The human electroretinogram and occipital potential in response to focal illumination of the retina

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Electrical responses to light stimuli of 1° angular subtense were recorded from the eye (electroretinogram, ERG) and from the occiput (visual evoked response, VER) in normal subjects and in patients with visual field defects. Suitable combinations of stimulus and background intensities were able to produce focal retinal stimulation, evidenced by absence of response to blind spot stimulation and by presence of a clear response with foveal stimulation. At a constant level of background light the range of stimulus intensity necessary to effect focal stimulation was much more critical in ERG (1 log unit) than in VER (4 log units). With these parameters, the distribution of VER amplitude on the horizontal meridian of the visual field showed augmentation at the macular area of the retina in the photopic and scotopic state. When the stimulus was moved from the center to the periphery along the horizontal meridian, the b-wave of the ERG diminished in most cases more greatly than the a-wave, and was reduced to a prolonged negative wave at the periphery. Under these conditions, combined recording of ERG and VER was found to be significant in judging whether field defects resulted from local disorders of the retina or from lesions higher in the visual system.

Key words: local electroretinogram, evoked visual response, visual field disorders (retinal origin), blind spot, background illumination, focal retinal illumination, scotopic vision, photopic vision.

The possibility of objective perimetry by utilization of the human visual evoked response (VER) has been suggested. Several studies suggest that the human VER is not suitable for objective perimetric examination, since it is predominantly a measure of macular function. The attempt to detect an electrical response to light from a small localized area of the human retina (local electroretinogram, local ERG) has become feasible with computer summation techniques. Although the clinical applications of this local ERG would appear obvious, it has remained almost unexplored save for the preliminary reports of Gouras and associates and Arden and Bankes. We now have attempted to apply this technique to
patients with visual field defects, simultaneous with observation of the VER evoked by focal retinal stimulation.

Methods

Our stimulus light was provided by an incandescent bulb (750 W., 100 v.). After passing through heat-absorbing filters, the light from the bulb was focused by a series of lenses upon the entrance end of a glass fiber light guide 5 mm. in diameter. A light-weight aluminum foil shutter, driven by a noiseless electromagnetic device, was situated between the light guide and the condensing lenses. The exit of the light guide was mounted at the center of an adaptometer sphere (Goldmann-Weekers). Stimulus intensity was controlled in steps by placing neutral density filters (Cray & Co.) in the light path. The distance between the exit end of the light guide and the stimulated eye was 28 cm., the visual angle of the stimulus spot 1.0 degree. The rise and fall times of the square wave stimulus light were 3 and 4 msec., respectively. Stimulus frequency was 2.7 c.p.s. in the VER recording, and 1.8 c.p.s. in the ERG recording.

Two incandescent bulbs (80 W., 6 v.) served as a source of background illumination. These were mounted on the upper portion of the adaptometer sphere and supplied by stabilized D.C. The light from the bulbs, after passing through a sheet of light-diffusing paper, illuminated uniformly all parts of the inner white surface of the adaptometer sphere. Adapting light intensity was varied by neutral density filters (Kodak). The maximum intensity (0.0 log unit in the illustrations) of the stimulus and of the adapting light were $5.0 \times 10^{-5}$ and 90 foot-lamberts respectively.

The VER was led from disc electrodes (Grass, 8 mm. in diameter) placed 2 cm. anterior and 3 cm. lateral to the inion on both sides of the occiput, unless otherwise specified. The ERG was picked up by a low-vacuum contact lens electrode, which was not used when the VER was

![Figure 1](http://iovs.arvojournals.org/pdfaccess.ashx?url=/data/journals/iovs/933002/)
recorded. All were referred to the joined earlobes. The space between the contact lens and the cornea was kept filled with normal saline. Special care was taken to avoid air bubbles in the lens. A ground electrode was attached to the chin. Electrical responses were fed, after being amplified by an EEG machine (Grass III D), to a computer of average transient (Mnemotron CAT) and recorded photographically. From 128 to 250 responses were summed. The frequency characteristics of the amplifier was 3 db. down at 0.7 c.p.s. and at 1.5 kc.p.s. Upward deflection indicates negativity of the occipital electrode in the VER, and positivity of the corneal electrode in the ERG, as dictated by the conventions of the techniques.

