Multifocal Topographic Visual Evoked Potential: Improving Objective Detection of Local Visual Field Defects

Alexander I. Klistorner, Stuart L. Graham, John R. Grigg, and Francis A. Billson

PURPOSE. To investigate the relationships between the pattern stimulation of different parts of the visual field (up to 25° of eccentricity), the electrode position, and the cortical response to improve objective detection of local visual field defects.

METHODS. The human visual evoked potential (VEP) was assessed using multifocal pseudorandomly alternated pattern stimuli that were cortically scaled in size. Monopolar and bipolar electrode positions were used. The visual field was investigated up to 26° of eccentricity. Twelve normal subjects and seven subjects with visual field defects of different nature were studied.

RESULTS. Although the monopolar response is heavily biased toward the lower hemifield, bipolar leads overlying the active occipital cortex (straddling the inion) demonstrate good signals from all areas of the visual field tested. The amplitude is almost equal for the averaged upper and lower hemifields, but the polarity is opposite, causing partial cancellation of the full-field VEP. The degree of cancellation depends mainly on latency differences between the vertical hemifields. The bipolar VEP corresponded well with Humphrey visual field defects, and it showed a loss of signal in the scotoma area.

CONCLUSIONS. The multifocal VEP demonstrates good correspondence with the topography of the visual field. Recording with occipital bipolar electrode placement is superior to standard monopolar recording. To avoid a full-field cancellation effect, a separate evaluation of upper and lower hemifields should be used for the best assessment of retino-cortical pathways. This technique represents a significant step toward the possible application of the multifocal VEP to objective detection of local defects in the visual field. (Invest Ophthalmol Vis Sci. 1998;39:937-950)

The visual evoked potential (VEP) is a powerful method for the investigation of brain activity and the mechanisms of human visual perception. The pattern-VEP (P-VEP), used in physiological and clinical studies, has proved to be an informative indicator of the state of retino-geniculo-cortical pathways. Amplitude decrease and latency delay have been reported in many pathologic conditions involving the impairment of conductivity along the optic nerve. In some cases the method proved to be even more sensitive for detecting compressive lesions than subjective perimetry.1,2

However, it is widely recognized that P-VEP is generated predominantly by cortical elements that receive projections from the central retina (which is mainly a result of its heavy cortical overrepresentation).3-8 This limits the application of the method in the detection of peripheral field defects, which is crucial in the diagnosis of such common diseases as glaucoma. A small unified check size, which is used commonly for stimulation, is another factor that tends to bias the central response.9,10

During the long history of visually evoked cortical recordings there have been numerous attempts to overcome these constraints. Different modes of stimulation have been used. The most common approach used partial stimulation of the visual field, including hemifields, quadrants, segments, annuli, or peripheral fields, as opposed to central field modes.11,15-22 This approach also used local stimulation with light-emitting diodes,12 which greatly improved detection of the peripheral visual field defect. However, higher responses from the stimulation of the upper hemiretina (lower visual field) compared with the lower hemiretina (upper visual field) often have been reported.11,23-28 This was interpreted by some researchers as a reflection of the functional superiority of the lower visual field.24,28

However, it has been shown that varying the placement of electrodes can considerably affect the field topography of the VEP response. For instance, conventional (occipito-frontal) electrode placement, used in the majority of studies and recommended by the International Standards Committee Electrophysiology of Vision as a standard for clinical use,29 favors the lower field response. Transferring the position of the reference electrode from mid-frontal to linked ears, however, significantly improves the detection of the signals from the upper field.19,30 The same tendency is observed when occipito-occipital bipolar electrode montage is used.31

This variation in response with electrode position is most likely caused by the complicated anatomy of retino-cortical projections from different parts of the visual field and the extreme convolution of the cortex,32,33 which lead to a variation of the underlying dipole sources.19 The central part of
the upper retina (up to 20°–25°) projects to the external (posterior) surface of the occipital cortex, just anterior to the inion. The central part of the lower retina projects to the inferior surface of the occipital cortex. This makes the cortical dipoles from the lower and upper central hemifields almost perpendicular. Therefore, electrode position is critical when recording VEPs from the central visual field. The orientation of the electrodes relative to the generating dipoles may substantially favor the input from either the upper or the lower field. The projection of the more peripheral parts of the upper and lower hemiretinas are to the upper and lower banks of the fissure calcarius. This leads to an almost opposite orientation of the generating dipoles.

