American Clinical Neurophysiology Society

Guideline 9B: Guidelines on Visual Evoked Potentials[1]

RECOMMENDED STANDARDS FOR VISUAL EVOKED POTENTIALS

I. Introduction

General Comments and Terminology

VEPs are electrophysiologic responses to stimulation by either patterned or unpatterned visual stimuli. Stimulation at a relatively low rate (up to 4/s) will produce "transient" VEPs. Stimulation at higher rates (10/s or higher) will produce responses that merge into relatively simple oscillations occurring at the frequency of stimulation. These persist for the duration of the stimulation and are referred to as "steady-state" VEPs. Responses evoked by patterned stimuli are "pattern" VEPs or PVEPs. Responses evoked by unpatterned stimuli are "flash" VEPs or FVEPs.

Choice of Stimulus

Patterned visual stimuli elicit responses that have far less intra- and interindividual variability than responses to unpatterned stimuli. PVEP testing will detect minor visual pathway abnormality with much greater sensitivity and accuracy than FVEP testing.

Checkerboard pattern reversal is the most widely used pattern stimulus because of its relative simplicity and reliability. Grid and sinusoidal grating stimuli will also produce clinically reliable test results. Unpatterned stimuli are generally reserved for patients who are unable to fixate or to attend to the stimulus. Unpatterned stimuli are also useful for the study of steady-state VEPs.

In pattern stimulation, the selection of check size, field size, and field location allow selective testing of specific segments of the visual pathway. The stimulus employed should be appropriate to the patient's individual clinical circumstances. The use of more than one stimulus may be advantageous.

Subject Conditions

The ability of the subject to focus on and to resolve the pattern is critical to PVEP testing. Defocusing of the pattern will affect response latency, amplitude, and waveform. Cycloplegics generally should not be used for clinical testing. Subjects with refractive errors should be tested with appropriate corrective lenses. Visual acuity should be measured in all subjects. Fatigue may affect the subject's ability to maintain focus on close objects. To avoid this effect, the subject should not be placed closer than 70cm to the stimulus. Any grossly apparent visual field defect should be measured by confrontation testing and noted in the test results.

[1] This topic was previously published as Guideline 9.

The subject's state of arousal and degree of attention to the test stimulus are of critical importance to VEP testing and should be noted. Variation in these factors during testing may affect measures of comparison between left and right eyes or sequential stimulation to the same eye.

The patient must maintain accurate visual fixation during testing. Eye position should be monitored throughout testing. Testing should be suspended when the subject's gaze or attention wanders. A malingering subject may produce abnormal appearing responses by purposely defocusing the pattern or by not maintaining fixation. Paralysis of accommodation by cycloplegic agents may be useful in preventing defocusing, if errors of refraction are corrected.

Variation in pupil size may affect test results. Very small pupils or very asymmetric pupil size may produce responses of abnormal latency, amplitude, or symmetry, particularly if combined with the effects of cataracts or vitreous opacities. Pupil size should be noted in test results if this could affect clinical interpretation.

The state of retinal light adaptation may be of importance for unpatterned VEP testing. VEP testing is performed at usual ambient light levels.

II. Pattern Reversal Visual Evoked Potential Testing

Objectives and Terminology

Test results should demonstrate the peak positive response to pattern reversal occurring at the occiput with a latency of approximately 100 ms with its topographic distribution into temporal and midline regions.

Response components are designated according to their apparent polarity and peak latency. Negative and positive polarities are designated N and P, respectively. Peak latencies are expressed in milliseconds after pattern reversal. Peaks N75, P100, and N145 are recorded over the occiput (Fig. 1). Wave Nl00 is recorded from the midfrontal region. Activity following N145 is highly variable and is not used for standard test interpretation.

Pattern Stimuli

Several parameters of patterned visual stimuli must be carefully measured and maintained constant from one examination to another. These parameters should be specified in the laboratory protocol and should be the same parameters used in collection of the laboratory normative control population data. Where relevant, they should be described in the test report.

Stimulus type and method of generation. Pattern stimuli may be produced by a variety of methods. The pattern may be back-projected by way of a rotating mirror to a translucent screen. Abrupt movement of the mirror produces a shift of pattern on the screen. The most commonly used technique is to produce computer-generated patterns on a video monitor. Oscilloscope and light-emitting diode (LED) display stimuli are also available. The speed of pattern change will differ among the stimulus types. Response latencies will depend on the stimulus type and speed of pattern change.

Type of pattern. Checkerboard patterns have been the most extensively studied and used in clinical testing. Bar and sinusoidal grating stimuli also produce clinically useful responses.

Sinusoidal grating stimuli have been reported to be less affected by refractive errors than checkerboard stimuli. If these are used, the vertical or horizontal orientation of the elements should be noted.

Size of pattern elements. Individual units of a pattern are specified in terms of their visual angle. When checks are rectangular, some laboratories report the visual angles subtended by both the vertical and horizontal dimensions. The visual angle subtended by an individual element of the pattern at the subject's eye is expressed in either minutes or degrees of arc. The tangent of the visual angle is equal to the check width divided by the distance from the eye to the screen.

The angle can therefore be calculated as:

$$B = \arctan W/D$$

This can be approximated for small angles by the formula:

$$B = A^* W/D$$

where W is the width of the unit in millimeters, D is the distance from the screen to the eye in millimeters, and B is the visual angle in minutes of arc when A = 3438 and in degrees of arc when A = 57.3.

Size of stimulus field. The size of the total stimulus field is specified by the visual angle it subtends at the subject's eye, measured as described above for individual pattern units.

