Principles and Practice of Clinical Electrophysiology of Vision

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Chromatic Recordings of Electroretinograms

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The electrophysiological investigation of chromatic responses is not a routine part of clinical ophthalmology, for better diagnostic methods exist. The interest lies in the information about intraretinal processing that is revealed by such recordings, mostly studied in congenital red-green color deficiency, as reviewed by Armington.[1] Most of the previous publications along this line dealt with the b-wave, flicker electroretinogram (ERG), or early receptor potential (ERP).[6-8, 11, 13, 14, 18-20, 22, 23] The spectral sensitivity of the b-wave and the flicker ERG were reported to be reduced at long wavelength in protans.[6, 7] Yokoyama and his coworkers[20, 22, 23] demonstrated in protans and deutans abnormal spectral response curves of the b-wave and abnormal ERG responses to a mixture of red and green stimuli sinusoidally flickering in counterphase. The b-wave or flicker ERG is not solely indicative of the receptor activity.

Two kinds of electrical responses have been reported as being generated in photoreceptor cells: the early and late receptor potentials.[2, 3] The major difference in waveform of the late receptor potential between the cones and rods lies in the off-response (response to a cessation of stimulus light); the off-response is rapid in the cones and slow in the rods.[2, 3] (The off-response of blue cones is slow,[20, 22, 25] but blue cones are not concerned, insofar as we know, with red-green color deficiency.)

In the human ERG the off-response begins with a rapid positive-going deflection (the rapid off-response) at a stimulus intensity above about 6 lux at the retina.[24] The rapid off-response in humans follows flickering stimuli of high frequency (not less than 34 Hz)[24] and is resistant to light adaptation,[24] and the relative spectral sensitivity function curve approximates the psychophysical photopic curve.[10] This ERG rapid off-response is unchanged in congenital stationary night blindness,[9] but no rapid off-responses can be obtained in rod monochromatism.[9] The rapid off-response is preserved in vitro after treatment of the retina with aspartate or glutamate,[24] which is known to abolish the postsynaptic responses of the retina without abolishing the receptor potential. Thus, the rapid off-response is photopic in nature and is useful for an objective examination of the photopic function at the photoreceptor level.

RAPID OFF-RESPONSE IN PROTANS AND DEUTANS

The method used is to employ a monochromatic, 4-Hz square-wave (50-duty cycle) flickering light. The maximum stimulus intensity was 1.0×10^{15} quanta $\cdot$ cm^{-2} $\cdot$ sec^{-1} at each wavelength at the position of the cornea of the eye to be examined. The pupil was fully dilated. Averaged responses to 40 stimuli were measured. Twenty-four protan patients

(10 protanopes and 14 protanomalous aged 9 to 22 years with a mean age of 15.3 years) and 23 deutan patients (7 deuteranopes and 16 deuteranomalous aged 9 to 25 years with a mean age of 15.7 years) were studied. All were males except for one protanomalous female. The normal control group consisted of 24 men with ages ranging from 15 to 29 years (mean, 23.5 years).

The inset in Figure 44–1,A′ shows a typical example of the ERG evoked by a monochromatic rectangular stimulus (550 nm) in a normal control subject. The onset of the stimulus light evoked the a-wave, the b-wave, and the oscillatory potential. The termination of the stimulus elicited an upward (positive-going) deflection, which is referred to as the rapid off-response. The relationship between the stimulus intensity and the amplitude of the rapid off-response was plotted at each wavelength of stimulus light. The reciprocal of the stimulus intensity needed to evoke a response of a constant criterion voltage (20 μV), i.e., the sensitivity, was obtained at each wavelength from the graphs depicting the amplitude-intensity relationship. The spectral sensitivity curves thus obtained for the rapid off-response showed a maximum sensitivity around 550 nm in all normal subjects studied and were approximated by the human photopic visibility curve (Commission Internationale de l'Eclairage [CIE] 10) (Fig 44–1,A).

The peak of the spectral sensitivity curve shifted toward the short wavelength (520 to 530 nm) in protans (Fig 44–1,B). The peak of the sensitivity curve in deutans was at 550 nm or its vicinity (Fig 44–1,C), as in normal subjects (Fig 44–1,A). The shape of the spectral sensitivity curves, however, clearly differed between normals and deutans; the sensitivity at 480 nm was definitely higher than the sensitivity at 620 nm in all normal subjects tested, whereas the sensitivities at 480 and 620 nm were nearly equal in deutans (Fig 44–1,A and C). This difference is clearly illustrated in Figure 44–3, which will be referred to in detail later.