Previous attempts to record a type of multifocal VEP by stimulating individual parts of the visual field have been limited by time constraints to using larger test areas such as hemifields or quadrantic fields. A recent study that attempted to detect visual field defects by means of traditional sequential (site-by-site) stimulation used a relatively large stimulus size (hemifields or quadrantic fields), which limited the resolution of the technique.

A different approach was suggested by Sutter's group. They used the method of pseudorandomly presented multifocal stimulation together with cortical scaling of the size of the stimulated patches. They were able to stimulate numerous locations of the visual field simultaneously and to extract individual responses from each of them. Signal-to-noise ratios were acceptable from as far as 7° of eccentricity. The bipolar (occipito-occipital) electrode placement used in their study permitted the recording of reliable responses from many locations of the visual field, including the upper and lower hemiretina.

The Sutter system provides a better technique for studying the visual field topography of cortical response because of its ability to stimulate a large number of visual field locations simultaneously and independently. This system is based on the special properties of the binary noise stimulation sequence (for more details, see Methods). However, recent studies with a multifocal pseudorandomly stimulated VEP have used retinally (not cortically) scaled flash stimulation, which favors the foveal response and generates a much more variable signal (in terms of waveform) than pattern stimulation.

The aim of the present investigation was to extend the study of Sutter's group in establishing the relationship between the topography of the expanded visual field (up to 25° of eccentricity) and the cortical response (VEP). We consider our study a significant step toward the possible application of multifocal VEP in the detection of local defects in the visual field.

**METHOD**

**General Description**

The electrophysiological method used in this study was the VERIS Scientific system for topographic and temporal analysis of evoked potentials (Electro-Diagnostic Imaging, San Francisco, CA), which uses a special class of pseudorandom white noise stimulation called binary m-sequences. It is based on the Wiener kernel expansion and uses a deterministic pseudorandom binary expansion of two opposite checkerboard pattern conditions at each of numerous sites (60 sites in this study) of the visual field. According to this sequence, there is a 50% probability for the checkerboard pattern to reverse its polarity with every frame of the stimulating display (15 msec). Each input (stimulation site) is modulated in time according to the same pseudorandom binary m-sequence.

An important advantage of the m-sequences (to be orthogonal to all their cyclic shifts) is that it permits computation of the signal by cross-correlation of the response evoked by the m-sequence stimulation with the m-sequence itself. This property allows one to obtain responses for hundreds of inputs from records of up to a million data points in a fraction of a minute and, therefore, makes m-sequence stimulation very effective for mapping.

The technique allows computation of first-order and higher order kernels, which characterize the nonlinear interaction between visual events. The first-order response however, is zero under the condition of pattern stimulation when both pattern polarities are equal. Thus, only the second-order kernel (first slice), which represents the interaction between two consecutive frames of the monitor and is considered to be analogous to the conventional P-VEP, was analyzed in this study. A full theoretical analysis of the method can be found elsewhere.

**Stimulation and Recording**

The visual stimulus was generated on a CRT screen (22-inch high-resolution display, stimulation rate 67 Hz, Mitsubishi, Tokyo, Japan). It consisted of 60 close-packed segments (Fig. 1A), the sizes of which were cortically scaled with eccentricity to stimulate approximately equal areas of cortical (striate) surface. The cortical scaling would, therefore, be expected to produce a signal of a similar order of amplitude from each stimulating segment. Figure 1B demonstrates the relationship between the size of the stimulus segments and the visual field. Each segment included a checkerboard pattern (16 checks) in which the sizes of individual checks were proportional to the size of the segment and, therefore, also were dependent on eccentricity. Checks were alternated in pseudorandom sequences, from which the individual kernels were calculated by a cross-correlation of the digitized output signal with the binary input sequences using a fast Walsh transform. The m-16 sequence that was used resulted in 216 – 1 frames, which corresponded to 52,288 pattern reversals at each site in each 16-minute recording.

The luminance characteristics of the screen were measured using a TV-Analyser (Minolta, Tokyo, Japan). The Commission Internationale de l'Eclairage coordinates for the monitor white color were: x = 0.29; y = 0.30. The luminance of the white check was 146 candelas (cd)/m², and the luminance of the black check was 1.1 cd/m², producing a Michelson contrast of 99%. The background luminance of the screen was maintained at a mean level of 73.5 cd/m². A dim room light was always on.

