

American Electroencephalographic Society Guidelines for Clinical Evoked Potential Studies

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Introduction

Electrical responses of the nervous system that are time-locked to a sensory stimulus, an electrical excitation, a movement, or other identifiable events are referred to as “event-related” potentials. In the context of the present recommendations, the term “evoked potentials” is used more specifically to designate the responses of sensory pathways to sensory or electrical stimuli. Because of the small amplitude of evoked potentials recorded by non-invasive methods in humans, computer summation or averaging generally is necessary to resolve them from background “noise.”

Optimal recording conditions, criteria for abnormality, and the clinical usefulness of some evoked potentials have been sufficiently well established to warrant the formulation of standards for their performance and interpretation. By contrast, our knowledge of other evoked potentials is undergoing such rapid evolution that it would be premature to suggest any precise standards at this time. Thus, the standards recommended by the present guidelines are limited to the following areas:

1. Clinical practice of evoked potentials.
2. Normative studies of evoked potentials, statistical analysis of results, and criteria for clinically significant abnormality.
3. Visual system evoked potentials.
4. Short-latency auditory evoked potentials.
5. Short-latency somatosensory evoked potentials.

These standards reflect the “state of the art” in clinical evoked potential studies. Because of the dynamic nature of this field, it is likely that revisions of these recommendations will be required at some future time.

No attempt was made to discuss in any detail the generator sources of individual response components nor to delineate specific areas of clinical application for each type of evoked potential. Moreover, no recommendations were formulated on evoked potential recording in newborns and infants as well as in the intensive care unit and the operating room.

Recommended Standards for the Clinical Practice of Evoked Potentials

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I. INTRODUCTION

Sensory evoked potentials are recorded in different clinical contexts. They may be used to assess peripheral sensory function, to evaluate the functional integrity of sensory projection pathways in the central nervous system, or both. Collaboration among the different disciplines which utilize evoked potential measures must be fostered as much as possible. The following guidelines recommend standards for recording and interpreting evoked potentials primarily aimed at evaluating the function of sensory pathways in the central nervous system with the intent of providing clinically relevant information.

II. QUALIFICATIONS FOR PRACTICE

Recommended Qualifications for Interpreters of Clinical Evoked Potential Studies

The training of a qualified interpreter of clinical evoked potential studies should be designed to provide thorough understanding and direct familiarity with all aspects of evoked potential data acquisitions, processing, and interpretation, including: the influences on evoked potentials of stimulus parameters and other experimental variables; the fundamentals of psychophysics; existing knowledge of the anatomical structures and neurophysiologic events underlying the generation of evoked potentials; the clinical significance and pathological correlates of dysfunction of neural pathways demonstrated by evoked potential alterations; and relevant statistics. This learning experience should include the personal performance by the trainee of about 100 evoked potential examinations as well as the supervised interpretation of several hundred evoked poten-

tial studies, including responses to visual, auditory, and somatosensory stimuli in all age groups.

Recommended Qualifications for Evoked Potential Technologists

An evoked potential technologist should have received training in the procedures for recording evoked potentials under the supervision of a qualified interpreter of clinical evoked potential studies. This training should include the supervised conduct of several hundred evoked potential tests using visual, auditory, and somatosensory stimuli on patients in all age groups. It is desirable that some of these recordings be obtained in infant nurseries, intensive care units, and the operating room, as well as in the evoked potential laboratory.

III. STANDARDS FOR CLINICAL EVOKED POTENTIAL EQUIPMENT

Minimal Standards

Amplifier

The amplifier must be capable of magnifying the input signal from 1,000 to 500,000 times. The differential input impedance of the amplifier must be greater than $10\text{ M}\Omega$. The common mode rejection should be at least 80 dB (10,000:1) at the highest sensitivity of the amplifier when the common-mode stimulus is applied between each input and neutral (which may be "ground" or "common" depending on the amplifier). The amplifier bandpass measured at the -3 dB points must be at least 0.1–5,000 Hz. The roll-off slopes of the filters must be specified.

The noise level of the amplifier must not exceed $3\text{ }\mu\text{V}$ rms with the inputs connected to neutral and with a bandpass of 0.1–5,000 Hz. The amplifier must meet all specifications in the presence of a sustained 300 mV offset applied differentially between the input terminals 1 and 2 or commonly to inputs 1 and 2 (with respect to neutral).

Averager

Time (horizontal) resolution of the averager should be at least $80\text{ }\mu\text{sec}$ /data point/channel. It is recommended that the amplitude resolution of the converter be at least 8 bits. At least 250 addresses of memory should be available for each channel. Resolution should allow the averaging of 4,000 trials. The onset of the averaging sweep should be easily and accurately synchronized to stimulus production. The minimal number of channels required depends on the individual applications which are specified in these guidelines.

Display and Write-out

A CRT display must be available to show the average waveforms, the ongoing unaveraged EEG, or both. Such a display must have easily understandable voltage and time scales. A permanent hard-copy of the evoked potentials obtained must be available.

Desirable Features

The previous section has described minimal standards for clinical evoked potential equipment. This section details features which are not absolutely necessary for re-

recording evoked potentials but are helpful for increasing the efficiency and accuracy of clinical studies.

Amplifier

It is desirable that input signals with peak-to-peak amplitudes of 5 μ V to 50 mV, with steps in a ratio of not more than 2 to 1, be amplified to equal the full range of the A-D converter. A common-mode rejection of 100 dB or more is helpful, especially in environments where there is a high level of electrical noise. Certain evoked potential studies are optimally performed with frequency bandpasses extending to 0 Hz (DC) in the low frequencies or to 10,000 Hz in the high frequencies. It is recommended that the amplifier system allow for easy switching between electrodes, rapid checking of electrode impedances, and simple amplitude calibration.