Two of the authors (K. K. and T. H.) served as subjects in most of the present study. They had no detectable ophthalmological or neurological abnormalities except for myopia of about 3.0 diopters. Refractive error was not corrected. Three patients with visual field defects were also studied. Subjects sat with forehead and chin supported, facing the adaptometer sphere. The right eye was stimulated except when responses to stimulation of each eye were compared in patients. The non-stimulated eye was carefully shielded from the stimulus and adapting light by opaque material.

The pupil was dilated by instillation of 1 per cent Tropicamide into the conjunctival sac. The subjects were requested to minimize muscle tension in the neck and shoulders in order to reduce artifacts of muscular origin from the recorded VER. Stimulation of peripheral retinal sites was achieved by having the subjects fixate points located along the horizontal meridian of the adaptometer sphere.

Results

VER. Fig. 1 shows the VER elicited by stimuli of varying intensity placed at the fixation point (henceforth referred to as foveal stimulation) or presented at the center of the blind spot scotoma (referred to as blind spot stimulation), under the brightest background illumination (0.0 log unit). With increasing stimulus intensity, a positive wave (IV in Fig. 1) preceding the later negative wave (V in Fig. 1)
gradually developed. Intense stimuli evoked an additional negative wave (III in Fig. 1) prior to the wave IV. The designations III, IV, and V are based upon those of Ciganek as to polarity and peak latency. These waves displayed a general tendency toward enhancement with increase in stimulus intensity. The amplitude of the wave V, however, seemed to vary in more irregular fashion with stimulus intensity than the earlier waves (Fig. 2). The VER threshold with stimulus centered at the blind spot was approximately 4 log units higher than that with foveal stimulation in this light-adapted state (compare open and filled squares in Fig. 2, A). When the background was very dim or dark and the stimulus bright, blind spot stimulation evoked a VER almost as large as that evoked by foveal stimulation (Fig. 2, B), as is the case with the ERG (Fig. 5).

When the intensity of background light was reduced, with stimulus intensity kept constant, the stimulating effect of the stray light from the stimulus is augmented. Thus, a decrease in background intensity must be accompanied by a decrease in stimulus intensity, in order to attain focal retinal stimulation. The experiment illustrated in Fig. 3 was designed to determine the stimulus intensity required for focal retinal stimulation with decreased background intensities. The VER threshold with blind spot stimulation was reduced when the background intensity was decreased, as might be reasonably expected (Fig. 3). It was possible to find a stimulus intensity bright enough to evoke a definite VER.

Fig. 3. VER elicited by blind spot stimulation at different levels of background. The five pairs of VER's at the top were evoked by foveal stimulation, intensity of which was so adjusted as to evoke no response when it was placed at blind spot scotoma. Average of 250 responses.
with foveal stimulation but not adequate to evoke a VER with blind spot stimulation. At the top in Fig. 3 are shown VER's evoked by such stimuli projected at the fixation point. These VER's may be assumed to result from stimulation of localized retinal area. Fig. 3 also shows that the blind spot may be detected by the VER without background light, if the stimulus was sufficiently dim. This suggests the possibility of objective perimetry by the VER in the scotopic state.

In the next experiment the stimulus image fell on retinal sites along the horizontal meridian at different levels of background light (Fig. 4). The stimulus intensity was adjusted so that virtually focal illumination was attained, as shown at the top of Fig. 3. The occipital electrode was placed on the midline 2 cm. anterior to the inion in this experiment. As seen in Fig. 4, the VER was drastically depressed when the stimulus image fell eccentrically on the retina. The VER amplitude obtained in the absence of background light showed no wider distribution on the horizontal meridian than those obtained under bright background illumination (Fig. 4).

In order to ascertain whether the light-adapting effect of the repetitive presenta-

![Fig. 4. VER amplitude as a function of location of 1° stimulus spot on the horizontal meridian of the visual field. Note that amplitude distribution on the horizontal meridian does not depend on background intensity, if stimulus intensity is so adjusted as to attain focal illumination at each level of background, and that VER is greatly dominated by macular function even in the absence of adapting light. At bottom are shown sample records evoked by stimulus of -5.0 log units at background of -4.0 log units. Average of 250 responses.](image-url)
tion of the extremely dim stimulus (−6.0 log units) used in this experiment with no background light suppressed scotopic function, a stimulus of identical intensity, duration, and frequency was presented to the retina 20° temporal to the fovea. The subjective light threshold of this retinal portion, immediately after being exposed to the stimulus, did not increase more than 1.0 log unit above the absolute dark-adapted threshold.