The right-hand graphs (A′, B′, and C′) in Figure 44–1 show the mean and the standard deviation of the spectral sensitivity of the rapid off-response in normals, protans, and deutans, respectively. As compared with the normal control, in protans the mean of the sensitivity of the rapid off-response was higher at short wavelengths (480, 500 nm) ($P < .005$) and lower at long wavelengths (560 nm and longer) ($P < .005$). The mean sensitivity in deutans was lower than normal between 480 and 560 nm ($P < .005$) and higher than normal at long wavelengths (620 nm) ($P < .001$) (Fig 44–1). Reflection fundus

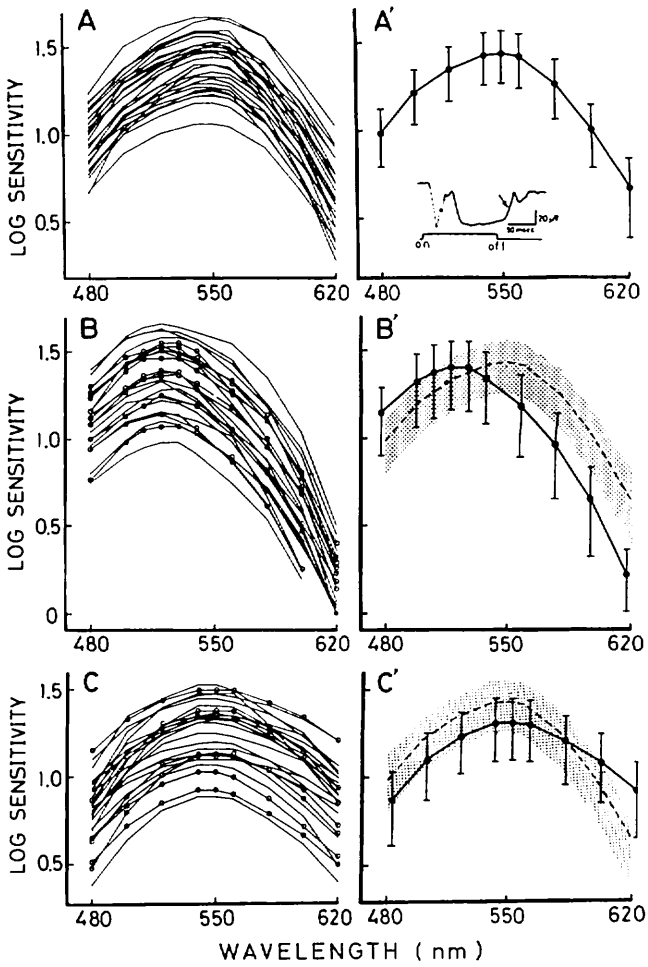

FIG 44–1.

Spectral sensitivity of the rapid off-response in normal subjects (**A** and **A′**), protans (protanopes, protanomals) (**B** and **B′**) and deutans (deuteranopes, deuteranomals) (**C** and **C′**). The *left* graphs show sensitivity curves in each individual tested. Curves with *small circles* indicate protanopes (**B**) or deuteranopes (**C**). The remainder of the curves pertain to protanomals (**B′**) or deuteranomals (**C′**). *Right* graphs show means and standard deviations of spectral sensitivity. The *dotted curve* and *shaded area* in **B′** and **C′** indicate the mean and standard deviation in normal subjects, respectively. Averaged waveforms of 40 responses to repetitive monochromatic stimuli of 4 Hz were analyzed in Figures 44–1 and 44–3 to 44–6. Ordinates indicate logarithms of the reciprocal of the quantal number of stimulus light to evoke the rapid off-response of the 20-μV criterion amplitude. Sensitivity at 0 log units on the ordinate corresponds to the sensitivity of 1.0×10^{15} quanta · cm^{-2} at the cornea. The inset in **A′** illustrates a typical example of an ERG at 550 nm in a normal subject. The *arrow* indicates the rapid off-response.

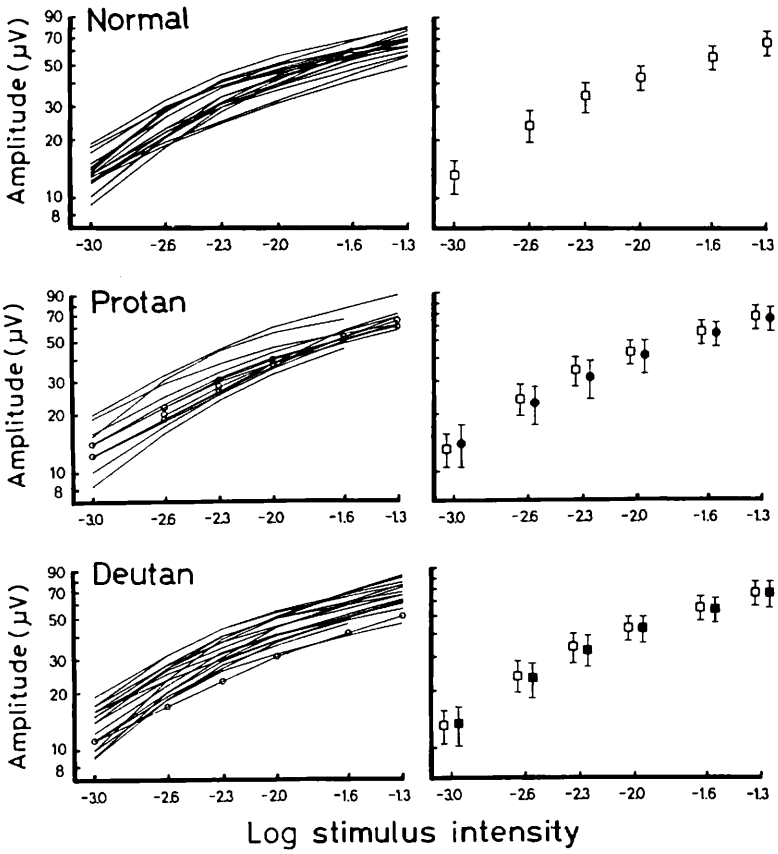

FIG 44–2.
Amplitude of the rapid off-response in 20 normal subjects (10- to 27-year-old males, *upper* graph), in 13 protans (12- to 22-year-old males, *middle* graph), and in 19 deutans (12- to 22-year-old males, *lower* graph) as a function of the intensity of white stimulus light. Zero log unit of stimulus intensity was 1.0×10^5 lux at the cornea. *Left* graphs are amplitude-intensity curves of individual subjects. *Right* graphs are means and standard deviations. Curves with *open circles* in the *left* graphs indicate dichromats. The rest of the curves indicate abnormal trichromats. *Open squares* in the *right* graphs indicate the mean amplitude in normal subjects. *Solid circles* and *solid squares* indicate the mean amplitudes in protans and deutans, respectively.