Averager

A minimum of four channels is desirable. A horizontal resolution of at least 5 μ sec/address/channel is preferred. The amplitude resolution of the converter should be 10 or 12 bits. At least 500 addresses of memory/channel are desirable. Sweep (analysis) times should vary from 5 msec to 100 sec. A preset sweep counter allowing the user to automatically stop data acquisition after a certain number of averaging sweeps have been performed is a very useful feature. The instrument should allow for the storage and display of replicate averages. A mechanism whereby artifact-contaminated trials can be simply and quickly excluded from the averaging process is extremely helpful. This is most commonly achieved by rejecting those trials that exceed the limits of the A-D converter or some adjustable percentage thereof. Capabilities for additive transfer of data between channels, for adding to and subtracting from all data points a binary constant, and for digital smoothing of the averaged waveforms are desirable. It is recommended that the averaging system be able to commence the analysis sweep before or after stimulus onset, and to initiate at least two different stimuli at independent times during the sweep.

Display and Write-out

It is recommended that the display system provide two independently controlled cursors with alphanumeric display of latencies and amplitudes for each cursor. The capability for permanent storage and rapid retrieval of the entire evoked potential waveform can greatly facilitate clinical evoked potential studies.

IV. STANDARDS FOR CLINICAL EVOKED POTENTIAL RECORDING

Electrical Safety

In recording averaged evoked potentials in the laboratory, measures must be taken to assure the patient's safety. The grounding and the chassis leakage current of all instruments connected to the patient or located in the same room as the patient must be periodically tested. Special caution must be exercised when recording evoked potentials with portable equipment at the patient's bedside, in the intensive care room, and in the operating room. The safety measures are similar to those recommended for EEG

recording (3). Additional precautions to be taken when using electrical stimulation to elicit somatosensory evoked potentials are described on p. 41 of these guidelines.

Filtering

The user must be fully aware that recording systems utilizing filter settings, i.e., cut-offs and roll-off slopes of high-pass and low-pass filters that differ from those recommended in these guidelines and employing a 60 Hz filter, may significantly alter the waveform, latency, and amplitude of evoked potentials, thus producing results that could prove clinically misleading (1).

Polarity Convention

There is no universally accepted polarity convention, i.e., no agreement as to whether negativity of the electrode connected to the input terminal 1 of the amplifier relative to the input terminal 2 should be displayed as an upward or downward deflection. The former convention is the accepted standard in clinical EEG, whereas the latter standard prevails in other electrophysiologic fields as well as in physics and engineering. There has been a tendency among students of evoked potentials to plot the averaged waveforms such that the clinically relevant peaks are directed upward. No polarity convention is recommended for general use. Whatever the convention followed by the individual laboratory, it is imperative that it be clearly indicated on each evoked potential record.

Calibration

The recording system must be calibrated at the beginning of each recording session before the evoked potential data are collected. Generally, this is achieved by feeding into the inputs to each channel square pulses of appropriate amplitude, usually 2–100 μ V, time-locked to the onset of the sweep. The calibration pulses must be amplified and averaged and their amplitude measured in conditions identical to those to be employed for the recording of the evoked potential under study.

Replications

It is recommended that a minimum of two averages be obtained for each evoked potential and superimposed. All measured components must demonstrate adequate consistency in form, amplitude, and latency between replications. When such consistency between two tracings is not demonstrated, a third or more averages must be elicited until coherent averages are obtained or the absence of coherence is clearly demonstrated.

V. STANDARDS FOR DOCUMENTATION AND INTERPRETATION OF RESULTS

Documentation

All evoked potential records should bear the following information:

1. The patient's name, identifying number, age, and sex.
2. The date of the examination and the procedure number.
3. The technologist's name or initials.

4. The derivation recorded in each channel in the form of abbreviated designations of the electrodes connected to the input terminals 1 and 2 of the amplifier, in that order.
5. The type, polarity (when relevant), intensity, and rate of presentation of the stimulus, and the side and site of stimulation.
6. Other information relevant to test results such as masking of the non-stimulated ear, state of retinal adaptation, etc.
7. The bandpass (-3 dB cutoffs in Hz) and the filter roll-off slopes (in dB/octave) of the whole recording system (including the amplifier, the averager, the FM magnetic tape recorder, and other instruments, if any) (1,2).
8. The number of individual trials averaged.
9. The horizontal resolution of the averager in milliseconds or milliseconds per data point/channel.
10. The time calibration in the form of a horizontal line, corresponding to the epoch averaged, with subdivisions appropriate to the temporal dimensions of the evoked potential recorded. An arrow or other mark should indicate stimulus onset. Whenever a prestimulus baseline is displayed, stimulus onset should correspond to zero in the time calibration.
11. The voltage calibration in the form of a vertical line indicating the amplitude of deflection produced by the calibration signal and the voltage of this signal.
12. Indication of the polarity convention followed by the user, in the form of a plus or minus sign near the upper and lower ends of the voltage calibration line, respectively. These signs should indicate the polarity of the electrode connected to the input terminal 1 of the amplifier, relative to that connected to the input terminal 2, during an upward and downward deflection of the record, respectively.
13. Marks indicating the peaks recognized and the approximate sites at which they were measured.

Interpretation

A written and signed interpretation must be provided for each clinical evoked potential study. This should begin with the object of the examination and a concise summary of the clinical history available at the time of recording. The type of evoked potential recorded should be briefly outlined, and information should be provided on any relevant medications received by the patient either as a treatment or in preparation for the test. The waveforms obtained should be described and the peak latencies, inter-peak intervals, and the amplitudes of the significant components detailed. The results of relevant ancillary tests should be specified. The clinical significance of evoked potential alterations should be described, whenever possible. Copies of the recorded waveforms should be included or made available upon request.

VI. REFERENCES

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Recommended Standards for Normative Studies of Evoked Potentials, Statistical Analysis of Results, and Criteria for Clinically Significant Abnormality

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I. INTRODUCTION

The successful clinical application of evoked potentials depends, in a large measure, on the availability of carefully collected and skillfully analyzed normative data. It is recommended that teaching laboratories having the necessary resources obtain and publish detailed normative information. In organizing new laboratories it is acceptable to utilize as a reference the normative data published by another center provided the following requirements are satisfied.

1. Stimulus, recording, and other conditions are established that are either identical to, or fully compatible with, those of the reference laboratory.
2. At least 20 normal subjects are studied, spanning the age range of the patients to be examined in the particular laboratory, and it is determined that a specified proportion (such as 95 or 99%) of this subset of normal values falls within the limits derived from the subset studied in the reference laboratory.