Location and designation of stimulus field types. A fixation point must be provided for the subject that is distinct from the reversing pattern itself. The location of the fixation point with regard to the stimulus field determines the region of the subject's visual field to be stimulated. A pattern that extends equally to both sides of the fixation point is referred to as a *full-field* stimulus. A pattern restricted to a small region of central vision, such as 2-4˚, with central fixation is designated a *central-field* stimulus. A pattern presented to one side of the fixation point in one-half of the visual field, such as right half or left half, is designated a half-field or hemi-field stimulus. A pattern presented to a small sector of the visual field is designated a *partial-field* stimulus, with the location described relative to the fixation point. Half-field stimuli presented in an alternating fashion with reversal of left and right half fields sequentially, with a central fixation spot, are designated *alternating half field* stimuli.

Whenever half-field or partial-field stimuli are used, the fixation point should be displaced to the nonstimulated visual field by a small amount, such as 1 check width of 10. This helps prevent stimulation of both retinal hemifields or regions outside the desired partial field from involuntary eye movement. When alternating half field stimuli are used, the two half fields should be separated by a nonreversing band, with the fixation point centered in the band. The distance of the fixation point to the stimulus pattern (retinal eccentricity) should be noted.

Luminance and contrast of pattern. The brightness of the dark and bright elements of a pattern directly affect the amplitude and latency of the VEP waveform. They must be calibrated and be kept constant as the stimulating equipment ages. Absolute luminance values are to be measured by a photometer in units of candela/meter^2 (cd/in^2). Luminance in cd/in^2 can be calculated by converting the values obtained by a photographic light meter (ASA, f-stop, and shutter speed) (Erwin, 1980). The pattern contrast is a ratio calculated as:

$$\text{Contrast} = \frac{\text{max} - \text{min}}{\text{max} + \text{min}} * 100$$

(max + min)

where contrast is in percent and max and min are the maximal and minimal luminances measured.

The mean luminance of the stimulated field is the average of the maximum and minimum luminances measured at the center and periphery of the field. The ambient luminance is the average of the luminance measured at various sites around the stimulating unit. The PVEP is relatively insensitive to the effects of changes in ambient luminance, but this should be kept as constant as possible.

Color of pattern elements. It is generally recommended that black and white stimulation be performed. It is difficult to calibrate and maintain constant any colored stimulus. If color stimuli are used, the color(s) and the method of calibration should be described in the test protocol.

Mode of pattern presentation. The most common presentation is pattern reversal where dark and light pattern elements are alternately reversed. Responses can also be obtained to pattern onset and/or offset where the pattern is presented and withdrawn on a blank field of the same mean luminance.

Stimulus rate. The rate can be designated in two fashions: "reversals per second" is the number of times the pattern changes per second; "cycles per second" is the number of black-to-white-to-black cycles (or pairs of reversals) per second. One cycle/s equals two reversals/s. Because of the possible confusion that can result in interpreting the rate, it is recommended that the test report specifically state which measure is used.

Monocular versus binocular stimulation. It is essential to specify whether the pattern stimulus is presented to one or to both eyes at a time. Clinical testing usually requires monocular stimulation.

III. Test Protocol for Full-Field Stimulation

Full-field PVEP testing is most sensitive in detecting lesions of the visual system anterior to the optic chiasm. The majority of the P100 response arises in the neural elements of the eye subserving the central 8—l0 degrees of the visual field. Lesions that produce half or partial visual field deficits but that spare much of central vision will usually not produce significant changes in P100 response latency or amplitude. Such partial lesions in prechiasmal, postchiasmal, or chiasmal locations may produce changes in response topography, but are best tested for using partial visual field stimulation.

Stimulus

Full-field stimulation should be performed monocularly, utilizing a high-contrast (>50%) black-and-white checkerboard pattern, at a reversal rate of 4/s or less. The subject should be placed no closer than 70 cm to the stimulus screen. Visual fixation should be at the center of the stimulus screen.

Check size and field size should be chosen to best evaluate the clinical problem. Small checks (12—16') and small fields (2-4˚) selectively stimulate central vision. These responses are particularly sensitive to defocusing and decreased visual acuity. Large checks (40—50') and large fields (l6-32') produce greater stimulation of peripheral vision. These responses are less

affected by defocusing or decreased visual acuity than those to smaller checks. Mid-size checks (24—32') and mid-size fields (6-l2˚) are a reasonable compromise for initial testing. The use of more than one check and field size combination has advantages.

Recording

System bandpass of 1-100 Hz (—3 dB) with filter rolloff slopes not to exceed 12 dB/octave for low frequencies and 24 dB/octave for high frequencies is needed.

Analysis time of 250 ms is required. The demonstration of markedly delayed, long-lasting major response components may require a longer analysis time, such as 500 ms, and a slower reversal rate of 2/s or less.

Replication. At least two responses should be recorded. An adequate number of stimuli should be presented in each trial to ensure reproducibility of major response components. As a general guideline the replicated response measurements should give P100 latency within a 2.5-ms difference and peak-to-peak amplitude of N75-Pl00 or P100-N145 within a 15% difference. These values can usually be obtained with 100-200 stimuli per response. With low-amplitude responses, 400 or more stimuli per response may be required to ensure reproducibility.

Recording electrodes. Standard disk EEG electrodes are suitable.

Electrode placement. Both the Queen Square System of placement (occipital leads labeled LO, MO, and RO) and the International 10-20 System placement (leads O1, Oz, and O2) have been used for routine testing. The Queen Square System is demonstrably superior because the lateral occipital leads are placed farther from the midline than in the 10—20 System. This allows improved recording of the scalp distribution of the PVEP in adults to partial field stimulation and to full-field stimulation in subjects with partial visual pathway lesions (Blumhardt and Halliday, 1979; Blumhardt et al., 1982). The International 10—20 System Fz placement is on average 11 cm above the nasion, whereas the Queen Square System MF electrode location is 12 cm above nasion (Chatrian et al., 1980). This minimal location difference should produce no detectable response difference.