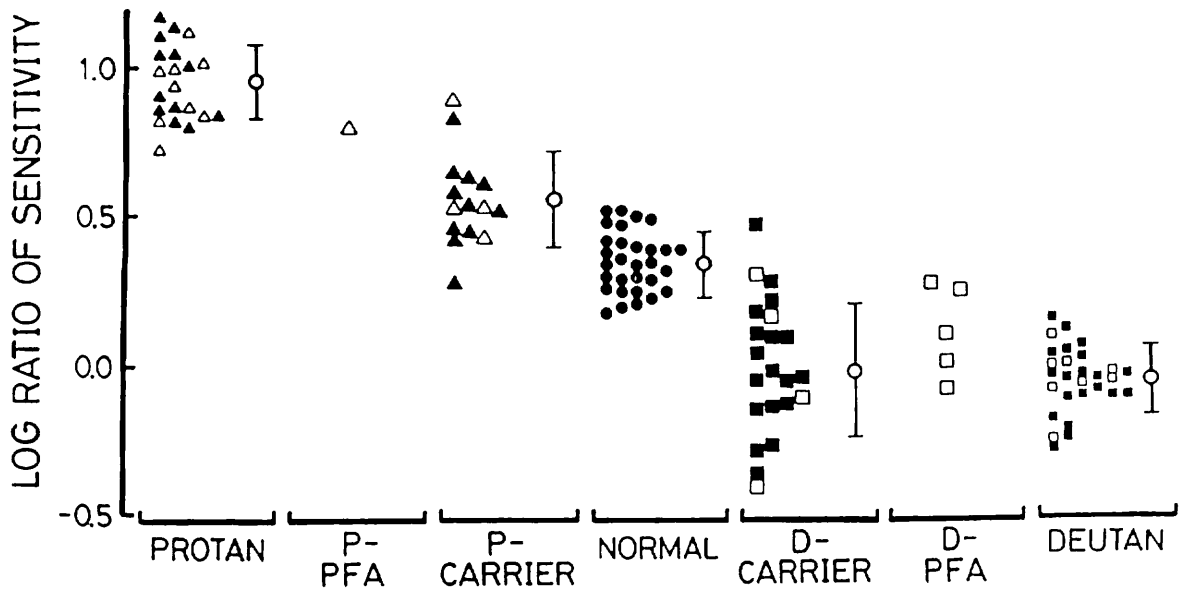

FIG 44–3.
Log ratio of sensitivity of the rapid off-response at 480 nm to its sensitivity at 620 nm in protans, Pigmentfarbenamblyopie of the protan type *(P-PFA)*, protan carriers *(P-carrier)*, normal control subjects, deutan carriers *(D-carrier)*, Pigmentfarbenamblyopie of the deutan type *(D-PFA)*, and deutans. Sensitivity was defined here as the reciprocal of the quantal number of stimulus light that is needed to evoke a rapid off-response of 20-μV criterion amplitude. *Open* and *filled triangles* in protans indicate protanopes and protanomals, respectively. *Open* and *filled squares* in deutans indicate deuteranopes and deuteranomals, respectively. *Open* and *filled triangles* in protan carriers indicate mothers of protanopes and those of protanomals, respectively. *Open* and *filled squares* in deutan carriers indicate mothers of deuteranopes and those of deuteranomals, respectively. *Open circles* and *vertical bars* indicate the mean and standard deviation in Figures 44–3, 44–4, and 44–7 to 44–9, respectively.

densitometry has demonstrated a decrease or loss of the visual pigment at long wavelengths in protans and at medium wavelengths in deutans.[16, 17] The reduction in sensitivity of the rapid off-response at long wavelengths in protans and at medium wavelengths in deutans (Fig 44–1) is in agreement with such densitometric results. It is noteworthy that the sensitivity of the rapid off-response is higher than normal at short wavelengths in protans and at long wavelengths in deutans (Fig 44–1). In this regard, we should refer to Wald's finding[21] that the psychophysical sensitivity was higher than normal at short wavelengths in protans and at long wavelengths in deutans. Wald[21] hypothesized that the red-absorbing cones lost in protans are replaced mainly by increased numbers of green-absorbing cones and that the green-absorbing cones lost in deutans are replaced mainly by added red-absorbing cones. This hypothesis is consistent with the high sensitivity of the rapid off-response at 480 to 500 nm in protans and at 620 nm in deutans (Fig 44–1). Although the spectral characteristics of the rapid off-response differed among normals, protans, and deutans (Fig 44–1), the amplitude of the rapid off-response to white stimulus light was not significantly different among these three groups (Fig 44–2). This finding is also compatible with Wald's hypothesis mentioned above.