II. SELECTION OF SUBJECTS

Appropriate selection of subjects for normative studies of evoked potentials is of critical importance (3). Individuals providing norms for *visual evoked potentials* should have no personal or family history of disease of the eye and the nervous system and should be ophthalmologically and neurologically normal for age. Ophthalmologic examination should include testing of visual acuity, refractive error (not to exceed -5 diopters for myopes), visual fields, and color sensitivity as well as fundoscopic examination. Subjects selected for normative studies of *auditory evoked potentials* should have no personal or family history of disease of the ear and the nervous system and should be otologically, audiologically, and neurologically normal for age. Audiometric examinations should include standard pure tone audiometry with determination of air-conduction and bone-conduction hearing threshold levels and tests of speech discrimination, acoustic impedance, and crossed acoustic reflexes. Persons contributing norms

for *somatosensory evoked potentials* should have no personal or family history of neurologic disease and must be neurologically normal for age. Any personal history of trauma, bone fractures, and alterations of sensation must be carefully evaluated. It is recommended that for studies dealing with cross-hemispheric comparisons, handedness, eye dominance, or ear dominance be specified, at least as perceived by the subject. Thorough inquiry should be made into the use of drugs by prospective normal subjects, including narcotics, stimulants, and neurotropic drugs. Individuals taking such medications should be excluded from normative studies.

III. NUMBER, AGE, AND SEX OF SUBJECTS

Each control group should contain an equal number of age-matched individuals of the two sexes. As a general rule, age-specific norms should be obtained by week in the perinatal period, by month in infants, and by decade in children and adults. It is desirable that each subgroup consist of a minimum of 20 subjects. *Regression analysis* (1,5) of data collected on individuals evenly spread over a given age range permits more parsimonious use of subjects.

IV. PAIRED OBSERVATIONS

Measures of responses to stimulation of right and left eyes, ears, or peripheral nerves of the same individuals should not be treated as independent observations, i.e., lumped together, unless correlation coefficient between them is either close to zero or is negative (4). In general, a high positive correlation exists between such paired evoked potential observations in normal subjects.

V. DESCRIPTION OF RESULTS AND CRITERIA FOR CLINICALLY SIGNIFICANT ABNORMALITY

The first step to be taken in the statistical analysis of evoked potential measures obtained in a normative study is to examine the *shape of the distribution of the observations* in the particular sample examined. Should this distribution be or approximate a normal bell-shaped (gaussian) curve, it is appropriate to describe the characteristics of the sample by computing standard measures of central tendency and dispersion, such as *the mean and the standard deviation*. It should be emphasized that these statistics assume normal distribution of values and have little validity unless this assumption is met. Unfortunately, the distribution of evoked potential measures obtained from the small samples generally studied frequently exhibits deviations from normality including significant skewness (deviation of the curve from symmetry), kurtosis (relative peakedness or flatness of the curve), or both. In these instances, it is recommended that *the observed data be transformed* (2,7) with the intent of obtaining a normal distribution or a distribution more closely approximating normalcy, before computing mean and standard deviation. Taking the logarithm, the square root, or the reciprocal of the values not conforming to normal distribution are the most commonly and successfully used transformations.

Clinical diagnosis frequently requires that measures obtained in individual patients be compared to population norms with the intent of determining whether they are "normal" or "abnormal." Because a small sample from the normal population represents a

very limited part of the entire set of relevant observations, it cannot be identified with the population. Thus, statements that clinically observed values, such as the latency or amplitude of a given wave exceeding 2, 2.5, or 3 standard deviations of the mean of a normal control group, are "*abnormal*" are acceptable provided the following requirements are satisfied: (a) it is clearly specified that the values in question are regarded as abnormal compared to "*a control sample from the normal population*," and (b) no precise probability is implied in predicting where these values are located relative to the normal population. Qualifying these same clinical observations as abnormal compared to "a normal control population" or to "the normal population" is statistically erroneous. Predictive statements giving the interpreting clinical neurophysiologist as well as the referring physician a quantitative appreciation of the statistical significance of the abnormality of a given clinical observation are made possible by the use of "*tolerance limits*" (6,8). For a normally distributed control sample of a given size and of known mean and standard deviation, tolerance limits that include a given proportion of the normal population with a given level of confidence can be computed with the aid of appropriate tables of tolerance factors. For example, one may elect to choose as the normal limit for a given evoked potential measure the 98% tolerance limit for 95% of the population. Such a decision implies that there is a 98% chance that 95% of the normal population will fall within the specified limit. For practical clinical purposes, generally, latencies and inter-peak intervals are regarded as abnormal when they are excessively long, and amplitudes are viewed as aberrant when they are excessively small. Thus, the use of *one-tailed* tolerance limits is recommended for evoked potential studies.

For any given limit of normality, there is a certain probability of falsely interpreting normal values as abnormal, i.e., of false-positive results and of conversely qualifying abnormal values as normal, i.e., of "false-negative" findings. Adopting more stringent normal limits has the advantage of decreasing the proportion of false-positive results but carries the penalty of increasing the proportion of false-negative decisions. The opposite is true when more liberal limits of normality are adopted. Setting normal limits is a decision to be made by each individual laboratory with full understanding of its statistical implications. Ultimately, the adequacy of any given normal limit in discriminating between normal and diseased individuals must be supported by appropriate clinical and/or clinico-pathological correlations.

An alternative to the techniques described above is the use of nonparametric methods of analysis, i.e., of techniques that do not assume a normal distribution of data. Ranking values to determine *cumulative percentiles* is an example of this approach that permits both descriptive and predictive statements. Unfortunately, substantial numbers of subjects are needed to utilize the full power of this method.

In other clinical circumstances, the need arises to *compare different samples* such as a group of patients with suspected multiple sclerosis and a group of normal control subjects. In these instances, sample means and standard deviations and the derived *confidence limits or intervals* are appropriate statistics. By contrast, the use of confidence limits or intervals is inappropriate when comparing individual clinical observations to a control sample from the normal population.

Some of the statistical analyses alluded to, including the transformation of values not conforming to a normal distribution and the use of techniques such as regression analy-

sis, among others, require extensive computational capabilities and advanced statistical skills. It is suggested that clinical laboratories undertaking the collection of normative data seek experienced advice on the design of their studies and support in the analysis of their results.

