Oscillatory potential of the human electroretinogram evoked by monochromatic light

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The oscillatory potential was recorded with photopically balanced monochromatic stimuli in normal eyes. This potential was almost constant both in amplitude and in latency at a range from 500 to 600 nm. The amplitude had a tendency to decrease at both shorter and longer wavelengths. The latency lengthened slightly at each end of the spectrum. The individual wavelets of the oscillatory potential did not disclose variation in color sensitivity one from the other.

Key words: human electroretinogram, oscillatory potential, photopic b-wave, photopically balanced monochromatic light, cone, spectral sensitivity curve, amplitude, peak latency.

The existence of a relationship between the oscillatory potential (positive humps, wavelets) in the electroretinogram (ERG) and color perception has been investigated by several workers in the human eye. Although these reports have suggested that the oscillatory potential has diagnostic value in color-deficient patients, the matter is unsettled. In previous studies, it had been found difficult to achieve the high intensities required to resolve the oscillatory potential with monochromatic stimuli. Hence, analysis was attempted on the responses evoked by white flashes following chromatic adaptation, expecting that the adaptation would reduce the contribution to the ERG of the mechanism maximally sensitive to the adapting wavelength. This is an indirect approach to the problem.

The purpose of the present study is to investigate this problem in the human ERG, using monochromatic light as the test stimulus and an averaging procedure combined with band-pass filters.

Method

Stimulating system. Stimulus light from a 1 kw. tungsten source, which was passed through a series of heat and neutral-density filters and an...
Fig. 1. Sample records of ERG evoked with 100 msec. rectangular monochromatic stimuli (497 nm.) under white light adaptation at 5.6 millilamberts. Two hundred and fifty responses were summed at a rate of three per second. The first and third traces were recorded with the amplifier time constants of 250 msec. and 3 msec., respectively. The second and fourth traces were recorded through band-pass filters, with low frequency cutoff at 8 Hz. and high cutoff at 60 Hz., and with low cutoff at 80 Hz. and high cutoff at 200 Hz., respectively. On the third trace, positive peaks of the oscillatory potential were denoted here by O₁, O₂, and O₃. On the fourth trace, the positive and negative potentials were expressed by P₁, P₂, P₃, and N₁, N₂, N₃, respectively. Subject K. F.

interference filter with a half-band width of 10 to 15 nm., was brought to a focus at a magnetic shutter which was driven by an electronic stimulator. The shutter controlled the light beam, providing rectangular flashes of 100 msec. at a rate of three per second. The light then entered one of the input ends of a 6 mm. diameter Y-shaped fiber optics.

An incandescent bulb (117 v, 150 w.) served as a source of white adapting light to eliminate rod responses. Light from the bulb was passed through a series of heat, conversion, and neutral-density filters and focused at another input end of the 6 mm. diameter Y-shaped fiber optics. The glass fibers carrying the light from each source were mingled together at the output end (7 mm. in diameter) which was held 5 mm. from the subject's contact lens. The spectral characteristics of the monochromatic stimulus at the output end were measured spectrophotometrically. Both stimulus and adapting lights subtended a visual angle of 70 degrees. Luminance of the adapting light was 5.6 millilamberts at the point where the cornea was positioned and that of the stimulus light without filters was 8.8 x 10⁴ millilamberts, measured by a S.E.I. photometer (Salford Electrical Instruments).

Recording system. The ERG was picked up by a low-vacuum contact lens electrode, which was referred to the joined earlobes. The space between the contact lens and the cornea was kept filled with a normal saline. A ground electrode was attached to the chin. Responses were amplified with capacitance-coupled amplifiers (Grass Model 7P511) with a rise time constant of 0.3 msec. and fall time constants of 250 msec. for first, second, and fourth channels and 3 msec. for third channel. Then, the responses were processed by a computer of average transients (Mnemotron CAT 400) and recorded photographically from the CAT oscilloscope screen. In second and fourth channels, band-pass filters having attenuation slopes of 24 db. per octave (Krohn-Hite, Model 330MR) were interposed between the amplifier and the computer. ERG signals were averaged to 125 or 250 stimuli.

Subjects. Two of the authors (Y. T. and K. F.) served as subjects. They had normal color vision and no detectable ophthalmologic abnormality except for mild myopia. The pupil of the right eye was maximally dilated with one per cent tropicamide. Wearing the contact lens electrode, without air bubble, the subject was seated with his face supported on a head and chin rest. Prior to each session of monochromatic light stimulations, there was a pause of two minutes in darkness, and then the right eye was exposed to the adapting light. After one minute of light adaptation, which was continued during stimulation, the ERG recording was started.