The difference in shape of the spectral sensitivity curve among normals, protans, and deutans can be described in a quantitative manner by the sensitivity ratio at short and long wavelengths. The number of quanta (reciprocal of the sensitivity) in the stimulus light that is required to evoke a rapid off-response of 20 μV was calculated from the amplitude-intensity curve in each subject at 480 and 620 nm. The ratio of the quantal numbers at 620 nm to those at 480 nm (ratio of the sensitivity at 480 nm to the sensitivity at 620 nm, S_{480}/S_{620}) is plotted on the ordinate in Figure 44–3. This ratio was greater in all protans and smaller in all deutans than in normal control subjects (Fig 44–3). It should be emphasized that we are able to differentiate protans and deutans from normals by recording the rapid off-response only at two different wavelengths of stimulus light. This would be a new method of diagnosing protans and deutans in an objective and quantitative manner.

The spectral sensitivity curve and the sensitivity ratio (S_{480}/S_{620}) of the rapid off-response showed no significant difference between protanopic and protanomalous or between deuteranopic and deuteranomalous patients (Figs 44–1 and 44–3.) This result is not unexpected because Pokorny and Smith[15] demonstrated that dichromats diagnosed by anomaloscopy with a small test field show trichromacy by anomaloscopy with a large test field. The stimulus field used in the present study subtended about 60 degrees in visual angle. Therefore, it would be reasonable that no difference in the rapid off-response was found between dichromats and anomalous trichromats in the present study using a large stimulus field.

Majima[12] classified red-green color deficiency into four grades by routine psychophysical examinations: (1) very mild, (2) mild, (3) moderate, and (4) strong. We studied the ratio of the sensitivity of the rapid off-response at 500 nm to its sensitivity at 600 nm (S_{500}/S_{600}) in protans and deutans at each of the four grades described above. The sensitivity ratio did not differ among the four grades both in protans and deutans (Fig 44–4). It should be emphasized that the sensitivity ratio of the rapid off-response is definitely

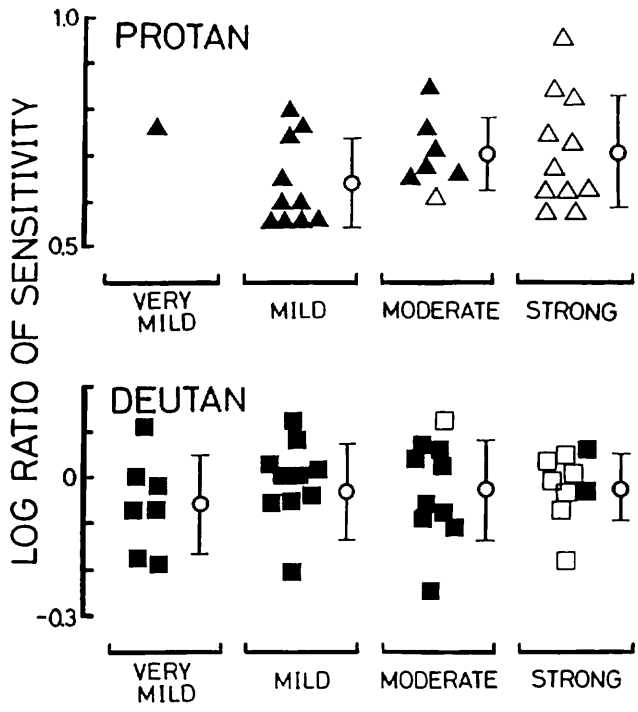

FIG 44–4.
Log ratio of the sensitivity of the rapid off-response at 500 nm to its sensitivity at 600 nm in protans (*upper* graph) and in deutans (*lower* graph). Protans and deutans were classified into four grades (very mild, mild, moderate, strong) by Majima's criterion.[12] *Open* and *filled symbols* indicate protanopes and protanomals in the *upper* graph and deuteranopes and deuteranomals in the *lower* graph, respectively. The criterion amplitude was 20 μV in Figures 44–4 to 44–6.