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Recommended Standards for Visual System Evoked Potentials

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I. TERMINOLOGY: DEFINITIONS AND ABBREVIATIONS

Visual system evoked potentials are electrophysiologic responses of the retina and the optic pathways to appropriate stimuli. This generic term encompasses two categories of events: the electroretinogram and cerebral visual evoked potentials. The *electroretinogram* is a mass response of the retina and *cerebral visual evoked potentials* are responses of cortical areas to visual stimuli.

Visual evoked potentials to stimuli repeated at relatively low rates (up to 2/sec) are referred to as "*transient*" *visual evoked potentials* (4,16). Recommended abbreviation is "T-VEPs." Generally, the qualification "transient" and the corresponding abbreviation are omitted, and these responses are referred to simply as "visual evoked potentials" (VEPs). Responses to visual stimuli delivered at relatively high rates (10/sec or higher) over a certain period of time overlap one another, and merge into relatively simple oscillations that remain fairly constant for the duration of stimulation. The conjecture that this behavior indicates a relatively stable condition of excitation of the visual pathways accounts for the term "*steady-state*" *visual evoked potentials*, which is applied to these responses (4,16). Suggested abbreviation is "S-VEPs."

II. PHYSICAL STIMULUS PARAMETERS: MEASUREMENT

Visual system evoked potentials can be elicited by either patterned or unpatterned stimuli.

Patterned Visual Stimuli

To obtain reliable responses, several parameters of patterned visual stimuli must be carefully measured, specified according to acceptable standard terminology, and maintained constant from one examination to another (1). These parameters include the following:

1. *Stimulus type and method of generation.* Patterned stimuli such as checkerboard patterns, bars, and gratings may be produced by different methods. Most commonly, they are back-projected on a translucent screen or displayed electronically on an oscilloscope or television screen. Although all these stimuli are capable of eliciting evoked potentials, each of them has unique characteristics that variously influence the response. Thus, stimulus type and method of generation must be specified.

2. *Orientation of pattern elements.* The orientation of the elements of the patterns (vertical, horizontal, etc.) should be specified, when applicable.

3. *Size of pattern elements.* The dimensions of individual elements of the pattern, such as the checks of the checkerboard pattern, can be specified by indicating the visual angle that they subtend at the observer's eye. This angle is expressed in degrees and minutes of arc. For checks of size smaller than 1° , the visual angle is calculated by the formula $\beta = (3450 \times W)/D$, where β is the visual angle in minutes of arc, W the width of the check in millimeters, and D the distance of the pattern from the corneal surface in millimeters. The visual angle subtended by checks 1° in size or larger are similarly computed by the formula $\beta = (57.3 \times W)/D$. The dimensions of the elements of a grating pattern (2) can be defined by the spatial frequency of the grating expressed in cycles/degree, i.e., as the number of pairs of dark and bright bands (a cycle) subtended in one degree of visual angle at the subject's eye. Conversely, the size of a band of a grating can be defined by its cycle length (CL) calculated by the formula $CL = 60/2F$, where CL is in minutes of arc and F is the spatial frequency in cycles/degree. Power spectral (Fourier) analysis demonstrates that checkerboard patterns contain a number of spatial frequencies with most of the power concentrated in the diagonal direction. Thus, the dimensions of a check of a checkerboard pattern can be expressed in terms of fundamental spatial frequency computed by the formula $F = 60/1.4 W$, where F is in cycles/degree and W is the width of the check in minutes of arc.

4. *Size, shape, and relation to fixation point of the total stimulating field.* The size of the total stimulating field should be specified by indicating the angle it subtends at the observer's eye, measured as described for individual pattern elements. Other relevant parameters include the form of the field and its relation to the fixation point. Whenever the patterned stimulus is presented eccentrically to the retina, its distance in degrees from the fixation point ("retinal eccentricity") should be specified.

5. *Luminance of pattern elements, pattern contrast, luminance of total stimulating field, and ambient luminance.* The luminances of dark and bright elements of the pattern, such as the white and black checks of a checkerboard pattern (maximal and minimal luminances), can be measured by means of precision spot photometers and are expressed in candela/square meter (cd/m^2) or foot Lamberts (ft-L). Knowing these values, it is possible to compute the contrast of the pattern by the formula $C = (L_x - L_m)/(L_x + L_m) \times 100$, where C is the contrast in percent and L_x and L_m are the maximal and minimal luminances. The mean luminance of the total stimulating

field is calculated by averaging maximal and minimal luminances measured at the center as well as at the periphery of the stimulating field. Similarly, the ambient luminance is determined by taking several measurements at various sites around the patterned field and computing the mean of these values.

6. *Color of pattern elements.* The color of the elements of the pattern should be specified.

7. *Mode of pattern presentation.* Pattern stimulation may be produced in various ways. The most common modes of stimulation are (a) *pattern reversal*, where light and dark elements of the pattern, for instance black and white checks, are alternately reversed by shifting them across the screen, generally in the horizontal direction (with checks of appropriately small size, this reversal can be accomplished without significantly altering the luminance of the total stimulating field); and (b) *pattern onset-offset*, where the pattern is presented and withdrawn, respectively, generally on a blank field of the same mean luminance.

8. *Stimulus rate.* The rate of stimulation, such as the rate of reversal of a checkerboard pattern, influences the evoked potentials. A full cycle of pattern reversal consists of two successive shifts causing first a change from black to white and then a change from white to black.

9. *Monocular vs. binocular stimulation.* It is essential to specify whether the pattern is presented to one or to both eyes at a time.

10. *Full-field vs. hemi-field stimulation.* Pattern stimuli that extend equally to both sides of the fixation point are referred to as "full-field," whereas patterns presented only in one half of the visual field, such as the right or left half, are designated "half-field" or "hemi-field" stimuli. Whenever the stimulus is presented in the right or left visual hemi-field, the fixation point should be in the non-stimulating visual hemi-field, such as one degree lateral to the center of the inner edge of the pattern. This prevents involuntary eye movement from causing stimulation of both retinal hemi-fields.