Subjects were comfortably sitting in chairs and were asked to fixate on a red fixation point at the center of the dartboard pattern. The distance to the screen was 30 cm, corresponding to a 52° total subtense of the stimulus. All subjects were refracted optimally. Pupils were undilated. All recordings were collected using monocular stimulation.

**Electrode Placement**

For electrode placement two different setups were used. The conventional monopolar (occipito-frontal) electrode place-
FIGURE 1. (A) Cortically scaled dartboard stimulus used in this study. Each of the 60 segments contains a black-and-white checkerboard pattern (16 checks), which is alternated with pseudorandom frequency. Because of the specific nature of the m-sequence, responses to pattern stimulation can be extracted from each individual segment. (B) Demonstrates the relationship between the sizes of the stimulus segments and the visual field.

Data Acquisition

All data presented in this study were recorded using a Neotrace amplifier (Digitimer Ltd, Hertfordshire, UK). The signal was amplified 100,000 times and was put through a band-pass filter between 3 and 100 Hz. The data sampling rate was 500 Hz, and the m-16 binary stimulation sequence was divided into 32 slightly overlapping segments. Raw data were scanned in real time, and the segments that were contaminated by a high level of noise, eye movements, or blinking were rejected.

Subjects

Two groups of subjects were used in this study. The first group consisted of 12 normal volunteers (6 males and 6 females). They had an age range from 22 to 65 years. All subjects were given a routine visual examination, had a corrected Snellen acuity of 20/20 or better, had a refractive error of less than 2 diopters, and had a normal Humphrey 24-2 visual field (Humphrey Field Analyzer; Humphrey Instruments, San Leandro, CA). There was no history of ophthalmologic abnormality in any of the subjects, and no systemic illness such as diabetes that could affect visual function. None of the subjects were familiar with the experimental setup. The study followed the tenets of the Declaration of Helsinki, and informed consents from all subjects were obtained.

The second group included patients with well-documented visual field defects. This group included three subjects with extensive glaucomatous field changes, which were confirmed on repeat automated perimetry, a patient with a pituitary adenoma causing chiasmal compression, a patient with optic atrophy secondary to trauma, a patient with cortical infarct, and a patient with congenital disk defect. The visual acuity in these seven patients was 20/30 or better. The glaucoma patients had primary open-angle glaucoma, with an intraocular pressure >20 mm Hg, typical optic disc cupping, and confirmed visual field loss.

RESULTS

Monopolar (Occipito-Frontal) and Bipolar Electrode Placements

In the first series of experiments the effectiveness of conventional monopolar (occipito-frontal) electrode placement were compared with that for BOS electrode placement. Traces derived from the stimulation of 60 cortically scaled individual segments of the visual field using monopolar and BOS electrode placements are presented in Figure 2.

There are several points that are apparent. First, the stimulation of the segments of the upper hemifield using monopolar placement (Fig. 2A) yielded much smaller responses than the stimulation of the segments of the lower hemifield. The best position of the electrodes in this respect (which produced approximately equal responses from upper and lower hemifields) was found when electrodes were placed at equal distances 2 cm inferior to (negative electrode) and 2 cm superior to (positive electrode) and straddling the inion. Thus, this modified electrode position will be referred to in the present study as bipolar-occipital-straddle (BOS) placement to differentiate it from Baseler's position.

Multifocal Topographic VEP
FIGURE 2. Examples of normal traces of multifocal pattern visual evoked potentials recorded using: (A) monopolar frontal-occipital electrode placement; and (B) bipolar-occipital-straddle (BOS) electrode placement. Although responses from the lower visual hemifield demonstrate equally reliable traces at both electrode placements, significant improvement in the responses from the upper hemifields is observed using the BOS electrode positions. Monopolar and bipolar recording for the same subject were performed simultaneously.

proportional distribution of the recorded potential throughout the whole stimulated area. Responses from practically all locations of the lower and upper parts of the visual field demonstrated good signal-to-noise ratios with a well-defined waveform and significant amplitude.

Second, practically all traces derived using monopolar electrode placement showed the same polarity of the waveform, with the major negativity at around 100 msec. As mentioned above, this is much more pronounced in the lower field. Traces produced using the BOS electrode placement, however, demonstrated opposite polarities in the upper and lower hemifields. The majority of the cortical signals derived from the stimulation of the different segments of the lower field exhibited well-defined negativity at around 100 msec, whereas most of the upper field stimulating sites produced traces with significant positive deflection at approximately the same latency.