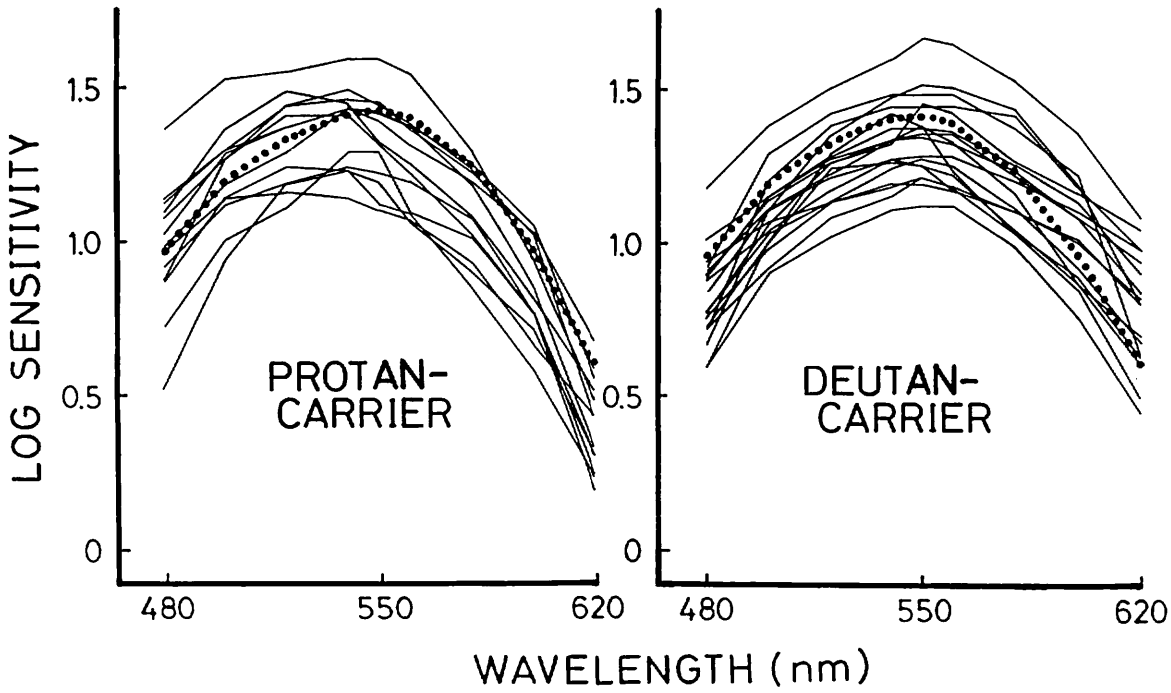

FIG 44–5.
Spectral sensitivity of the rapid off-response in protan carriers (mothers of protans) aged 30 to 46 years with a mean age of 40.4 years) and in deutan carriers (mothers of deutans) aged 32 to 50 years with a mean age of 39.7 years. All of these mothers showed no anomaloscopic abnormality. *Dotted curves* indicate the mean sensitivity in normal control subjects.

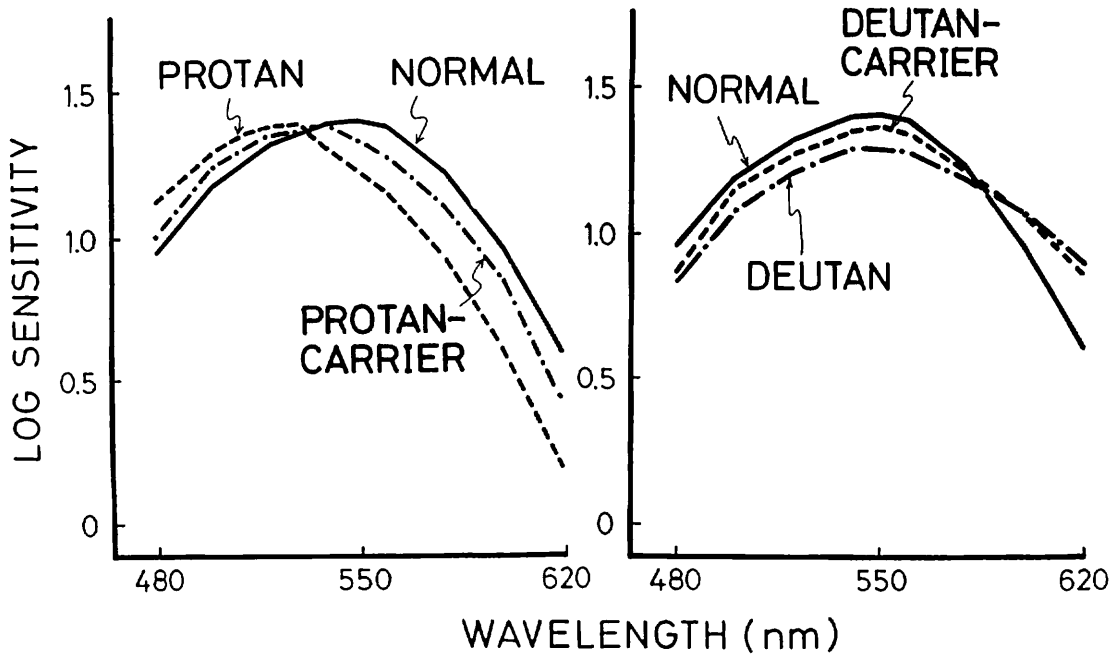

FIG 44–6.
Mean sensitivity of the rapid off-response in protans, protan carriers (*left* graph), deutans, and deutan carriers (*right* graph). *Solid curves* pertain to normal control subjects.

abnormal even in protans or deutans with minimal anomaly detected by routine psychophysical examinations.

RAPID OFF-RESPONSE IN GENETIC CARRIERS

ERG sensitivity was studied in only one protan carrier in the literature, the sensitivity to 32 Hz flickering stimuli being low at long wavelengths in a mother of protanopes.[6] We investigated the rapid off-response in mothers of protans (protan carriers) and in mothers of deutans (deutan carriers). The mean sensitivity curve of the rapid off-response in protan carriers was lower than normal at long wavelengths ($P < .05$ at 560 and 580 nm, $P < .01$ at 600 nm, $P < .001$ at 620 nm) and deviated upward toward the sensitivity curve of protans at the wavelengths of 480 to 520 nm. The mean sensitivity curve in deutan carriers was higher than normal at long wavelengths ($P < .005$ at 600 nm, $P < .001$ at 620 nm) and deviated downward toward the curve in deutans at 560 nm and shorter wavelengths. In brief, the mean sensitivity curve in protan carriers was situated between the mean sensitivity curves of normals and protans. The mean sensitivity curve in deutan carriers was between the mean sensitivity curves of normals and deutans (Figs 44–5 and 44–6). The mean of the ratio S_{480}/S_{620} was larger in protan carriers than in normals ($P < .001$) (see Fig 44–3). The ratios were not significantly different between carriers of protanopes and those of protanomals or between carriers of deuteranopes and those of deuteranomals (see Fig 44–3).