In the Queen Square System, the electrodes are labeled and positioned as follows:

MO: Midoccipital, in midline 5 cm above inion
LO and RO: Lateral occipital, 5 cm to left and right of MO
MF: Midfrontal, in midline, 12 cm above nasion
Al/A2: At ear or mastoid, left and right
Ground: At vertex

These additional leads may also be useful:

MP: Midparietal, in midline 5 cm above MO
I: Inion, in midline at the inion

Recording montage. At least four channels should be recorded. In routine testing, the following montage and derivations are recommended (Fig. 1):

Channel 1: Left occipital to midfrontal = LO-MF
Channel 2: Midoccipital to midfrontal = MO-MF
Channel 3: Right occipital to midfrontal = RO-MF
Channel 4: Midfrontal to ear/mastoid = MF-Al

In situations in which the P100 is low in amplitude or apparently absent, the following montage should be used to ensure that the peak is not displaced above or below the usual MO electrode site (Fig. 2):

Channel 1: Inion to ear/mastoid = I-Al + A2
Channel 2: Midoccipital to ear/mastoid = MO-Al + A2
Channel 3: Midparietal to ear/mastoid = MP-Al + A2
Channel 4: Midfrontal to ear/mastoid = MF-Al + A2

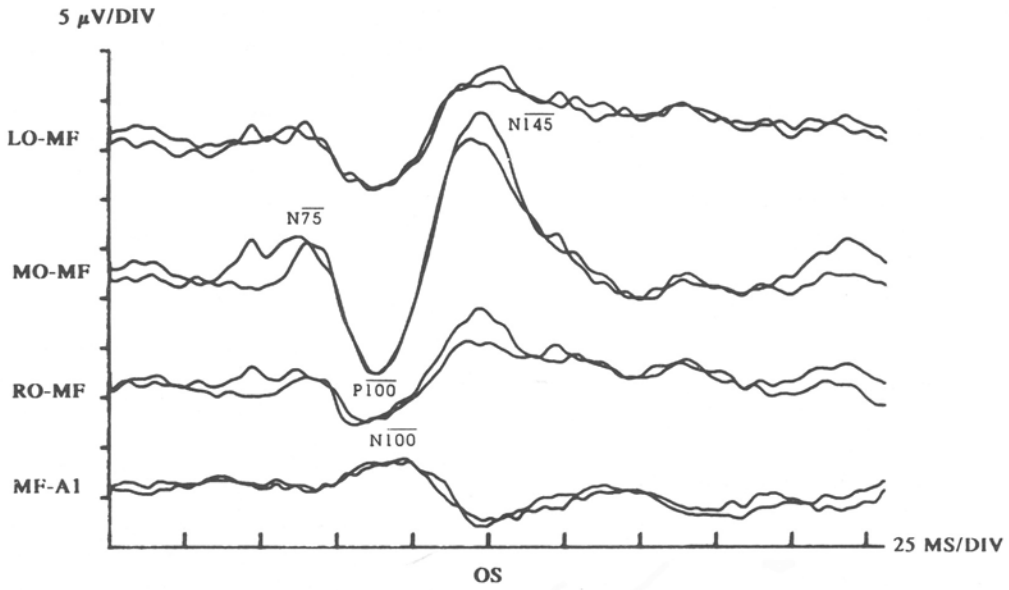

FIG. 1. PVEP to full-field stimulation shows the lateral extent of the occipital components N75, P100, and N145, which are maximal at the MO lead with lower amplitudes at the LO and RO reads. The frontal component NIOO is recorded with the MF lead referenced to Al. If this component is prominent, it will distort the waveforms recorded with these occipital-to-frontal derivations. The Al and A2 leads may also be active when used as reference leads. Passband, 1—250 Hz; rate, l.88/s**; field size,** 19.8; check size, 30:400 stimuli per average.

Analysis of Results

Records are analyzed to identify the major response components described in normal subjects — the N75, P100, and N145 components in the occipital regions and the N100 in the midfrontal region. Of these, the P100 is the most consistent and least variable peak.

The P100 must be positively identified by its topographic distribution, demonstrating maximal amplitude at the midoccipital site. It must be distinguished from other positive polarity peaks that may occur with disease (such as with a central scotoma where the maximum peak positivity may be located laterally (Halliday et al., 1979; Jones and Blume, 1985). If the P100 maximal amplitude is displaced to one of the lateral occipital regions then additional testing with hemi-field or partial-field stimulation will be necessary for definite peak identification.

If the P100 amplitude is low in all occipital regions, then additional testing should be performed with recording electrodes at additional midline sites. This is necessary to detect

occurrence of the P100 peak maximally at occipital sites more rostral or caudal than the MO position (a rare normal variant). It is also helpful in detecting the occurrence of an abnormally absent P100 at the MO lead in the presence of an intact N100 at the MF lead, which can resemble a P100 in the MO-MF derivation (Spitz et al., 1986).

The most clinically useful measurements on the responses to monocular full-field stimulation are (1) the P100 latency at the MO site and (2) amplitude of the P100 component at all three occipital sites. Additional latency, duration, and amplitude measures generally add little to clinical interpretation.

Amplitude may be measured from baseline to peak, or peak to peak of the N75-P100 component or the P100-N 145 component or both, depending on the VEP waveform.