Results

Fig. 1 shows averaged records of ERG evoked with 100 msec. rectangular monochromatic light stimuli (497 nm.) at a rate of three per second under white light adaptation at 5.6 millilamberts. On the first trace, which was recorded with amplifier time constant of 250 msec., the a-wave and the b-wave, on which the oscillatory potential is superimposed, are observed. On the second trace, potentials after amplification were passed through a band-pass filter with a low frequency cutoff at 8 Hz. and a high cutoff at 60 Hz. As the result, the oscillatory potential was completely eliminated and a positive po-
Oscillatory potential of human ERG

Fig. 2. Effect of the intensity of monochromatic stimuli on four traces of the ERG. Numerals at left signify log stimulus intensities. Numbers at the top of columns show wavelengths (blue, green, yellow, and red). Four monochromatic lights are balanced at the intensity of 0.9 to produce an equal amplitude of the positive potential (second traces). Subject K. F.

Potential with a peak latency of about 44 msec. was recorded.

On the third trace, the ERC was recorded with amplifier time constant of 3 msec. The b-wave was considerably reduced and the oscillatory potential more apparent. The positive peaks were denoted O₁, O₂, and O₃ in temporal order.

On the fourth trace, the amplified potential was passed through another bandpass filter with a low cutoff at 80 Hz. and a high cutoff at 200 Hz. This procedure had the effect of excluding the b-wave, hence isolating some rhythmic wavelets. These wavelets have been designated as the fast retinal potential (FRP) by Dawson and co-workers. However, the positive peaks of the wavelets (P₁, P₂, and P₃) coincide in latency with these of the oscillatory potential (O₁, O₂, and O₃), respectively. We have considered these wavelets essentially the same as the oscillatory potentials and will mention some of the reasons later. These wavelets are called here the oscillatory potentials, as in the conventional ERC.

Fig. 2 shows the effect of variation of intensity of each of four monochromatic stimuli (450, 539, 571, and 647 nm.) on the ERG responses. As the stimulus intensity decreased, the b-wave of the first trace, together with the positive potential of the second trace, diminished in amplitude. Decreasing the intensity reduced the amplitude and prolonged the latency of the oscillatory potential, as seen on the third and fourth traces.

Fig. 3 illustrates the relation between the amplitude of the positive potential (second trace) and the stimulus intensity. This potential was identified as the photopic b-wave, since the peak latency (44 msec.) was shorter than that of the scotopic b-wave (60 to 140 msec.) and the spectral sensitivity curve of this potential derived from Fig. 3, based on 30 μV criterion voltage, matched that for human cone vision by Hecht and Hsia for wavelengths longer than 500 nm; however, the match was not good at shorter wavelengths, as shown in Fig. 4.

In order to provide an equally photopic condition over the different wavelengths, the amplitude of the photopic b-wave (second trace) served as an index. It is not modified by the oscillatory potential.
Fig. 3. Plots of the photopic b-wave (second trace) amplitude measured from negative troughs as a function of stimulus intensity. Numbers attached to the curves represent wavelengths. Numeral at each scale on the abscissa signifies a log density of neutral filters attenuated from the equal energy level. Intervals shown on the abscissa represent steps of 1 log unit. Each point is the average of four responses. Subject Y. T.

Fig. 4. Circles show the relative spectral sensitivity of the positive potential (second trace) derived from Fig. 3 based on 30 μV criterion voltage. A smooth line is the spectral sensitivity curve for human cone vision.9 which may differ in amplitude at different wavelengths in the equally photopic condition. Densities of the neutral filters annexed to individual interference filters were carefully adjusted on the basis of Fig. 3 so as to be capable of producing a constant amplitude of the photopic b-wave, as seen in the uppermost records (0.0) in Fig. 2. With the monochromatic lights obtained in this way, which has been called photopically balanced lights,10 the photopic b-waves were recorded in expectation of constant amplitude from each subject.

Fig. 5 exhibits constancy of the photopic b-wave amplitude over a range of wavelengths from 450 to 647 nm, on two subjects. Analysis of variance showed no statistically significant difference of the b-wave amplitude on each subject (F ratio, 0.31 for K. F. and 1.36 for Y. T.).

If the wavelets of the oscillatory potential are the summation of activity from independent cone systems with different latencies, each wavelet would be expected to increase in amplitude or shorten in latency at the wavelength of its maximum sensitivity under the equally photopic condition.