These differences became even more apparent when the combined responses from the upper and lower hemifields recorded using monopolar (Fig. 3) and BOS (Fig. 4) electrode arrangements were compared. As can be seen clearly in Figure

FIGURE 3. Examples of averaged vertical hemifield responses recorded from three normal subjects using monopolar electrode placement. The traces demonstrate significant amplitude asymmetry between the upper and lower hemifields (extremely small upper hemifield signal), but uniform polarity. 1, upper hemifield traces; 2, lower hemifield traces.
Figures 4A, 4B, and 4C demonstrate responses from the same subjects as presented in Figure 3, whereas Figure 4D shows the averaged hemifield VEPs from the remaining nine normal subjects.

The polarity of the major components in all tested subjects demonstrated an opposite character. The lower hemifield response exhibited a positive-negative waveform with a latency of the first positivity of 75.0 (SD = 3.4) msec and major negativity at 97.2 (SD = 2.7) msec. The upper hemifield response showed almost the opposite polarity of the peaks with a negative deflection at 79.0 (SD = 6.7) msec and a major positive peak at 105.5 (SD = 4.7) msec.
TABLE 1. Amplitude and Latency Values for Summed Upper and Lower Hemifield Response Derived from Normal Subjects (Displayed by Subject Number)

<table>
<thead>
<tr>
<th></th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
<th>11</th>
<th>12</th>
<th>Mean</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sex</td>
<td>m</td>
<td>m</td>
<td>f</td>
<td>m</td>
<td>m</td>
<td>f</td>
<td>f</td>
<td>f</td>
<td>m</td>
<td>m</td>
<td>f</td>
<td>f</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Age</td>
<td>22</td>
<td>32</td>
<td>37</td>
<td>38</td>
<td>39</td>
<td>44</td>
<td>52</td>
<td>55</td>
<td>62</td>
<td>63</td>
<td>65</td>
<td>65</td>
<td>47.9</td>
<td></td>
</tr>
<tr>
<td>Upper hemifield latency (msec)</td>
<td>110</td>
<td>99</td>
<td>102</td>
<td>106</td>
<td>100</td>
<td>96</td>
<td>105</td>
<td>110</td>
<td>104</td>
<td>115</td>
<td>112</td>
<td>106</td>
<td>105.5</td>
<td>4.7</td>
</tr>
<tr>
<td>Lower hemifield latency (msec)</td>
<td>97</td>
<td>97</td>
<td>97</td>
<td>97</td>
<td>94</td>
<td>92</td>
<td>93</td>
<td>99</td>
<td>100</td>
<td>102</td>
<td>102</td>
<td>99</td>
<td>97.2</td>
<td>2.7</td>
</tr>
<tr>
<td>Upper hemifield amplitude (μV)</td>
<td>3.6</td>
<td>2.9</td>
<td>5.5</td>
<td>2.4</td>
<td>3.7</td>
<td>4.1</td>
<td>3.4</td>
<td>2.5</td>
<td>2.9</td>
<td>2.5</td>
<td>3.7</td>
<td>4.7</td>
<td>3.49</td>
<td>0.94</td>
</tr>
<tr>
<td>Lower hemifield amplitude (μV)</td>
<td>4.4</td>
<td>2.7</td>
<td>5.5</td>
<td>3.3</td>
<td>4.2</td>
<td>4.4</td>
<td>4.5</td>
<td>3.6</td>
<td>3.4</td>
<td>3.8</td>
<td>3.8</td>
<td>4.1</td>
<td>3.99</td>
<td>0.68</td>
</tr>
</tbody>
</table>

The values of the latencies of the major peaks for all tested subjects (Table 1) clearly indicated that the lower field tended to respond faster. The difference of a few milliseconds was detected in all subjects tested.

Although there are some interindividual variations, the data presented in Table 1 illustrate that the magnitude of the VEP signals from the upper and lower parts of the tested visual field recorded using bipolar electrode placement tends to be quite small. Figure 5 showed extremely small variations of the amplitude, waveform, and latency of the response.

There were, however, no polarity reversals or waveform changes in bipolar recordings across the vertical meridian of the stimulated visual field. To avoid the equivocality caused by a horizontal polarity change, quadrants (instead of the left and right hemifields) have been analyzed. A typical example (Fig. 6) shows that both upper hemifield quadrants exhibit a similar negative–positive waveform, whereas low hemifield quadrants show similar positive–negative waveforms of opposite polarity.