We studied the rapid off-response in a mother who had three sons; two of them were deutans, and one was a protan. The ratio of the sensitivity of the rapid off-response at 480 nm to its sensitivity at 620 nm (S_{480}/S_{620}) in these sons was typical for their diagnosis: large in the protan and small in the deutans. Their mother, who was most likely a compound heterozygote, showed normal color discrimination by routine examinations. The ratio of the sensitivity of the rapid off-response at the two different wavelengths (S_{480}/S_{620}) was also within the normal range in this mother (log S_{480}/S_{620} was 0.39).

EARLY RECEPTOR POTENTIAL IN PROTAN AND DEUTAN PATIENTS

A study of the ERP in congenital color deficiency would be pertinent because the ERP is closely related to photobleaching of visual pigments of the photoreceptors,[2, 3, 5] particularly of cones in humans.[4] We recorded the ERP in 27 eyes of 26 normal male subjects aged 19 to 24 years with a mean age of 20.9 years in response to monochromatic stimuli having equal quanta. The method of recording the ERP was previously described.[19] Briefly, the stimulus source was a 1.2×10^3-J xenon discharge tube.

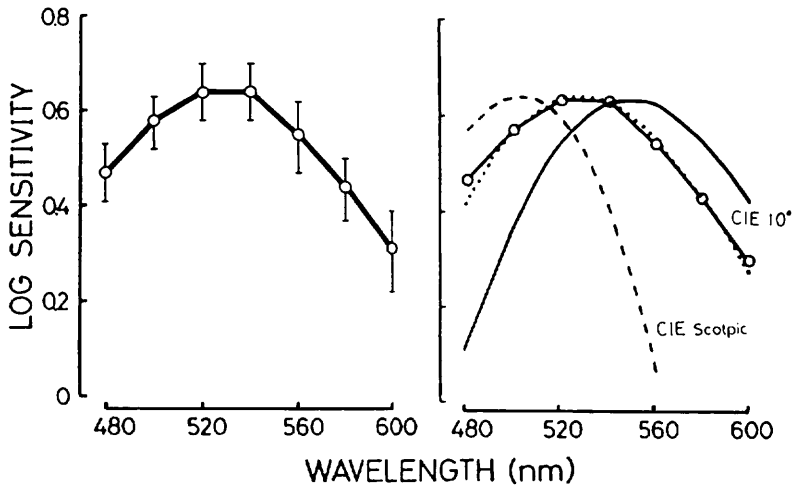

FIG 44–7.

Left, mean and standard deviation of the spectral sensitivity curve of the ERP (R_2) in 54 eyes of normal subjects (criterion amplitude, 10 μV). *Right*, approximation of the spectral sensitivity curve between the ERP (*solid curve with circles*, from the *left* graph) and psychophysical measurement. The dotted curve was composed of the summation of the photopic *(solid curve)* and scotopic *(dashed curve)* psychophysical curves in the ratio of 3:2. The ordinate indicates log relative sensitivity in arbitrary units. The top of each curve was at the same scale on the ordinate.

Interference filters (460 to 600 nm, half-width of 26 to 38 nm) and neutral-density filters were placed in the light path to obtain a monochromatic flash having equal numbers of quanta (1.08×10^{15} quanta · cm^{-2} per flash at the cornea). The spectral response curve (amplitude vs. wavelength) showed the maximum amplitude of the R_2 at 520 to 540 nm in all these normal subjects. The mean spectral sensitivity curve of the R_2 closely followed a curve composed of the summation of the photopic and scotopic psychophysical curves at a ratio of 3:2 (Fig 44–7). The stimulus flash illuminated the posterior area of the ocular fundus, measuring approximately 60 degrees in the visual angle. The number of rods within this posterior fundus surpasses that of cones within the same retinal area (approximately 24:1). In humans the R_2 from a single cone is assumed to be much larger than the R_2 from a single rod, which agrees with this result.

Lapp and Tanabe[11] demonstrated a low sensitivity of R_2 at long wavelengths in protanomalous subjects. Okamoto et al.[13] reported that the mean amplitude of the R_2 evoked by a white flash was smaller than normal in protans and deutans. Tamai et al.[18] reported that the ERP evoked by a colored flash in protanopes was abnormal. We studied the ERP in 10 protans (5 protanopes and 4 protanomals aged 9 to 18 years with a mean age of 14.9 years) and 26 deutans (6 deuteranopes and 20 deuteranomals aged 10 to 20 years). Anomaloscopic examination could not be performed in one protan patient because of his lack of cooperation. The mean R_2 amplitude was smaller at long wavelengths (580 and 600 nm) in protans ($P < .01$) and at 520 nm in deutans ($P < .05$) as compared with the mean amplitude in normal subjects (Fig 44–8). These results are consistent with the spectral sensitivity of the rapid off-response in protans and deutans (see Fig 44–1). Neither group differed significantly from normal controls at short wavelengths. Since the rods as well as cones participated in producing the ERP in our stimulus parameters, possible abnormalities of the ERP at short wavelengths would be masked by the response from the rods.