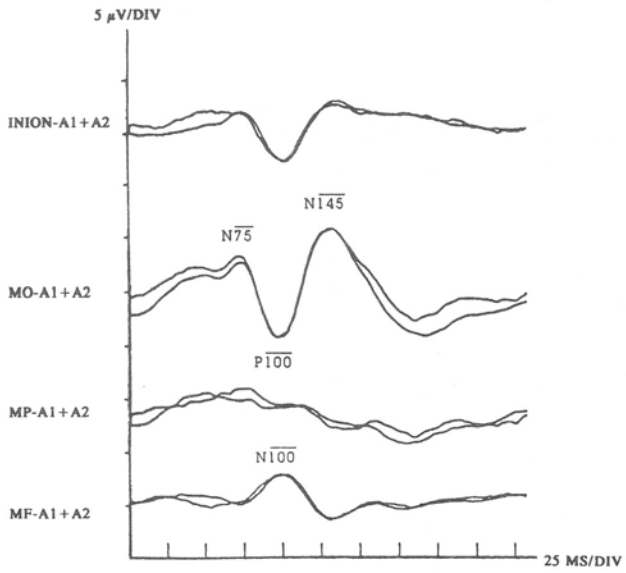

FIG. 2. PVEP to full-field stimulation shows the rostral—caudal extent of the occipital components N75, P100, and N 145. These may be maximal above or below the midoccipital site in normal individuals with a minimal amplitude response as the midoccipital lead. The frontal N100 component may be recorded widely over the anterior head regions. Check size, 30'; rate, l.97/s; sweep; 256 ms.

The following derived measurements are useful:

1. The difference in P100 latency measured at the MO site to left and right eye stimulation, the *inter-ocular latency difference.*
2. The ratio of P100 amplitude measured at the MO site to the left and right eye stimulation, the *interocular amplitude ratio.*
3. The ratio of the P100 amplitude measured at the LO and RO sites on stimulation of each eye individually, the *interhemisphere amplitude ratio.*

(Amplitude ratios are usually calculated as the quotient of the larger over the small value.)

Criteria for Clinically Significant Abnormality Latency Criteria

Abnormality may present as changes in latency, amplitude, topography, and waveform. P100 latency prolongation is the most reliable indicator of clinically significant abnormality, being least affected by technical factors and degree of patient cooperation. Amplitude and topographic measures are closely related and may be indicators of clinically significant abnormality. However, the are more prone to alteration with technical factors and changes in patient cooperation, fixation, and alertness. Waveform abnormalities are generally subjective in nature and difficult to quantify. They are therefore open to over-interpretation and are of questionable clinical relevance.

Each laboratory performing VEP testing should either collect its own normative data, using its own stimulating and recording equipment or follow in detail the suggestions found in Section V of these Guidelines. VEP normative data are not routinely interchangeable between laboratories. Laboratories using the same stimulating and recording equipment may be able to interchange normative data if all recording and stimulating parameters are identical. This requires in addition to other stimulation and recording parameters that light and dark components of the stimulus pattern be accurately measured (photometer) and set at equal levels in both laboratories. Normative data vary with age and gender. The apparent effects of gender on latency values may actually be determined by head size (Chatrian et al., 1980; Guthkelch et al., 1987).

Latency Criteria

1. Abnormally prolonged P100 peak latency.
2. Abnormally prolonged P100 interocular latency difference, with the longer latency eye abnormal.

Most laboratories regard as abnormal P100 latencies and interocular latency differences exceeding 2.5 or 3 standard deviations above the mean as an age-matched control sample from the normal population. The warnings concerning the limits of statistical comparison of individual subjects to population norms discussed earlier in these Guidelines should be heeded.

Latency abnormalities are indicative of visual pathway dysfunction only when ocular and retinal disorders have been excluded by appropriate examination. When these factors have been excluded, a monocular latency abnormality indicates a unilateral optic nerve dysfunction. Bilateral latency abnormality suggests bilateral visual pathway dysfunction that cannot be localized to pre- or postchiasmatic sites without further evaluation of amplitude and topographic features.

Amplitude Criteria

1. Absence of any response when recording from multiple midline and lateral occipital sites, with prolonged analysis times as long as 500 ms.
2. Absence of an identifiable P100 when recording from multiple midline and lateral occipital sites; other positive peaks may be present as discussed in the “Analysis of Results” section (see later).
3. Abnormally low amplitude of the P100.
4. Abnormally high P100 interocular amplitude ratio.

Amplitude and amplitude ratio values are not normally distributed in control populations, so it is inappropriate to use the mean value plus standard deviations to determine the limits of the normal control population. As discussed in the introductory sections to the Guidelines, the values

may be transformed (such as by taking the square root or the log of the values) to a more normal distribution. The 99% upper Tolerance Limit for the interocular amplitude ratio usually lies within the range of 2:1—2.5:1 when large-field stimulation is used.

Amplitude abnormalities are indicative of visual pathway dysfunction only when ocular and other patient factors have been excluded. P100 amplitude values are much more sensitive to ocular and retinal disease than latency values. Midoccipital amplitude may also be decreased by patient factors of poor fixation, defocusing, tearing, inattention, or drowsiness. When these factors have been excluded, a monocular abnormality indicates a unilateral, prechiasmal dysfunction. Bilateral abnormality indicates bilateral disease that cannot be specifically localized to prior postchiasmal sites without more detailed analysis of topographic features or responses to partial field stimulation.

Low-amplitude P100 measures to both left and right eye stimulation, without significant asymmetry, are of uncertain clinical significance. Further testing with hemi- or partial-field stimulation should be performed to determine if more objective criteria of abnormality can be found. At this time, neither the absence of the N75 and N145 components, nor its excessively prolonged latency, can be regarded as a clinically significant abnormality in the presence of a normal P100 component.

Topographic Criteria

1. Abnormal interhemispheric amplitude ratio.

This is primarily an amplitude measure. The warnings under "Amplitude Criteria" need also to be heeded here. Most laboratories find the upper limit of the ratio to fall between 2:1 and 2.5:1 for large-field stimulation.

Lateral occipital amplitude asymmetries may be found in testing one or both eyes. In the absence of P100 latency or interocular amplitude abnormality, they do not specifically indicate definite clinical abnormality. However, they may be the only sign of chiasmal or postchiasmal visual pathway dysfunction. In these cases, the abnormalities are usually found in testing both eyes. If the abnormality is unilateral, it may indicate a partial prechiasmal dysfunction. In all cases, confirmation of a suspected abnormality requires hemi- or partial-field stimulation to characterize the deficit.