These findings indicate that the human VER is dominated by macular function, without regard to state of adaptation.

**ERG.** Another possible approach to objective perimetry may be based on the ERG. Fig. 5 shows the summed ERG elicited by various stimulus intensities. In the absence of background light, blind spot stimulation as well as foveal stimulation evoked a distinct ERG (Fig. 5, AA'). However, differences in the ERG waveform and time course were discernible between blind spot stimulation and foveal stimulation, when the stimulus was dim (−2.0 log units) (compare the uppermost traces in Fig. 5). When a brighter stimulus was used without background light, the ERG with blind spot stimulation was as large as or even slightly larger than that with foveal stimulation (second traces in Fig. 5, AA'). This may be ascribed to stray light effect.

When the retina was light-adapted to reduce stray light effect, the ERG was greatly depressed. Stimulus of −2.0 log unit intensity evoked no response (Fig. 5, BB'). When stimulus intensity was increased up to −0.5 log unit, foveal stimulation evoked a definite ERG response, while blind spot stimulation elicited almost no response (Fig. 5). This indicates that the ERG is recordable from a localized area of the human retina by use of adequate combinations of stimulus and background intensities. The ERG evoked by our bright-

![Blind Spot Fovea](image-url)

**Fig. 5.** Summed ERG evoked by 1° stimulus spot placed at blind spot scotoma (left column) and at fixation point (right column). Records AA' were obtained without background light, records BB' with background light of 0.0 log unit. Average of 200 responses except for the second traces in AA', which were average of 15 responses.
The est stimulus in the light-adapted state consisted of a small a-wave followed by a slightly larger b-wave. This was followed by an additional small positive-going hump (fifth trace of Fig. 5, B').

There are at least four possible sources of this last component. It may be: (1) the wave produced by the retinal region stimulated by stray light, 9'19 (2) the ERG off-response, (3) the diminished scotopic b-wave, or (4) an artifact due to movements of the eyeball or eyelids. Further study is required to settle this point.

Using the criteria described above, stimulus and background intensities of -0.5 and 0.0 log unit, respectively, were suitable to detect the ERG from a localized retinal area. Using this set of parameters, the stimulus image was made to fall on retinal sites along the horizontal meridian (Fig. 6). Shifting the stimulus image to the periphery decreased the amplitude of both the a- and b-waves, the latter more greatly depressed than the former. Only a prolonged negative wave was found at the peripheral stimulus location (40° at the bottom of Fig. 6).

As in the case of the VER, decrease in background intensity must be accompanied by decrease in stimulus intensity, if we wish to obtain no ERG response with blind spot stimulation and a definite response with foveal stimulation. Such intensities of stimulus were determined at two additional levels of background illumination. The amplitude of the ERG obtained with these combinations of stimulus and background intensities was plotted as a function of

![Graph](http://iovs.arvojournals.org/pdfaccess.ashx?url=/data/journals/iovs/933002/)  

**Fig. 6.** ERG amplitude as a function of location of 1° stimulus spot on the horizontal meridian of the visual field. Stimulus intensity was so adjusted at each level of background as to evoke no ERG, when it was placed at blind spot scotoma. Sample records evoked by stimulus of -2.0 log units at background level of -2.0 log unit are shown at bottom. Open symbols pertain to the a-wave, filled symbols to the b-wave (measured from trough of the a-wave to peak of the b-wave). Average of 250 responses.
Fig. 7. Subjective sensation of 1° stimulus spot at various levels of background. Sensation of stimulus is indicated by following symbols: •, no light; ○, very dim light without halo; ◦, distinct light without halo; circle within circle, bright light with small halo; circle within circle within another circle, very bright light with halo all over the visual field. Stimulus spot was placed at fixation point (left) and at blind spot scotoma (right). Dashed line indicates VER threshold with foveal stimulation, dotted line that with blind spot stimulation. Note that VER threshold is very near subjective threshold.