Figs. 6 and 7 illustrate the effect of photopically balanced stimuli on the amplitude of the oscillatory potential. In Fig. 6, the amplitude of the oscillatory potential recorded after short amplifier time constant was measured according to the methods of Usami11 and Algvere.12 The curves for O₂ (middle) on 2 subjects show a broad plateau ranging from 500 to 600 nm, and delineate smooth decreases on both sides. This tendency is observed also on the curves for O₁ and O₃. The descents of the curves for O₁ and O₃ at longer wavelengths were significant in both subjects (p < 0.05). However, there is no evidence to support the idea that each wavelet shows a maximum amplitude at a distinct wavelength.

The oscillatory potential recorded after
passage through the band-pass filter was much more clearly demonstrable, allowing more precise analysis. In Fig. 7, the curve for \( P_2 \) shows a broad peak ranging from 500 to 600 nm, having a smooth decrease on either side of the spectrum. The curves for \( P_1 \) and \( P_3 \) demonstrate a similar effect, although the descents at shorter wavelengths are not sharp. The decreases of \( P_2 \) and \( P_3 \) amplitude at longer wavelengths were significant \((p < 0.01)\).

Since the oscillatory potential has been considered as a negative potential by Brunette\(^1\) and evidence favorable to this hypothesis has been observed,\(^7\) we gave consideration also to the negative potentials \((N_1, N_2, \text{and } N_3)\) seen in the fourth trace. In Fig. 7, the curves for \( N_1, N_2, \text{and } N_3 \) show effects no more similar than those for the positive potentials \((P_1, P_2, \text{and } P_3)\). It is notable that in both subjects no systematic effect of monochromatic light was observed on any of the individual positive or negative potentials.

Electrophysiologic observations on the cat\(^14\) and on the frog\(^15\) demonstrate that color information in the retina can be represented by the difference in latency of the OFF effect. Peak latencies of the oscillatory potential were measured as a function of wavelength. Each of the peak latencies for \( P_1, P_2, P_3, N_1, N_2, N_3 \) were almost constant through the range from 500 to 600 nm, with only a slight prolongation (2 to 4 msec.) at each end of the spectrum.

**Discussion**

Dawson and Stewart\(^5\) have used the band-pass filter to record the rhythmic wavelets in the human ERG and called these wavelets fast retinal potential (FRP). However, we have considered these wavelets essentially the same as the oscillatory potentials in the conventional ERG,\(^7\) because of the coincidence of peak latencies (Fig. 1) and because of the parallel effects of intensity on both the potentials (Fig. 2) as far as our experimental conditions are concerned.

In this report we did not obtain any evidence to indicate that individual wavelets of the oscillatory potential varied in color sensitivity. Although only normal subjects were used here, this result does not confirm previous investigations in which some wavelets have been shown to delineate color dependent changes in normal and color-deficient eyes.\(^1-3\) The discrepancy between these results might be caused, in part, by disparities in stimulus light and/or the difference of subjects.

The results of this study are in agreement with the report of the pigeon’s ERG by Nye,\(^4\) in which photopically balanced stimuli as well as flashes of a constant in-
Fig. 6. Plots of the amplitude of the oscillatory potential (third trace, O₁, O₂, and O₃) as a function of photopically balanced lights on Subjects Y. T. (circles) and K. F. (stars). The amplitude was measured according to the method of Usami¹² and Algvere¹² as shown in the inset. Each point is the average of 6 responses. Vertical bars signify standard deviations.

Intensity level were used and no wavelength-dependent changes were observed in the wavelets; although this animal had been known to have a cone-rich retina and the ability to make color discriminations. Our results also agree with the recent work on the human eye by Adams and Dawson,⁶ in which they used an equal energy spectrum rather than our photopically balanced stimuli and concluded that the fast retinal potentials were not differentially related to any single spectral mechanisms. In the monkey retina, there seemed to be no basic difference in the latencies of the three cone mechanisms subserving foveal vision and reaching small ganglion cells.¹⁰
Fig. 7. Plots of the amplitude of the oscillatory potential (fourth trace, \( P_1, P_2, P_3 \) (stars) and \( N_1, N_2, N_3 \) (squares)) as a function of photopically balanced lights on Subject K. F. Amplitude was measured from the base line. Each point is the average of six responses.

On the basis of these considerations, it is conceivable that the oscillatory potential of the ERG may not play the special role of color coding in the human retina.

REFERENCES


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