Waveform Criteria

Waveform morphologic peculiarities of the P100, in the presence of normal latency and amplitude measures, do not of themselves represent clinically significant abnormality. However, they do suggest the need for further testing, usually with hemi- or partial-field stimulation.

The double-peaked or "W" P100 waveform may cause confusion in interpretation. When analyzing this type of response, it is inappropriate to assume that either peak is the "true" P100. Additional testing, involving hemi- or partial-fields or different check sizes, must be performed to determine the clinical significance of the response. It is possible that neither peak may be the P100 (as in a central scotoma) (Blumhardt et al., 1978). The first, the second, or both peaks may be the P100, in various types of partial visual pathway abnormality (Blumhardt et al., 1978; Halliday et al., 1979; Blumhardt et al., 1982; Spitz et al., 1986).

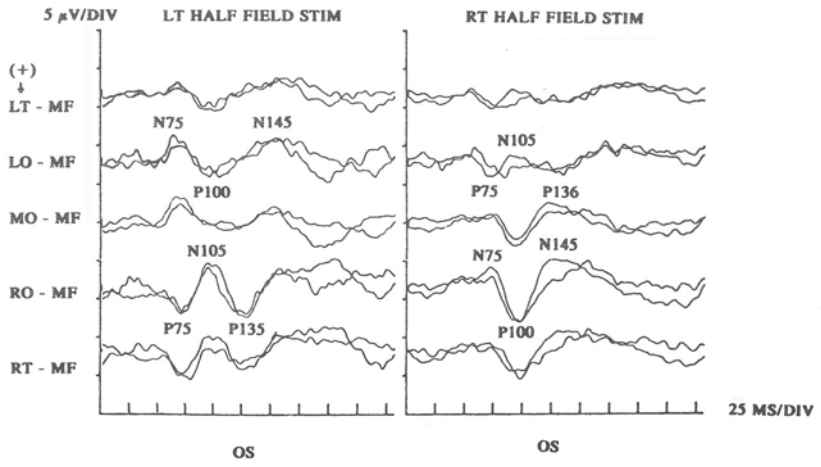

FIG.3. PVEP to half-field stimulation. The central half-field components N75, P100, and N145 are most consistently recorded over the lateral occipital lead ipsilateral to the half-field stimulated. The peripheral half-field components P75, N105, and P135 are most consistently recorded over the lateral temporal lead contralateral to the half-field stimulated. If the central half-field P100 peak is lost (for example, in association with a central scotoma), the peripheral half-field P75 and P135 may be apparent in all occipital leads. This may then be mistakenly identified as the P100. Passband, 1-250 Hz; rate, 1.88/s; field size, 19.8; check size, 50':400 stimuli per average.

IV. Suggested Additional Protocol for Testing to Half-Field Stimulation

Introduction and Terminology

Half-field PVEP testing is more sensitive than full-field testing in detecting lesions of the visual system at chiasmal or postchiasmal sites. Such testing can often clarify the cause of ambiguous findings on full-field testing. Half-field testing may demonstrate visual pathway abnormality in the presence of normal full-field PVEPs. Half-field testing requires greater patient cooperation and is technically more demanding than full-field testing.

Full-field VEP waveforms represent the algebraic summation of the cortical responses to left and right half-field stimulation. The waveform and topographic features of full-field responses appear less complex than those of half-field stimulation only because there is marked cancellation of simultaneously occurring positive and negative polarity peaks in the lateral occipital and posterior temporal regions (Blumhardt and Halliday, 1979). Recommendations for stimulation, recording and data analysis for full-field VEP testing will also apply to half-field VEP testing, with some exceptions as noted below.

Response components are designated similarly to full-field VEP components. Normal response components to monocular, half-field stimulation include the following (Fig. 3):

1. N75, P100, and N145 found at the midline and lateral occipital areas ipsilateral to the half field stimulated.

2. P75, N105, and P135 found at lateral occipital and posterior temporal areas contralateral to the half field stimulated.

Stimulus

Half-field stimulation should be performed monocularly, utilizing a high-contrast (>50%) black-and-white checkerboard pattern, at a reversal rate of 4/s or less. Check size should be a visual angle of approximately 50 minutes of arc to allow preferential stimulation of peripheral visual fields. Small check size may allow more specific testing of the central vision if needed. The total field width should subtend to a visual angle of 16 degrees. Smaller fields may be used but will produce a much greater variability in response topography. The fixation point should be displaced away from the inner edge of the pattern, into the nonstimulated visual field. Displacement by one check width or 1 degree may be adequate to avoid contra-lateral half-field stimulation by involuntary or wandering eye movement. It can be extremely difficult for a patient to maintain visual fixation when stimulation is occurring in only one lateral half field.

Optimal half-field VEP testing is provided by using alternating half-field stimulation. Commercial stimulators are available that alternately display left and right half fields. Fixation is at the center of the stimulus screen, in a blacked-out vertical band separating the two half fields. Left and right half fields reverse alternately at a fixed interval of 250 ms or longer. The individual half-field responses can be recorded, or both responses can be acquired on a suitably long time base to capture both (500 ms or longer). The advantages are improved patient cooperation and fixation, decreased inter-test variability from fatigue or inattention, and increased efficiency of testing.

Recording

Recording parameters are generally the same as for full-field testing with the following exceptions.

Replication. Half-field responses are lower in amplitude than full-field responses and may require an increased number of stimuli to obtain reproducible responses, up to 200 or more stimuli per response.