11. *Pupillary size.* Pattern stimuli generally are presented to pupils unaltered by mydriatic or other drugs. Patterned stimulation of fixed pupils of very small or very large size may elicit cerebral responses of abnormal latency. In these instances, additional studies may be indicated.

Unpatterned Visual Stimuli

To obtain consistent responses, a number of parameters of unpatterned visual stimuli must be measured, specified using standard terminology, and kept constant from one examination to the next. These parameters include the following:

1. *Stimulus type and method of presentation.* Unpatterned visual stimuli commonly consist of brief light flashes produced by the discharge of a xenon light tube from a stroboscope. Sometimes the flashes are generated by a matrix of light-emitting diodes (LEDs) or the stimulus consists of presentation of a plain light field. Each of these stimuli has special features that significantly influence the response.

2. *Stimulus intensity and duration, and ambient luminance.* It is exceedingly difficult to obtain meaningful measurement of the intensity of individual light flashes of microsecond duration delivered by a focal light source such as a photostimulator lamp placed in front of a subject's eyes. In these circumstances, the type of stimulator and

intensity setting employed should be indicated. Moreover, ambient luminance should be measured and specified as described above under Patterned Visual Stimuli, paragraph 3. Measurement of flash intensity is facilitated by the use of a "ganzfeld" system (cf. paragraph 7 below).

3. *Distance of the photostimulator lamp from the eye.* The distance (in centimeters) of the photostimulator lamp from the eye should be specified.

4. *Stimulus color.* To deliver stimuli of different wavelengths (colors), high quality standard filters should be employed. Filter types and their transmittance characteristics should be specified. The latter is defined by the wavelengths (λ) transmitted, expressed in nanometers (nm). Whenever combinations of standard filters are employed, the resulting transmittance should be determined and specified. When the effect of flashes of different wavelengths are compared in either the dark-adapted or the light-adapted state, their intensities should be balanced by means of neutral density filters (8).

5. *Stimulus rate.* When stimuli are not delivered at random, rate of delivery should be specified in terms of stimulus frequency (stimuli/sec) or inter-stimulus interval (time elapsed between individual stimuli).

6. *Monocular or binocular stimulation.* Whether unpatterned stimuli are delivered to one or both eyes depends on the type of procedure and should be specified.

7. *Full field (ganzfeld) stimulation.* Optimal conditions of unpatterned visual stimulation are achieved by the use of a full field "ganzfeld" stimulator (5). This device consists of a reflecting, diffusing, integrating sphere that delivers brief light flashes of specified luminance and wavelength to the entire visual field of the subject. The stimulus can be delivered in the presence or absence of a steady background light of defined luminance. In this system, the distance of the stimulating and background light sources from the eye is constant, and direction of gaze is of little importance. Ganzfeld stimulators are virtually essential for conducting truly quantitative studies of visual system flash-evoked potentials, especially, but not exclusively, the electroretinogram. When ganzfeld stimulators are employed, flash luminance is best measured in terms of integrated light value and expressed in candela/square meter second ($\text{cd}/\text{m}^2\cdot\text{sec}$) or foot-Lambert second ($\text{ft}\cdot\text{L}\cdot\text{sec}$). This requires the use of precision pulsed light photometers. Once the system has been so calibrated, flash intensity can be kept constant from one examination to the next by monitoring it with a simple photodiode circuit and making the necessary adjustments (15).

Choice of Optimal Stimulus

Properly controlled patterned visual stimuli elicit responses that tend to display far less intra- and inter-individual variability in waveform as well as in other parameters than do responses to unpatterned stimuli (4-7,11). Checkerboard pattern reversal stimulation has won widespread acceptance because of its relative simplicity and the reliability of the responses it evokes. However, it should be emphasized that no one type of stimulus is appropriate for studying every visual electrophysiologic event and is optimal for all clinical applications. Light flashes are best suited for eliciting electroretinograms and steady state evoked potentials, whereas checkerboard pattern reversal or gratings are especially useful for demonstrating dysfunctions of the visual pathways posterior to the retina.

Checks or gratings of different sizes are most suitable for evaluating the function of the anterior and the posterior visual projection pathways. Thus, the stimulus employed should be the most appropriate to each individual clinical circumstance. The utilization of more than one stimulus is encouraged.

III. SUBJECT CONDITIONS

1. *Ability to resolve patterned stimuli.* The ability of the subject to visually resolve the pattern is of critical importance for eliciting visual system pattern-evoked potentials. Thus, no cycloplegics should be employed when studying these responses. Individuals with refractive errors should wear appropriate corrective lenses.

2. *Fixation of stimulus source.* Fixation of the pattern by the patient is essential for eliciting pattern-evoked potentials, and direction of gaze is of critical importance when recording flash-evoked electroretinograms by means of periorbital electrodes (14). In these circumstances, eye position should be mentioned either directly or via closed circuit TV system. Electrical recording of eye movement may be of further assistance.

3. *Pupillary size and retinal illuminance.* The amount of light reaching the retina, i.e., "retinal illuminance," is critically dependent on the size of the pupil. Retinal illuminance is calculated by multiplying the luminance of the light source (in cd/m^2) by the pupil area (in mm^2) and is measured in trolands. Quantitative studies of visual system-evoked potentials to unpatterned stimuli, especially the electroretinogram, require that pupil size be maintained constant irrespective of the intensity of the stimulating and background lights. To this effect, the pupils should be maximally dilated by conjunctival instillation of mydriatics and the resulting pupillary diameter should be measured and specified.

4. *State of retinal adaptation.* Some visual evoked potentials must be elicited in different conditions of retinal adaptation, i.e., in the dark adapted or the light adapted states. These conditions should be specified. Dark adaptation requires that the eye(s) remain for a minimum of 30 min in total darkness.

IV. STANDARDIZED PROTOCOLS

Standardized Protocol for Electroretinogram

A. Terminology

Definition, abbreviation, and scope. The electroretinogram is a mass response of the retina to visual stimuli. This response is generated by cells in the outer and inner nuclear layers of the retina without detectable contribution of the ganglion cells and the optic nerve. The abbreviation "ERG" is recommended.