The ratio of the R_2 amplitude at 460 nm to its amplitude at 600 nm (V_{460}/V_{600}) was larger in all protans than in all deutans thus far tested (Fig 44–9). Therefore, the protan and deutan groups were differentiated by this ratio. This indicates that protans and deutans differ from each other at the level of visual pigments. This ratio (V_{460}/V_{600}) is useful for the differentiation of protans and deutans in an objective

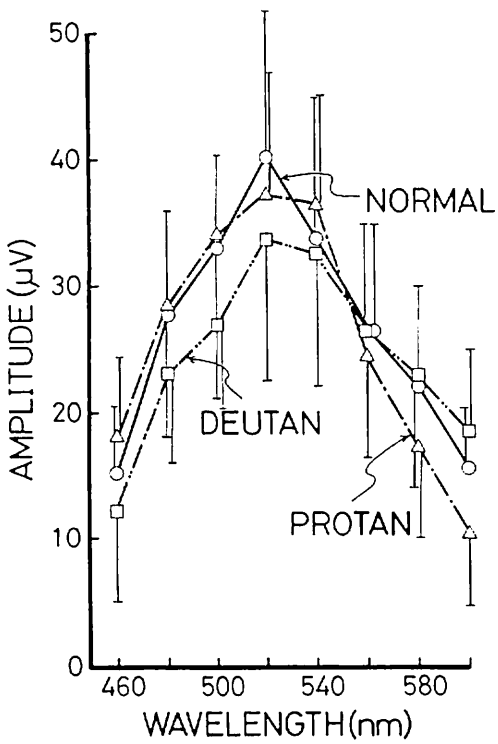

FIG 44–8.
Mean and standard deviation of the amplitude of the ERP (R_2) evoked by monochromatic stimuli having equal quanta (1.08×10^{15} quanta · cm^{-2} per flash) in 18 normal *(circles)*, 15 protan *(triangles)*, and 31 deutan *(squares)* subjects.

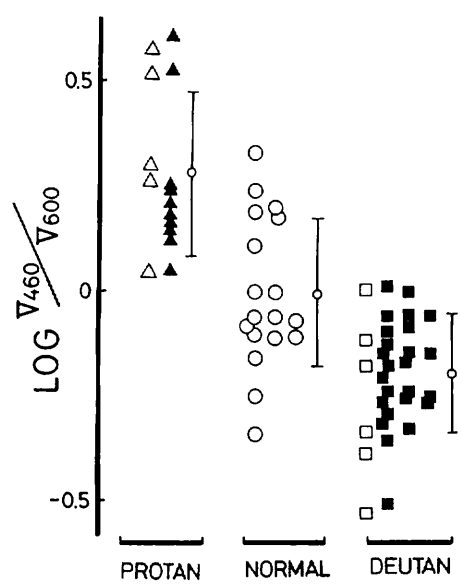

FIG 44–9.
Log ratio of the ERP (R_2) amplitude at 460 nm to the amplitude at 600 nm. *Open triangles* and *squares* indicate dichromats. *Filled triangles* and *squares* indicate abnormal trichromats.

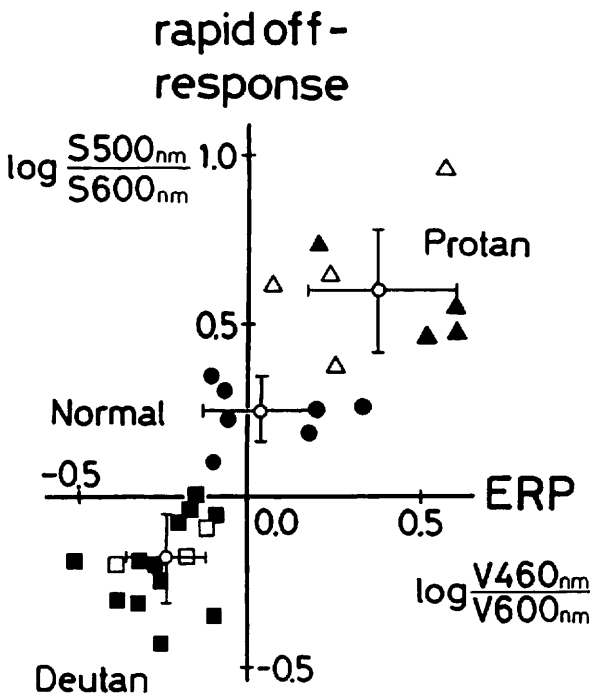

FIG 44–10.
Relationship between the ERP (R_2) and the rapid off-response. The log ratio of the ERP (R_2) amplitudes at 460 nm to that at 600 nm (abscissa) is plotted against the log ratio to the sensitivity (criterion amplitude, 20 μV) of the rapid off-response at 500 nm to that at 600 nm (ordinate). *Filled circles* indicate normal subjects. *Open* and *filled triangles* indicate protanopes and protanomals, respectively. *Open* and *filled squares* indicate deuteranopes and deuteranomals, respectively. *Open circles* and *crosses* indicate the mean and standard deviation in normal, protan, and deutan groups.

manner at the level of the visual pigments in the photoreceptor cells.