The polarity reversal across the horizontal meridian had an important effect on the recording of full-field P-VEP, which has not been properly addressed in the available literature. Based on the additive nature of the P-VEP, one may assume that the summation of the opposite polarity signals evoked by the stimulation of equal areas of the upper and lower fields would produce partial or even complete cancellation of the full-field response. We found that the full-field BOS VEP exhibits such behavior: The larger hemifield constituents often produce a much smaller resulting full-field waveform.

Although the degree of cancellation depends to some extent on the relative amplitude of VEPs for the upper and lower hemifields, it is also dependent on the difference in latency between hemifield responses: the shorter the difference between opposite peaks of averaged upper and lower hemifield responses, the smaller the resulting full-field signal. For instance, the traces presented in Figure 7 show approximately equal amplitudes of the responses from the upper and lower hemifields for a particular subject. However, the difference in latency of the major upper and lower hemifield peaks demonstrates a significant impact on the full-field response. The smallest (relative to the hemifield response) full-field VEP was recorded from the subject presented in Figure 7A who has the shortest difference in latency between upper and lower hemifield responses (1.7 msec). The largest full-field VEP was detected in the subject presented in Figure 7C, who has a large discrepancy (8.4 msec). The subject presented in Figure 7B (3.3 msec difference) occupies an intermediary position. This observation makes the interpretation of the bipolar full-field VEP (at least under the conditions of stimulation used in our study) questionable.

From the trace arrays presented, it is evident that this observation holds for small central stimulating areas of a few degrees in diameter (which are usually used for VEP recordings). Figure 7D confirms this with summed central (10°)
hemifields that show significant cancellation of the signal for full-field VEP.

However, the above-mentioned consideration is inapplicable to monopolar recordings, in which the lower retina contributes little if anything to the full-field response. Although the summation of the signals from the whole stimulating area recorded using bipolar electrode montage produced an extremely small VEP, the average full-field monopolar VEP demonstrated a substantial amplitude that is practically equal to the sum of the lower and upper hemifield responses (Fig. 8). The combined response from the whole stimulated area in this case was mainly determined by the signal from the upper hemiretina, which minimized the phenomenon of cancellation. Thus, although the full-field signal was large, the result of the monopolar recording could be misleading in a case of upper visual field defect.

Another visible consequence of the polarity reverse is an often observed significant reduction in the BOS VEP amplitude at locations along the horizontal meridian (see Fig. 2), which may well be explained by retino-cortical topography (see Discussion).

Multifocal Visual Evoked Potential Recorded from Subjects with Visual Field Defects

To substantiate the local nature of generated signals, a few subjects with well-defined defects of visual field caused by a variety of pathologic conditions were investigated using the BOS VEP protocol. Figures 9 and 10 illustrate the correspondence between visual field defects and multifocal VEPs in the above-mentioned subjects.

Overall there is a good agreement between the topography of the scotoma detected by automated perimetry and the areas of the visual field from which no detectable response was recorded. When examining these figures it is important to consider that the representation of the multifocal VEP traces shown is not correlated exactly with visual field test locations, because the VEP stimulus areas are cortically scaled, as seen in the dartboard arrangement and Fig. 1B. The averaged quadrant responses, which have been presented for some patients, reflected the area of field loss with smaller amplitudes in the quadrant most affected.

Full-field responses, however, did not reflect the damage reliably. An example of how misleading the interpretation of the full-field response can be is shown in Figure 11. This shows the relationship between averaged full-field responses and hemifield responses in one eye with and one eye without a visual field defect. The traces are from the glaucoma patient represented in Figure 9A. This patient had primary open-angle glaucoma in the right eye with upper field loss but had no visual field defect in the left eye. Although the amplitude of the upper hemifield response from the right eye was much smaller than the upper hemifield response of the fellow eye, the full-field VEP averaged over the whole tested area of the right eye was larger than the response from the whole field of the left eye.

Such a contradictory finding was most likely the result of a reduced cancellation effect as a result of the smaller amplitude of the upper hemifield. Thus, in this case, the decrease in amplitude of one of the hemifields leads to an actual increase in the averaged full-field amplitude.