Clinically, the main goals of the electroretinographic examination are:

1. To inquire into the existence, nature, and extent of retinal dysfunction.
2. To determine whether this functional alteration involves the rod, the cone, or both photoreceptor systems.

Dysfunctions of elements in the outer and inner nuclear layers of the retina may account for abnormalities of visual evoked potentials. Moreover, the demonstration of retinal dysfunction helps distinguish between diseases involving the outer and inner nuclear layers of the retina and conditions affecting the ganglion cell layer, the optic

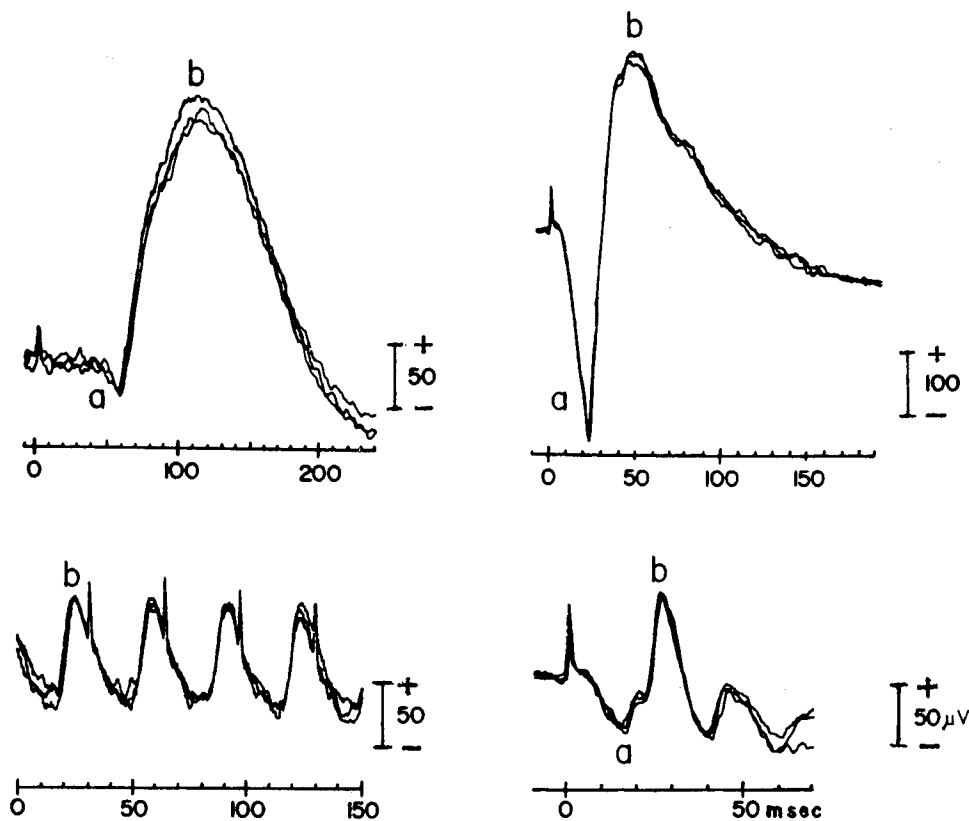


FIG. 1. Single-trace (unaveraged) electroretinograms (ERGs) recorded by “bipolar” contact lens corneal electrode from right eye of 26-year-old normal woman. Stimuli from full-field (ganzfeld) stimulator consisted of (**upper left**): 0.5/sec dim, suprathreshold, blue ($\lambda < 470$ nm) flashes delivered in the dark adapted state; (**upper right**): strong (16-ft L) white flashes in the dark adapted condition; (**lower left**): 30/sec white flicker (16-ft L) in the absence of background light; and (**lower right**): 0.5/sec white flashes (16-ft L) in the presence of steady background light (10-ft L). Pupil was dilated (8 mm) by conjunctival instillation of Neo-Syneprine® 2.5% and Cyclogyl® 1%, and topical anesthesia was produced by Dorsacaine® 0.4%. Onset of flash artifact corresponds to 0 in time calibration for all ERGs except the one on the lower left, which displays four successive flash artifacts.

nerve and more central portions of the visual pathway. The former diseases generally alter the electroretinogram, whereas the latter usually do not modify it. Because the electroretinogram has primary ophthalmologic applications, special training and insight into retinal physiology and disease are essential to perform this examination, supervise its conduct, and interpret its results.

Labeling of components. The main components of the flash-evoked electroretinogram are: a cornea-negative potential, the a-wave, and a subsequent cornea-positive component, the b-wave. These potentials are best demonstrated by the ERG elicited by white flashes in the dark adapted state (Fig. 1, upper right). High frequency “oscillatory potentials” also may be discerned in appropriate circumstances. By contrast, the demonstration of the “early receptor potential” of the electroretinogram requires

special stimulating and recording conditions and is of exclusive ophthalmological interest.

B. Stimulation

The ERG examination (8) requires that light flashes of appropriate intensity and wavelength be delivered monocularly or binocularly by a ganzfeld stimulator through maximally dilated pupils in defined conditions of retinal adaptation. The recommended *minimal procedure* consists of the delivery of the following stimuli:

1. Dim, supra-threshold, blue ($\lambda < 470$ nm) flashes in the absence of background light and with the subject's eye(s) dark adapted (Fig. 1, upper left);
2. Strong (typically 8 ft-L) white flashes in the absence of background light and with the subject's eye(s) dark adapted (Fig. 1, upper right);
3. White flashes at high rate (30–40 Hz) with no background light (Fig. 1, lower left); and/or
4. Strong (typically 16 ft-L) white flashes in the presence of steady background light (typically 8–10 ft-L or more) (Fig. 1, lower right).

The response elicited in test 1 above is generated by the rod system without detectable contribution from the cone system. The ERGs evoked in tests 3 and 4 are produced by the cone system without demonstrable participation of the rod system. Those obtained in test 2 are "mixed" ERGs generated by both photoreceptor systems (9).

A *more complete protocol* includes the recording of ERGs to red ($\lambda > 600$ nm) flashes in the dark adapted state and yellow-red ($\lambda > 550$ nm) and blue-green ($\lambda > 550$ nm) flashes in the presence of an adapting light (8).