Electrode placement. In many subjects, the N105 component contralateral to the half-field stimulated is better developed at the posterior temporal lead than at the lateral occipital lead. To record this, two additional leads should be placed as follows:

LT and RT Left and right temporal, 5 cm lateral to LO/RO

Recording montage. At least four channels should be recorded. With these few channels, the montage should be changed for each field stimulated (Fig. 3). These montages allow optimal recording of the P100 at the ipsilateral lateral occipital and midoccipital leads and of the P75, N105, and P135 at the contra-lateral lateral occipital and temporal leads. The midfrontal reference is preferred to Al, A2, or Al + A2 because the ear leads may become asymmetrically active with half-field responses (Jones and Blume, 1985). In subjects with a prominent

midfrontal N100, a midline reference located more anteriorly or a noncephalic reference might be necessary to avoid confusion in peak identification.

For left half-field stimulation:

Channel 1: Left occipital to midfrontal = LO-MF
Channel 2: Midoccipital to midfrontal = MO-MF
Channel 3: Right occipital to midfrontal = RO-MF
Channel 4: Right posterior temporal to midfrontal = RT-MF

For right half-field stimulation:

Channel 1: Left posterior temporal to midfrontal = LT-MF
Channel 2: Left occipital to midfrontal = LO-MF
Channel 3: Midoccipital to midfrontal = MO-MF
Channel 4: Right occipital to midfrontal = RO-MF

For alternating half-field stimulation, additional channels should be recorded, although recording four channels from temporal and lateral occipital leads referenced to the midfrontal can give clinically useful information.

Analysis of Results

Records are analyzed to identify the major response components described in normal subjects. The N75, P100, and N145 waves are found in mid-occipital and lateral occipital leads ipsilateral to the half-field stimulated. The P100 is the most consistent and least variable peak. The P75, N 105, and P135 waves are found in the lateral occipital and temporal leads contralateral to the half field stimulated. These peaks may extend to the midoccipital region. They are usually lower in amplitude and more variable than the peaks seen ipsilateral to the half field stimulated.

The P100 must be positively identified by its topographic distribution. It must be distinguished from the P75 and P 135, which may be seen at the mid-occipital lead. The P75 and P135 may be present in the absence of the P100 in abnormal subjects. Correct interpretation of half-field PVEP testing depends on differentiating whether an abnormal P100 is absent or prolonged.

The P100 peak latency and amplitude are the most clinically useful measures in half-field PVEP testing. The P75, N100, and P135 are identified to ensure proper identification of the P100. The P100 peak may be measured from the waveform occurring at either the midoccipital lead or the lateral occipital lead ipsilateral to the half-field stimulated. The measures are usually less variable at the lateral occipital lead.

Measurements should include (1) P100 latency to left and right half-field stimulation and (2) P100 amplitude to left and right half-field stimulation.

As with full-field testing, amplitude may be measured from baseline to peak or peak-to-peak in the N75-P100 component, the P 100-N 145 component, or both, depending on the VEP waveform.

The following derived measurements are of use:

1. The difference in P100 latency to left and right eye stimulation of the same half field, the *interocular half-field latency difference* for left or right half field.

2. The difference in P100 latency to left and right half-field stimulation in the same eye, the *monocular half-field latency difference* for left and right eyes.
3. The ratio of Pl00 amplitude to left and right eye stimulation of the same half field, the *interocular half-field amplitude ratio* for left or right half field.
4. The ratio of P100 amplitude to left and right half-field stimulation in the same eye, the *monocular half-field amplitude ratio* for left and right eyes.

(Amplitude ratios are usually calculated as the quotient of the larger over the smaller value.)

Criteria for Clinically Significant Abnormality

Criteria for interpretation of half-field PVEP testing are similar to those for full-field testing. The full-field PVEP response is the algebraic summation of the left and right half-field responses. The half-field responses are lower in amplitude than the full-field responses and therefore may be somewhat more variable. Otherwise, the Guidelines and warnings concerning interpretation of full-field PVEPs are applicable.

Warning

Because of the multiple measures made on half field responses, there is considerable risk of overinterpretation of minor changes. When the eight latency and eight amplitude measures described above are considered individually at a $p < 0.05$ level of significance, it is to be expected that 80% of normal subjects will have at least one value in the abnormal range.

The proper approach to these measures involves two steps. The first step is to use stringent criteria for abnormality, preferably at the $p < 0.01$ level. The larger the deviation of the measurement from normal, the more likely the finding is to have clinical significance. The second step is to require that the abnormalities found be internally consistent and be present on more than one measure. For instance, a latency prolongation to one half-field stimulus must also exceed the measures of symmetry to the other half-field stimulus. Technical difficulties in testing are more likely to affect amplitude measures than latency measures. More stringent criteria should therefore be met for amplitude abnormality than for latency abnormality.

Latency Criteria

1. Abnormally prolonged P100 latency from any half-field response.
2. Abnormally prolonged P100 interocular half-field latency difference from either half field.
3. Abnormally prolonged P100 monocular half-field latency difference from either eye.

A monocular latency abnormality indicates a unilateral optic nerve dysfunction. Bilateral latency abnormality implies:

1. Possible bilateral prechiasmal dysfunction.
2. Possible chiasmal dysfunction if bitemporal fields are involved.
3. Possible unilateral postchiasmal dysfunction if homonymous fields are involved.

Amplitude Criteria

1. Absence of an identifiable P100, with or without the presence of the P75 and P135.

2. Abnormal interocular half-field amplitude ratio for left or right half fields.
3. Abnormal monocular half-field amplitude ratio for left or right eyes.

Because of the technical considerations of testing, half-field response amplitude ratios are generally the most variable and potentially the most misleading of test results. Amplitude measures should only be used if repeated tests are closely reproducible and the patient has remained cooperative and alert throughout testing. The use of alternating half-field stimuli can control for much test-to-test variation.

Amplitude abnormalities are interpreted similarly to latency criteria. In addition, the absence of the P100 in the presence of the P75, N105, P135 complex suggests the involvement of central vision pathways (approximately the central 4˚ of the half field) with the preservation of peripheral vision. The absence of the P75, N 105, or P135 peaks is of uncertain significance at this time.