**DISCUSSION**

There are several findings in this study of the multifocal pseudorandomly stimulated P-VEP that could be of practical interest for the future development of an objective visual field test. First, it is clear that the position of recording electrodes is crucial for extraction of the signal from areas of the cortex corresponding to the peripheral parts of the visual field. Bipolar leads overlying the active occipital cortex seem to be optimal for this purpose. The linking line between recording electrodes vertically straddling the inion (BOS protocol used in this study) is practically at an equal (but opposite) angle to the dipoles originating in the striate visual cortex that subserve the upper and lower central to midperiphery hemifields. This produces VEP signals from...
FIGURE 7. (A, B, C) Cancellation of the full-field response as a result of the opposite polarity of upper and lower hemifield visual evoked potentials (VEPs). The degree of cancellation depends mainly on latency differences between the upper and lower hemifields. The first subject demonstrates a minimal latency difference (1.7 msec) and, accordingly, the smallest full-field VEP, whereas the third subject exhibits the largest latency difference (8.4 msec) with fewer consequent cancellations of the full-field response. (D) Responses limited to the central 10° also demonstrate the cancellation effect on the full-field VEP. The upper row shows hemifield responses, and the middle row also demonstrate the cancellation effect on the full-field VEP. The averaged upper and lower hemifields of similar amplitude but reversed polarity.

The line between Oz and Fz electrodes (monopolar recording), however, is almost perpendicular to the upper field dipole, making its contribution minimal. Thus, disproportional responses from the upper and lower hemifields found in some recent studies can be explained readily on the basis of different dipole orientations rather than as a reflection of real functional disparity.

As a result of the relationship between the amplitude and the polarity of the responses of the vertical hemifields discussed above, the full-field BOS VEP seems to be partly (or in some cases almost totally) cancelled. This also applies to small central stimulating areas of a few degrees in diameter. The extent of cancellation is largely dependent on the small differences between the implied times of opposite hemifield peaks. Therefore, the larger the difference in latencies between hemifields, the greater the full-field response elicited.

It should be noted also that in cases of bipolar recordings in which the full-field VEP produces a measurable signal, the waveform of the response often does not resemble the responses from single locations or upper and lower hemifields, and it tends to have a longer latency. This results in a misleading impression of conductivity delay. Thus, it follows that the full-field bipolar VEP has little significance as a true indicator of visually evoked cortical activity. This observation also agrees well with the seemingly paradoxical result described in one of the glaucoma patients (see Fig. 11) when the upper hemifield scotoma leads to a significant reduction of the cancellation effect and therefore to an increase in full-field amplitude.

However, because of the fact that the monopolar response does not produce a vertical reversal of polarity, and that it is greatly biased toward the lower hemifield, it also cannot be
Examples of multifocal VEP traces recorded from subjects with glaucomatosus visual field defects. The corresponding Humphrey perimeter gray scale is shown. Shaded areas of the visual evoked potential (VEP) array highlight those segments where the responses approach zero. These areas correlate well with the automated perimetry findings. The shading is a subjective addition for the purpose of presentation, but it does not represent a statistical analysis. Note that the representative scales for perimetry and VEP plot are not exactly the same: The perimetry plot is linear, whereas the VEP plot is cortically scaled (that is, VEP has a greater number of test points within the central 10° compared with perimetry).
FIGURE 10. Examples of multifocal visual evoked potential (VEP) traces recorded from subjects with neurologic visual field defects. (A) A trace array from a subject with optic atrophy secondary to trauma. Although all amplitudes are significantly reduced, there is still a good correlation between the full loss of signal and the perimetry plot. (B) A subject with pituitary adenoma demonstrates the demarcation of the response across the vertical meridian. Averaged quadrantic traces show no response from the area of absolute scotoma (upper temporal quadrant) and show significantly reduced amplitude from the lower temporal quadrant. (C) A trace array and quadrantic response from a subject with upper nasal quadrantopia caused by cerebral infarct. There is a total absence of response from the affected area of the visual field. (D) A patient with congenital disc defect. The amplitude of the averaged quadrantic VEPs is proportional to visual field losses. (continued on next page)

considered as a reliable indicator of full-field testing. Thus, although the monopolar VEP can give an adequate functional assessment of the lower hemifield projections, it is not sufficiently sensitive to the upper hemifield losses. The best indicator of true cortical response is therefore achieved with a bipolar recording that analyzes individual points or hemifields.