C. Recording

System bandpass. Recommended system bandpass is 0.2–0.5 to 800–1,500 Hz (–3 dB), with filter roll-off slopes not exceeding 12 dB/octave for the low frequencies and 24 dB/octave for the high frequencies.

Analysis time. Analysis times recommended for tests 1–4 are: 250, 200, 150, and 80 msec, respectively.

Number of trials. ERG responses generally consist of unaveraged single trials, two or more of which are superimposed to demonstrate coherence. Averaging of several individual trials (typically 5–12) is indicated when the responses are extremely reduced in amplitude or apparently nondetectable in pathological conditions.

Recording and ground electrodes. The electroretinogram should be recorded by special corneal electrodes applied over the eye under topical anesthesia. To minimize the chance of corneal abrasions, only electrodes manufactured according to the highest standards should be employed. "Bipolar" corneal electrodes (13) are preferred to "monopolar" electrodes to reduce noise. A disc EEG electrode placed on the face or the scalp, for instance at position Fz of the 10–20 International System of electrode placement, should be employed as a ground lead.

Montage. In studying retinal diseases that often tend to be bilateral if not symmetrical, the electroretinogram frequently is recorded from a single eye. When ERGs are

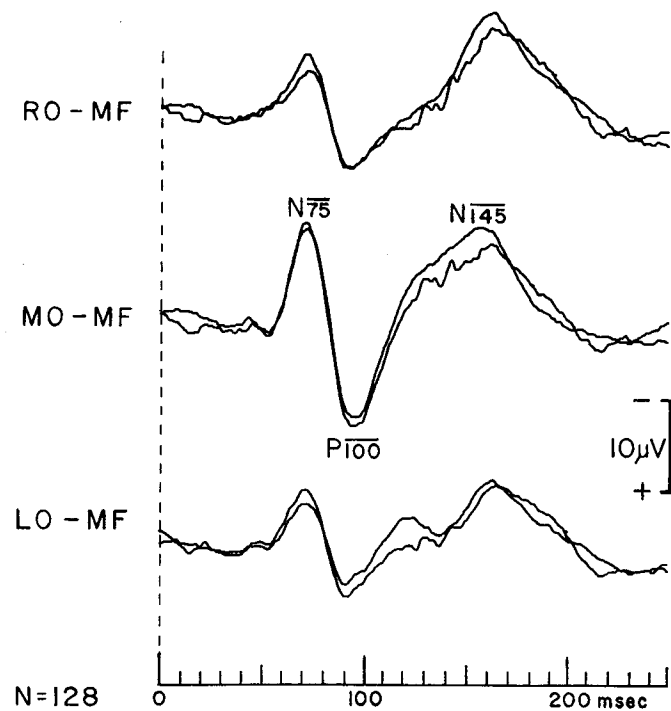


FIG. 2. Cerebral pattern reversal-evoked potentials (PREPs) to full-field stimulation of right eye in 25-year-old normal woman. Stimulus consisted of black and white checkerboard pattern. Individual checks and total stimulating field subtended visual angles of 30° and 18° at the observer's eye, respectively. In this and following figures, pattern reversal was produced by horizontal shifts occurring at 600 msec intervals with full cycle of pattern reversal requiring 1.2 sec. Vertical dashed line corresponding to 0 in time calibration indicates onset of pattern shift.

recorded from both eyes with a two-channel system, the following montages are suggested:

With "bipolar" corneal electrodes:

Channel 1: Right eye: inner electrode-outer electrode

Channel 2: Left eye: inner electrode-outer electrode

With "monopolar" corneal electrodes:

Channel 1: Right corneal electrode-interconnected ears (A_1A_2)

Channel 2: Left corneal electrode-interconnected ears (A_1A_2)

Polarity convention. It is an accepted standard in electroretinography that positivity of the electrode connected to the input terminal 1 of the amplifier produces upward deflection.

Recordings in children. The use of corneal electrodes in children below the age of 7 years or so usually requires general anesthesia. An alternative method consists of recording these responses by means of disc EEG electrodes placed just below each eye and averaging several individual trials. However, the amplitude and other characteristics of averaged infraorbital electroretinograms are influenced by many factors that are difficult to control, including direction of gaze (14). Moreover, electroretinograms of pathologically reduced amplitude may be difficult if not impossible to resolve from

noise with this method. Thus, great caution should be exercised in interpreting the results obtained with this limited, non-quantitative technique.

D. Analysis of Results

Components to be recognized. Records are analyzed primarily for the presence of the characteristic a- and b-waves. The former is poorly developed if at all detectable in test 1.

Measurements. Measurements to be taken include:

1. The peak latency of the a- and b-waves which is referred to in the ophthalmological literature as "implicit time."
2. The amplitude of the a-wave, which is measured from baseline to peak, and that of the b-wave, which is measured peak-to-peak, i.e., from the peak of the preceding a-wave.

E. Criteria for Clinically Significant Abnormality

Clinically significant abnormalities include:

1. Absence of the b-wave or of both the a- and b-waves.
2. Excessively long peak latencies (implicit times) and/or excessively small amplitudes of the a- and b-waves. Most laboratories regard as abnormal peak latencies and amplitudes that are beyond 2 standard deviations of the mean of an age-matched control sample from the normal population. The implications of the choice of any given normal limit, the limitations inherent in the use of the standard deviation from comparing results in individual patients to population norms, and the possible use of alternative measures are discussed on pp. 12-13 of these guidelines.

Standardized Protocol for Cerebral Pattern Reversal-Evoked Potentials to Full-Field Stimulation

A. Terminology

Definition and abbreviation. Cerebral pattern reversal-evoked potentials to full-field stimulation are electrophysiologic responses of visual and possibly other, cortical areas to a reversing pattern that extends equally to both sides of the fixation point. Recommended abbreviation is "PREPs (FF)." These responses are best suited for evaluating optic nerve function.

Designation of components. It is recommended that response components be designated according to their apparent polarity and peak latency. Negative and positive polarities should be designated N and P, respectively, and peak latencies should be expressed in milliseconds. Latencies of idealized response components believed to characterize normal subjects should be identified by a line over them to distinguish them from latencies effectively observed in a given individual or group of individuals. Based on the experience of several investigators, waves N75, P100, and N145 are the most common components of pattern reversal-evoked potentials to full-field stimulation (Fig. 2). These waves occur within 250 msec of onset of reversal, in normal subjects (2-7,10,11). The activity following the N145 wave is highly variable.