VER threshold depends on all parameters, including stimulus diameter, frequency, and duration. In addition, no observation was made in the present study of later VER components, which might appear more than 225 msec after the onset of the stimulus.

The VER threshold with blind spot stimulation was approximately 4 log units higher than that with foveal stimulation at each level of background light (Fig. 7). Thus, the stimulus intensity required for discrimination of the blind spot by the VER was not as critical as has been asserted.1

The size of the halo subjectively perceived around the stimulus spot depended on both stimulus and background intensities. When both were so adjusted as to produce no halo with foveal stimulation, no VER was evoked by blind spot stimulation, with our stimulus diameter. This might be valuable for rough estimation of the stimulus intensity required to achieve focal stimulation in VER recording with varying background intensities.

Clinical application. The preceding results demonstrate that the ERG, as well as the VER, may be used for detecting responses to focal illumination of the human retina. Combined recordings of the ERG and the VER in response to focal retinal illumination would seem to be of clinical interest in patients with visual field defects and might be expected to provide a means of differentiating retinal from central lesions causing field loss. In the clinical cases described below, the brightest background (0.0 log unit) was employed, to suppress stray light effect, unless otherwise specified.

Case 1. A 65-year-old white man with left homonymous hemianopsia with macular sparing of 5 degrees was tested on the right eye, the left eye being occluded by opaque material. His uncorrected and corrected visions were 20/50 and 20/20, respectively, in each eye. When the stimulus spot was placed in his scotoma (10° nasal to the fixation point), the recorded ERG was as large as that evoked by stimulus located

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at a seeing site (10° temporal to the fixation point) (Fig. 8), despite the patient's inability to perceive the stimulus at the former site. These ERG's may be assumed to arise from the local retinal area, since no ERG was evoked by blind spot stimulation (B.S. in Fig. 8). The stimulus spot placed in his scotoma (10° nasal to the fixation point) elicited virtually no VER from either side of the occipit (Fig. 8). When the stimulus was placed in an area of vision (10° temporal to the fixation point), a small but definite VER was obtained from the left occipit (Fig. 8). These results strongly suggest that the lesion responsible for his field defect was not in the retina, but in the higher visual system. Carotid angiography revealed an aneurysm measuring 4 cm. in its maximum diameter arising from the right anterior cerebral artery.

**Case 2.** A 67-year-old white man had had an absolute central scotoma subtending 5 degrees in the left eye. His visual acuity was O.S. 5/400 and O.D. 20/40, not correctible. To avoid unsteadiness of the fixation of the left eye due to the poor visual acuity, he was requested to try to fixate the center of a circle subtending 10 degrees drawn concentrically around the stimulus spot. The patient was able to perceive this circle, situated outside his central scotoma. A centrally placed stimulus evoked a distinct ERG from the right, better eye, while the identical stimulation failed to elicit an ERG from the left, affected eye (Fig. 9). It should be stressed that this contrast in the ERG between the right and left eyes was detectable only in the highly light-adapted state (0.0 log background intensity). An almost normal ERG was obtained from each eye in the absence of background light.

This is compatible with a localized retinal lesion responsible for the visual disorder in the left eye of this patient. The VER was much smaller on stimulation of the left eye than that on stimulation of the right, better eye, when the background was bright (Fig. 9). Ophthalmoscopic examination revealed macular degeneration in the left eye. The right eye showed some pigmentation in the macular area, but no central scotoma.

**Case 3.** An 81-year-old white woman had had an absolute central scotoma subtending 3 degrees in the left eye. The uncorrected vision was O.S. 20/200, O.D. 20/100. The corrected vision was
Fig. 9. Case 2; age 67; central scotoma (5°, O.S.). Centrally fixed focal stimulation with background of 0.0 log unit. No ERG, and depressed VER on stimulation of left affected eye. Stimulus intensity −0.5 log unit. Average of 128 responses in ERG, 250 responses in VER.

Fig. 10. Case 3; age 81; central scotoma (3°, O.S.). No ERG and depressed VER on foveal stimulation of left involved eye at maximum background level (0.0 log unit) (left and middle columns). In absence of background light, left eye stimulation evoked VER almost as large as that evoked by stimulation of right, better eye (right column). Stimulus intensity −1.0 and −2.0 log units in ERG and VER, respectively. Average of 128 responses in ERG, 250 responses in VER.