Low-amplitude P100 measures without significant asymmetry of amplitude ratios is of uncertain clinical significance.

Topographic and Waveform Criteria

There are currently no criteria for clinically significant abnormality of topographic or waveform changes in the presence of normal half-field response latency and amplitude measures.

V. Flash Visual Evoked Potential Testing

Objectives and Terminology

FVEPs are less sensitive than PVEPs to dysfunction of the visual projection pathways. Their use in clinical testing is generally limited to: (1) subjects with severe refractive errors or opacity of ocular media who cannot visually resolve a pattern stimulus and (2) subjects who are too young or too uncooperative to reliably fixate on a pattern stimulus. (Pattern VEP testing can be successfully performed on infants and toddlers but may be quite time consuming.)

Test results should demonstrate reproducible peak positive responses to flash stimulation that are free of stimulus locked movement or muscle artifact or auditory response to sound accompanying the flash stimulus.

FVEPs typically consist of up to six major peaks in the first 250 ms after flash stimulation, alternately negative and positive in polarity relative to an ear reference. These are labeled sequentially I, II, III, IV, V, and VI (Fig. 4). Any of the peaks may be replaced by several faster peaks. The latency of the individual peaks may vary considerably between individuals and are dependent on the level of arousal. These characteristics often make it difficult to compare specific response components between individual subjects.

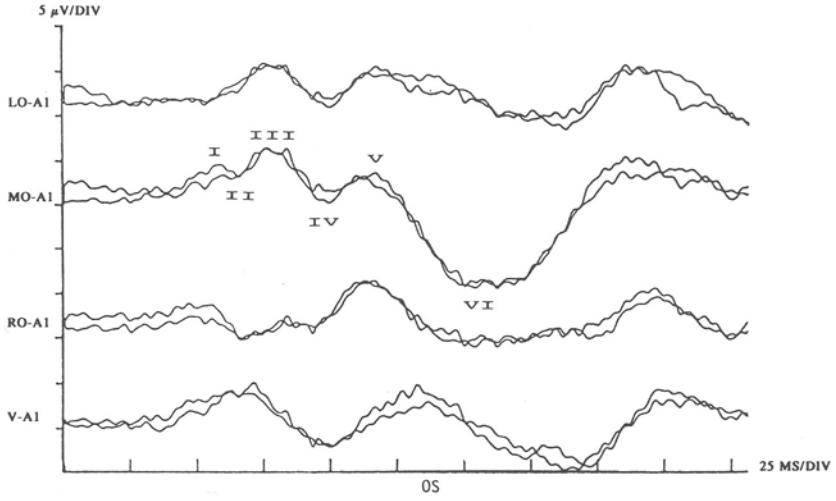

FIG.4. Flash VEP to LED goggle stimulation. Response waveforms may be quite variable. Latency and amplitude abnormalities must be interpreted with caution (see text).

Unpatterned Visual Stimuli

Unpatterned visual stimuli commonly consist of brief flashes of light with no discernible pattern or contour. Parameters of stimulus generation should be kept constant.

Stimulus generation. Stimulation may be presented by photostimulator lamp, a matrix of light emitting diodes (LEDs), or a Ganzfeld stimulator. The photo-stimulator lamp is the most readily available stimulus. It produces very brief flashes of light by the discharge of a xenon light tube such as that used in a stroboscope. If the stroboscope produces an audible discharge click or noise, white noise masking should be used to avoid an associated auditory evoked potential.

A light emitting diode (LED) board can be viewed from a distance or LED goggles can be placed directly over the eyes. Goggles have the advantage of producing a very large field of stimulation that minimizes the effect of changes in direction of gaze. They have the disadvantage that the eyes cannot be observed and stimulation usually takes place through closed eyelids.

Truly quantitative and controlled stimulation can only be performed by using a Ganzfeld stimulator. This consists of the inside of a reflecting, diffusing sphere viewed through an opening in the wall of the sphere. Brief light flashes of specified luminance and wavelength can be delivered in the presence of defined background luminance. The stimulus is delivered to the subject's entire visual field. This produces a precisely controlled stimulus, but it has the disadvantage of requiring a more cooperative subject for testing.

Stimulus intensity. It is impractical to measure the intensity of a photostimulator lamp. The best that can be done is to note the stimulator type and intensity setting and maintain this constant. The main determinant of intensity then becomes the distance between the subject and the lamp. The lamp should be placed approximately 30—45 cm in front of the subject. Stimulation should take place with the subject's eyes open and with gaze directed toward the lamp. Background light should be adequate to allow observation of the subject's eyes without causing glare or discomfort. An LED stimulator can be calibrated by a photographic light meter

as described under "Pattern Stimulation." Ganzfeld stimulators require precision pulsed light photometers for calibration.

Stimulus field: Pattern onset/offset responses may be triggered by stroboscopic illumination of patterns. Quite different responses can be obtained if the stimulus is truly unpatterned at one time and patterned at another. Changing the cover of a photo-stimulator lamp from translucent glass, to clear glass, to patterned wire glass may produce different response waveforms. Any background illuminated by the flash should be as featureless as possible.

Stimulus rate. The rate should be approximately 1/s. Slower rates may be necessary for young infants.

Monocular/binocular stimulation. Clinical testing is best performed with monocular stimulation. The nonstimulated eye must have all light occluded to avoid extraneous and unwanted stimulation.

Recording

Recording parameters are identical to those described for PVEP testing with minor changes in recording montage. In simple screening testing to determine the presence or absence of a response, a single recording channel is adequate to demonstrate a midoccipital FVEP. However, if a response is not noted, then multiple channel recording with a long time base should be performed. A simple four-channel recording montage would be:

Channel 1: Left occipital to reference: LO—Reference
Channel 2: Midoccipital to reference: MO—Reference
Channel 3: Right occipital to reference: RO—Reference
Channel 4: Vertex to reference: V—Reference

The reference can be single or linked ears/mastoids. A frontal reference closer to the eyes is more likely to be contaminated with electroretinographic (ERG) activity.

