmona et al. (2008). Because female observers No. 2 and No. 11 have the same matching range (7 units), both of them have been excluded, resulting in a total of 15 color normal female observers.

Comparing the saturation match data after this modification (using 19 males and 15 females), a statistically significant difference is maintained for axes 225° and 240° ($p = 0.007, \alpha = 0.05$, independent sample $t$-test, power of 78%). Following the argument above, excluding the 4 females who performed worst in the anomaloscope task should have reduced the peripheral saturation loss and thus increased the difference between the males and females. In fact, the mean saturation loss for the female group remained unchanged at 26% so that the overall male–female saturation difference was unaffected. Note, however, that the $p$-value for the comparison of the 19 males versus the 15 residual females increased from 0.003 to 0.007. For the sake of completeness, the same 4 females were excluded from the hue rotation data, but it did not have any significant effect on the results.

### Discussion

In this study of sex differences between ostensibly color normal human observers, we have taken the novel approach of assessing color vision in the peripheral visual field, as opposed to the central visual field, which has been the focus of previous studies. Experiments were performed on a group of male ($n = 19$) and female ($n = 19$) observers who exhibited no significant differences in either the midpoints or the ranges of their Rayleigh matches. Both groups demonstrated measurable shifts in the appearance of color stimuli that were presented in more eccentric regions of the retina, similar to those that have been previously reported (e.g., Parry et al., 2006). We measured chromatic axis-dependent shifts in perceived hue with increasing retinal eccentricity, but there were no significant sex-related differences. However, there was a statistically significant difference ($p = 0.003, \alpha = 0.05$) between male and female observers in the perceived saturation of stimuli in the green–yellow region of color space between the chromatic axes of 225° and 240°. Females were found to exhibit a decrease in the perceived saturation of peripheral color stimuli, which was 38% less than that experienced by males. This difference remained virtually unchanged when potential (deutan) heterozygous carrier females (i.e., those with the largest Rayleigh matching ranges) were excluded from the analysis.

The study of sex-related differences in color vision has tended to deliver conflicting and ambiguous results (Rodriguez-Carmona et al., 2008). Previous studies have employed experimental paradigms that differ substantially in terms of the demands they place on the observers’ perceptual, cognitive, and linguistic capabilities. The differing extents to which these abilities are called upon across studies may be a potential source of the discrepant findings that are feature of study of sex-related differences in color vision. For example, Jameson et al. (2001) used a psychophysical test to assess how many different color bands are present in the range of the visible spectrum, and as they state, their experiment is more likely to reflect higher order color processing. Pardo et al. (2007) used a modified version of a Rayleigh matching procedure concentrating on hue discrimination while ignoring potential differences in sensitivity. Rodriguez-Carmona et al. (2008), on the other hand, used a test for color vision deficiencies based on chromatic sensitivity only, ignoring any possible differences in hue discrimination. Differences in higher order cognitive processing and in social and linguistic abilities between males and females have, in the past, been cited as being the reason behind reports of sex-related differences in color vision (Bimler et al., 2003; Hurlbert & Ling, 2007; Nowaczyk, 1982; Pérez-Carpinell et al., 1998; Simpson & Tarrant, 1991; Thomas et al., 1978). Following this notion, one possible explanation for the improved color perception exhibited by females in the green region of color space in this study may be related to the findings of Bimler et al. (2003). They showed that females were more critical in their discrimination judgments in a red–green direction. As a result, females may be more careful in the matching task deployed here resulting in more precise settings. However, a problem with this explanation is that our data fail to show the same levels of improvement for the red region of the color space that would be expected if the same reported female bias for red–green was the basis for the differences in peripheral saturation loss reported here. Our paradigm, which employs a color matching task and measures both hue discrimination and sensitivity, is more likely to reflect the earlier stages of color processing rather than higher order color capabilities. The novel departure from previous studies lies in the fact that in this study color performance is assessed in the peripheral visual field. It could be argued that, in everyday life, observers use mostly central vision that is specialized for color due to high cone and neural density. Perhaps, then, the task described here is not representative of everyday color vision. However, we argue that in the central visual field there are major physiological differences between individuals that could mask male–female differences.

The green–yellow region of the color space where a significant difference in perceived saturation has been identified between males and females lies within 520–550 nm in the visible spectrum. This corresponds to the region of the color space where M-cones have their peak
spectral sensitivity. Another possible explanation for the findings described here could, therefore, be M-cone polymorphism. The prevalence of M-cone polymorphism in the male population is 6% for the serine variant and 94% for the alanine (Sharpe et al., 1999), while for females, due to X-chromosome inactivation, the serine variant accounts for 0.3%, the alanine variant 88.4%, and the remaining 11.3% possessing both types. These percentage differences are enough to account for the male–female difference in saturation loss described here. However, in the absence of information regarding the subjects’ genotypes, we can only speculate that this M-cone polymorphism is responsible for these sex-related differences.

The exclusion of the four females with widest Nagel anomaloscope matching ranges might be expected to reduce the overall peripheral saturation loss, thus reducing the difference between the two groups. Instead, the mean saturation loss for the residual female group remained unchanged although there was a slight increase in variance. Hence, the presence of these females in the analysis reduces the variability in saturation loss in the original female group. Paradoxically, the inclusion of the four females improved the overall performance of the female group in the green region of color space, suggesting that their wide matching range on the anomaloscope is not necessarily an index of abnormality. Hood et al. (2006) argue that carriers of deutan but not protan deficiency differ from color normals. If this is the case, then the four females in this experiment (who show an effect in the green region of color space), could be potential carriers of a deutan defect expressing a normal and an abnormal M-cone in their retinas. However, this extra abnormal M-cone does not necessarily make them worse observers than the others but seems to confer a “richer color experience” on them, as Jameson et al. (2001) argue.

In summary, our experiments demonstrate the existence of a sex-related difference in color vision in the near peripheral retina. This difference takes the form of losses in the perceived saturation of green–yellow stimuli that are significantly greater for male than for female observers. This difference is minimally affected either by the inclusion or exclusion in the analysis of potential heterozygous female carriers of deutan color vision deficiencies. We speculate that this advantage of female over male color vision is conferred by M-cone polymorphism.

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