O.S. 20/100, O.D. 20/70. The stimulus intensity for the ERG was −1.0 log unit, 0.5 log unit less than that used in cases 1 and 2. We chose this because of the small size of the central scotoma in this patient. To facilitate fixation of the left, affected eye, the same procedure used in case 2 was employed. A centrally fixed stimulus evoked an ERG response from the right, better eye, while it evoked almost no ERG from the left, worse eye (left column in Fig. 10). An essentially normal ERG was recorded from each eye when no background light was used. These findings indicate a localized retinal lesion and, indeed, macular degeneration was visible in the left eye. The right eye had some pigmentation of the macula.

Stimulation of the left, worse eye, evoked a much smaller VER than stimulation of the right, better eye, did, when the eye was light-adapted to the brightest background (middle column in Fig. 10). On the other hand, stimulation of either eye evoked a VER of equivalent amplitude in the absence of background light (right column in Fig. 10). The findings in cases 2 and 3 indicate that macular degeneration is associated
with loss of the ERG and with marked deterioration of the VER, when we employ the combination of stimulus and background intensities which achieve focal retinal stimulation.

**Discussion**

A much brighter stimulus was required to evoke the ERG than to evoke the VER, with our brightest background (Figs. 1 and 5). The difference between the threshold with foveal stimulation and that with blind spot stimulation was about 1 log unit in the ERG, but 4 log units for the VER (Figs. 1, 2, and 5). Hence, the stimulus intensity required to achieve focal stimulation is much more critical in the ERG than in the VER.

The amplitude distribution of the a-wave of the ERG on the horizontal meridian of the visual field is as wide as or slightly wider than that of the b-wave (Fig. 6). The onset of the prolonged negative wave found in the ERG with peripheral location of the stimulus spot is probably responsible for the initial phase of the a-wave (Fig. 6). This prolonged negative wave probably corresponds with the sustained negative wave reported in the human ERG by use of weak stimulus of large subtense, and suggests that the threshold is lower for the a-wave than for the b-wave under the particular conditions of our experiment, as well as that of others.

The findings of this study indicate that the human VER is dominated by macular function at photopic and scotopic states of adaptation (Fig. 4). The VER related to the scotopic mechanism by Vaughan (6 log attenuation in his Fig. 6, polarity reversed) is closely similar in wave form, latency, and polarity to the VER obtained in this study, under conditions favoring scotopic function (Fig. 3). This VER, however, is predominantly an index of macular function (Fig. 4).

The apparent area of the pupil decreases when it is viewed obliquely 20° from the fixation point. Nevertheless, stimulus at this eccentric location failed to evoke the VER (Fig. 4). The drastic depression of the VER by peripheral location of stimulus cannot be accounted for by decrease in stimulus intensity due to reduction of the effective area of the pupil.

We feel that the lack of linearity of response, with macular stimulation evoking a disproportionately large VER, makes it difficult to utilize the human VER for objective perimetry. The macular area of the retina is represented in a large posterior portion of the cortex, while the representation of the peripheral retina is away from the occipital pole and deep in the calcarine fissure. This may explain, as pointed out by Fishman, the fact that the human VER led off from scalp electrodes is greatly dominated by the macular function.

This lack of linearity, however, may mean that the human VER is useful as an indicator of macular function. It should be stressed that the combinations of stimulus and background intensities which achieve focal retinal stimulation, as well as small area stimulus, are crucial factors for detection of deterioration of the VER in cases with macular degeneration (Fig. 10). Kooi and colleagues stated that patients with macular disease could not be differentiated from normal subjects by means of the VER. They, however, used a large-sized stimulus and a dim background.

One of the most important points in experiments to attempt focal retinal stimulation is to locate the stimulus image at the desired site of the retina. This is not very difficult, if the subjects are cooperative and their vision is adequate for fixation. Patients who are sufficiently cooperative to allow recording of the focal ERG will also be cooperative enough to allow accurate subjective field plotting. The number of patients in whom this objective technique will be useful, therefore, is limited.

When the location of stimulus spot on the retina is directly visualized by the examiner by means of a specially designed
device,27 28 combined recording of the ERG and the VER in response to focal illumination will be a more reliable technique for investigation of localized retinal lesions and of alterations in the function of the higher visual system.

REFERENCES