No significant difference in the R_2 amplitude or the ratio V_{460}/V_{600} was found between protanopes and protanomalous or between deuteranopes and deuteranomal persons. This may be accounted for by the large stimulus field (approximately 60 degrees in the visual angle) in our ERG recordings, as already discussed in this chapter.

After recording the ERP, the eye was dark adapted for 1 hour. The rapid off-response was then recorded in the same subjects (7 normals, 8 protans, 15 deutans) to study the relationship between the ERP and the rapid off-response. The log ratio of the R_2 amplitude at 460 nm to its amplitude at 600 nm (V_{460}/V_{600}) was significantly correlated with the log ratio of the sensitivity of the rapid off-response at 500 nm to its sensitivity at 600 nm (correlation coefficient, 0.823; $P < .001$) (Fig 44–10). Thus, the present study electrophysiologically demonstrates that the anomaly in congenital red-green color deficiency is initiated in the outer segment of the photoreceptor cells.

REFERENCES

1. Armington JC: *The Electroretinogram.* New York, Academic Press, Inc, 1974.
2. Brown KT: The electroretinogram. Its components and their origins. *Vision Res* 1968; 8:633–677.
3. Brown KT, Watanabe K, Murakami M: The early and late receptor potentials of monkey cones and rods. *Cold Spring Harb Symp Quant Biol* 1965; 30:457–482.
4. Carr RE, Siegel IM: Action spectrum of the human early receptor potential. *Nature* 1970; 225:88–89.
5. Cone RA: The early receptor potential of the vertebrate retina. *Nature* 1964; 204:736–739.
6. Copenbaver RM, Gunkel RD: The spectral sensitivity of color-defective subjects determined by electroretinography. *Arch Ophthalmol* 1959; 62:55–68.
7. Dodt E, Copenhaver RM, Gunkel RD: Photopischer Dominator und Farbkomponenten im menschlichen Elektroretinogramm. *Pflugers Arch Gesamte Physiol* 1958; 267:497–507.
8. François J, Verriest G, De Rouck A: New electroretinographic findings obtained in congenital forms of dyschromatopsia. *Br J Ophthalmol* 1960; 44:430–435.
9. Kawasaki K, Tsuchida Y, Jacobson JH: Positive and negative deflections in the off-response of the electroretinogram in man. *Am J Ophthalmol* 1971; 72:367–375.
10. Kawasaki K, Yonemura D, Nakazato H, Kawaguchi I: Abnormal spectral sensitivity of the electroretinographic off-response in protanopia and protanomalia. *Doc Ophthalmol* 1982; 53:51–60.
11. Lapp ER, Tanabe J: Das frühe Rezeptorpotential (ERP): Aktionsspektren bei normal farbtüchtigen und Farbblinden. *Ber Dtsch Ophthalmol Ges* 1981; 78:727–731.
12. Majima A: Diagnostic criteria of defective color vision, The 3rd report. Majima's classification for social adaptability. *Folia Ophthalmol Jpn* 1972; 23:170–175.
13. Okamoto M, Okajima O, Tanino T: The early receptor potential in human eyes. II. ERP in dichromats. *Acta Soc Ophthalmol Jpn* 1981; 85:296–299.
14. Padmos P, van Norren D: Cone spectral sensitivity and chromatic adaptation as revealed by human flicker-electroretinography. *Vis Res* 1971; 11:27–42.
15. Pokorny J, Smith VC: New observations concerning red-green color defects. *Color Res Appl* 1982; 7:159–164.
16. Rushton WA II: A cone pigment in the protanope. *J Physiol* 1963; 168:345–359.
17. Rushton WA II: A foveal pigment in the deuteranope. *J Physiol* 1965; 176:24–37.
18. Tamai A, Wada H, Kitagawa K, Wariishi S, Wariishi V, Sasaki T, Takemura M, Ueno H: Monochromatic flash ERP (early receptor potential) in dichromats. Presented at the 23rd Symposium of the International Society of Clinical Electrophysiology Vision, Mie, Japan, May 22, 1985.

19. Tanabe J, Yonemura D, Kawasaki K, Fujii S, Sakai N: Spectral sensitivity of the early receptor potential in man. *Acta Soc Ophthalmol Jpn* 1983; 87:1017–1021.
20. Uji Y: Spectral characteristics of electroretinography in congenital red-green color blindness. *Jpn J Ophthalmol* 1987; 31:61–80.
21. Wald G: Defective color vision and its inheritance. *Proc Natl Acad Sci USA* 1966; 55:1347–1363.
22. Yokoyama M: Blue sensation in eye disease. *Jpn J Clin Ophthalmol* 1979; 33:111–125.
23. Yokoyama M, Yoshida T, Ui K: Spectral responses in the human electroretinogram and their clinical significance. *Jpn J Ophthalmol* 1973; 17:113–124.
24. Yonemura D, Kawasaki K: New approaches to ophthalmic electrodiagnosis by retinal oscillatory potential, drug-induced responses from retinal pigment epithelium and cone potential. *Doc Ophthalmol* 1979; 48:163–222.
25. Zrenner E, Gouras P: Blue sensitive cones of the cat produce a rodlike electroretinogram. *Invest Ophthalmol Vis Sci* 1979; 18:1076–1081.