There is a marked decrease in amplitude along the horizontal meridian seen in some bipolar recordings, for example Figure 2B. This, unfortunately, will limit the application of the bipolar VEP as a type of objective visual field assessment, especially because glaucomatous field loss often is first recognized along the horizontal. This may be caused
by the alteration of the dipole orientation, cancellation of the upper and lower hemifield components, or a combination of both. Generally, it is agreed that the horizontal meridian of the peripheral visual field is represented (with slight individual variability) deep within the calcarine banks at the fissure base. This may lead to such an alteration of dipole orientation that it may become much more perpendicular to the linking line between bipolar electrodes, which minimizes the recorded signal. However, the amplitude decrease may be simply a result of the cancellation of the opposite signals from upper and lower hemifields that meet each other around the horizontal meridian.
Glaucomatous eye

Hemi-field responses

<table>
<thead>
<tr>
<th>Latencies</th>
<th>Values</th>
<th>µV</th>
</tr>
</thead>
<tbody>
<tr>
<td>74.8</td>
<td>1.2</td>
<td>1.6</td>
</tr>
<tr>
<td>95.1</td>
<td>-2.0</td>
<td>2.0</td>
</tr>
</tbody>
</table>

Full-field response

<table>
<thead>
<tr>
<th>Latencies</th>
<th>Values</th>
<th>µV</th>
</tr>
</thead>
<tbody>
<tr>
<td>74.8</td>
<td>-1.2</td>
<td>1.6</td>
</tr>
<tr>
<td>102.9</td>
<td>2.1</td>
<td>1.3</td>
</tr>
<tr>
<td>134.7</td>
<td>-1.3</td>
<td>1.3</td>
</tr>
</tbody>
</table>

Normal eye

Hemi-field responses

<table>
<thead>
<tr>
<th>Latencies</th>
<th>Values</th>
<th>µV</th>
</tr>
</thead>
<tbody>
<tr>
<td>74.8</td>
<td>1.0</td>
<td>1.9</td>
</tr>
<tr>
<td>91.3</td>
<td>-0.3</td>
<td>2.2</td>
</tr>
<tr>
<td>132.8</td>
<td>1.9</td>
<td>2.2</td>
</tr>
</tbody>
</table>

Full-field response

<table>
<thead>
<tr>
<th>Latencies</th>
<th>Values</th>
<th>µV</th>
</tr>
</thead>
<tbody>
<tr>
<td>157.1</td>
<td>1.2</td>
<td>1.3</td>
</tr>
<tr>
<td>231.1</td>
<td>-1.1</td>
<td>1.3</td>
</tr>
</tbody>
</table>

FIGURE 11. Hemifield and full-field responses from both eyes of the glaucoma patient whose traces are shown in Figure 8. The traces from the glaucomatous (right) eye are presented in (A), whereas (B) presents the responses from the fellow eye that still has a normal visual field (left panels are hemifield responses, upper field; 2, lower field, right panels are full-field responses). Because of the reduced amplitude of the upper hemifield response in the affected eye, the full-field response is paradoxically larger than in the eye with a normal visual field, in which full-field signal cancellation occurs.

Although it is difficult to assess reliably the degree of amplitude depression quantitatively (as a result of the extreme convolution of the visual cortex), good correspondence is demonstrated between areas where no response was elicited and the location of a dense scotoma in the visual field. Amplitude differences between subjects remain a limiting factor in the application of this technique to objective visual field assessment at the present time.

The recordings from patients with different visual field defects confirm the focal character (in the sense of stimulating the area of the visual field) of the generation of the VEP. Although it is difficult to assess reliably the degree of amplitude depression quantitatively (as a result of the extreme convolution of the visual cortex), good correspondence is demonstrated between areas where no response was elicited and the location of a dense scotoma in the visual field. Amplitude differences between subjects remain a limiting factor in the application of this technique to objective visual field assessment at the present time.

VEP perimetry, however, has several advantages. It is objective, and it requires minimum cooperation and no decision making by the patient. In fact, many subjects who have completed this test indicated that they prefer it to perimetry. The technique also has a potential for use in patients who are uncooperative or are malingers. Because of its high topographical resolution, it also may have a role in the early detection of retino-cortical pathway abnormalities in many different diseases.

From this study, it may be concluded that the multifocal BOS VEP demonstrates good correspondence with the topography of the visual field. BOS electrode placement, instead of the standard ISCEV recommended monopolar electrode placement, provides a much more reliable signal from the upper
visual field. Cancellation effects caused by the different orientations of generating dipoles, relative to electrode positions, need to be considered for the correct assessment of retinocortical pathways.

References