Analysis of Results

Records are analyzed to identify reproducible peaks distinct from random variation of the baseline. Peak latencies and peak-to-peak amplitudes are measured. The ratio of amplitude of left and right eye responses is calculated.

Criteria for Clinically Significant Abnormality

Because of the considerable interindividual variability of FVEPs, the only definitely significant abnormality is the absence of a demonstrable response. Marked asymmetries of amplitude or latency may be indicative of unilateral abnormality in the eye with the lower amplitude or longer latency. Markedly increased response amplitudes may be indicative of brain dysfunction.

The measured latency or amplitude values should fall well beyond the laboratory normative data collected on normal subjects of similar age and level of arousal or sedation. Less dramatic

alterations in waveform, latency, or symmetry between the eyes must be interpreted with extreme caution.

If the FVEP is unobtainable, then study of the flash ERG recorded from corneal, scleral, or infraorbital skin electrodes may give additional information concerning the site of visual system abnormality. The absence of an occipital FVEP implies that no stimulation has reached occipital cortex. The absence of an ERG implies that the abnormality lies in the retina alone or in addition to visual pathway dysfunction.

Demonstration of an intact FVEP provides evidence that some visual input has reached the occipital cortex. However, it cannot be determined whether this input arises from the macula or the peripheral retina, nor can it be determined how the brain can process this visual information. In an infant or uncommunicative subject, the presence of an intact FVEP does not demonstrate the presence of conscious visual perception.

VI. Electroretinogram Testing

The ERG is the mass response of the retina to visual stimulation. The response to flash stimulation is generated by cells in the outer and inner nuclear layers without detectable contribution from the ganglion cells or the optic nerve. The response to pattern stimulation is generated primarily by the ganglion cells in the inner nuclear layer.

ERG testing can document the presence of retinal dysfunction and distinguish whether the abnormality involves the photoreceptors (rods, cones, or both) or the ganglion cell layer. In conjunction with VEP testing, the ERG can help clarify whether a VEP abnormality is due to retinal disease or to more central visual pathway disease. Accurate interpretation of ERG test results requires training and insight into retinal physiology and ophthalmologic disorders affecting the retina.

Flash ERG

The main components of the Flash ERG are the cornea-negative a-wave and the subsequent cornea-positive b-wave. Superimposed high-frequency “oscillatory potentials” may also be present with intense stimulation.

Quantitative ERG testing requires the use of corneal lens electrodes, corneal anesthesia and pupil dilatation, a cooperative (or anesthetized) patient, and a detailed protocol involving stimulation at different light luminances and wavelengths in both the light and dark adapted eye. The use of this test in evaluation of ophthalmologic diseases of the retina is beyond the scope of these Guidelines (Chatrian et al., 1980; Marmor et al., 1989).

Qualitative ERG testing from noncorneal sites may be a useful adjunct to FVEP testing. The electrode can consist of(1) an EEG electrode placed on the periorbital skin and (2) a wick or lightweight metal foil electrode placed against the sclera inside the lower eyelid.

The electrode is referenced to a distant site such as the mastoid. The ERG is then recorded simultaneously with FVEP testing using the same recording parameters. The ERG recorded in this fashion is influenced by the direction of the eye relative to the electrode. The direction of gaze should be maintained as constant as possible.

Interpretation is limited to the presence or absence of a demonstrable ERG waveform. An

absent ERG implies widespread retinal disease. If macular vision is spared, the ERG may be absent with an intact FVEP. Absent ERG and FVEP waveforms imply the main site of abnormality is in the eye, although additional brain abnormality is not excluded. An intact ERG and absent FVEP imply visual pathway abnormality, as a FVEP will usually be present if only central vision is lost (whereas a PVEP may be absent with loss of central vision).

Noncorneal ERG testing should be considered to be a screening examination. Corneal ERG testing may show responses where none are apparent with noncorneal testing. Clinical interpretations of absent, low-amplitude, prolonged, or asymmetrical noncorneal ERG responses *must* be very cautious. Any suggestion of ERG abnormality should be confirmed by corneal ERG testing and ophthalmologic evaluation.

Pattern ERG

The main components of the pattern ERG resemble those of the flash ERG, although they have a different cell origin, longer latency, and lower amplitude. They are labeled PERG-a and PERG-b for the initial corneal negative and positive peaks.

As with flash ERG testing, quantitative pattern ERG can only be performed with corneal electrodes and a tightly controlled test protocol. Likewise, qualitative testing can be performed with the same type of noncorneal electrode as described for flash ERG. Pattern stimulation is identical to that used for pattern VEP testing. It is important that no residual flicker occur during pattern stimulation. A flickering stimulus can produce a flash ERG response, which may be much higher in amplitude than the pattern ERG response. This can be checked by defocusing the pattern with a diffusing screen or with a blurring lens and then testing a normal subject. In the absence of flicker, there should be no demonstrable pattern ERG response.

Maximal pattern ERG amplitude is recorded to large-field (>9˚) stimulation with check size ranging from 20’ to 80’. High luminance, high-contrast patterns give the best responses. Stimulus rate is <4/s for transient responses and >10/s for steady-state responses. The use of additional low-contrast or small check size patterns may be useful. The test protocol is identical to that for pattern VEP testing. If the pattern ERG is not recorded simultaneously with the PVEP, then a shorter time base of approximately 120 ms may be used for greater detail.

Interpretation is similar to that for flash ERG. Absence of a response implies damage to the ganglion cell layer of the retina, which may accompany optic nerve damage or intrinsic metabolic disease. Any suggestion of abnormality should be confirmed by corneal pattern ERG testing and ophthalmologic evaluation.

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