B. Stimulation

It is recommended that full-field stimulation be performed monocularly, utilizing a high contrast (black and white) checkerboard pattern with individual checks subtending visual angles of 28–32 min of arc at the observer's eye and having a contrast greater than 50%. Although check sizes of 12–16 min of arc are best suited for stimulating the fovea, and check dimensions greater than 40 min of arc are optimal for stimulating the parafoveal region of the retina, it has been found that checks subtending visual angles of 28–32 min of arc are a satisfactory compromise for anterior visual pathways evaluation. The use of more than one check size, including smaller and larger sizes, is encouraged. Full-field size should be greater than 8° of arc and the fixation point should be at its center. The magnitude of pattern shift should equal the width of one individual check. Reversal rate should be 500 msec or greater, with completion of the full cycle of pattern reversal requiring 1 sec or longer. The subject's pupils should be unaltered by cycloplegic or other drugs. Subjects with refractive errors should wear appropriate corrective lenses and should acknowledge that they can see the checks in focus.

C. Recording

System bandpass. Recommended recording system bandpass is 0.2–1.0 to 200–300 Hz (–3 dB), with filter roll-off slopes not exceeding 12 dB/octave for the low frequencies and 24 dB/octave for the high frequencies.

Analysis time. An analysis time of 250 msec is suggested. The demonstration of markedly delayed, long-lasting major positive response components may require the use of longer analysis times, such as 500 msec.

Number of trials to be averaged. Averaging about 100 to 200 individual trials is recommended.

Recording electrodes: type and placement. Standard disk EEG electrodes are suitable for recording these responses. It is suggested that the recording electrodes should be placed on the scalp according to the Queen Square System (2,3) in the following locations:

Electrode No. 1: Over the midline occipital (MO) region, 5 cm above the inion.

Electrode Nos. 2 and 3: Over the right and left occipital (RO and LO) regions, 5 cm lateral to the midline occipital electrode.

Electrode No. 4: Midline frontal (MF), 12 cm above the nasion.

The lateral occipital electrodes should be sufficiently far from the midline to record lateralizing potentials to hemi-field stimulation (cf. pp. 24–26). For this reason, among others, these electrode positions are preferred to the corresponding electrode locations of the 10-20 International System that are designated O2, Oz, O1, and Fz, respectively. The ground electrode should be placed on the head, for instance at the vertex (Cz position of the 10-20 system).

Montage. A montage consisting of the following three derivations is suggested for a four-channel system:

Channel 1: Right occipital (RO)-midline frontal (MF).

Channel 2: Midline occipital (MO)-midline frontal (MF).

Channel 3: Left occipital (LO)-midline frontal (MF).

It should be noted that a two-channel system is inadequate for efficiently studying full-field (as well as hemi-field) pattern reversal-evoked potentials.

D. Analysis of Results

Potentials to be recognized. Records are analyzed to identify those potentials that have been described in normal subjects, i.e., the N75, P100, and N145 components over the midline and the right and left occipital areas. Of these, the P100 is the most consistent and the N145 the most variable.

Measurements. The following measurements should be taken on the responses to monocular full-field stimulation:

1. The peak latency of components N75 and P100 in all derivations.
2. The amplitude of the P100 component measured in all derivations either from the baseline to the P100 peak or from the peak of the preceding N75 wave to the P100 peak.

Using the above measurements, the following values should be computed:

1. The difference in peak latency of N75 and P100 components recorded in midline occipital-midline frontal derivations in response to stimulation of the right and of the left eye, respectively, i.e., the "inter-ocular latency difference."
2. The peak amplitude ratio of the P100 components recorded over the lateral occipital areas on stimulation of each eye. This ratio is defined as the quotient of the larger P100 amplitude (RO or LO) divided by the smaller P100 amplitude (LO or RO). In normals, this ratio usually is less than 2.5.

E. Criteria for Clinically Significant Abnormality

At present, criteria for clinically significant abnormality of pattern reversal-evoked potentials to full-field stimulation are as follows:

1. Absence of any demonstrable response even when using analysis times as long as 500 msec;
2. Abnormally prolonged peak latency of the P100 wave; and/or
3. Abnormally increased P100 inter-ocular latency difference.

Most laboratories regard as "abnormal" P100 peak latencies and interocular latency differences that exceed 2.5 or 3 standard deviations of the mean of an age-matched control sample from the normal population. Pages 12–13 of these guidelines discuss the implications of the choice of any given normal limit, the limitations inherent in the use of the standard deviation for comparing results in individual patients to population norms, and the possible use of alternative measures of normality. It should be emphasized that both abnormally prolonged P100 peak latencies and abnormally increased P100 inter-ocular latency differences should be interpreted as indicative of dysfunction of the optic pathways only when ocular, and especially retinal, pathology has been ruled out by appropriate ophthalmological examination. This may be complemented by an ERG test, if indicated.

Small amplitude and morphologic peculiarities of the P100 midline component do not represent acceptable criteria of clinically significant abnormality when the latency of this wave is normal. Similarly, amplitude asymmetries of the same component over the lateral occipital areas with amplitude ratios as large as 2.5 or larger, do not provide

sufficient evidence of dysfunction of the visual pathways in the face of normal P100 latency and inter-ocular latency difference. However, further investigation by hemi-field stimulation may be indicated to rule out a hemianopic defect.

Neither the absence of a N75 component nor its excessively prolonged latency can be regarded as a clinically significant abnormality in the presence of a normal P100 wave. Whenever the P100 latency is borderline in value, the finding of an excessively prolonged N75 latency significantly increases the suspicion of, but does not adequately prove, dysfunction of the visual pathways.

Standardized Protocol for Cerebral Pattern Reversal-Evoked Potentials to Hemi-Field Stimulation

A. Terminology

Definitions and abbreviations. Cerebral pattern reversal-evoked potentials to monocular hemi-field stimulation are electrophysiologic responses of visual and, possibly, other cortical areas to a reversing pattern presented in one visual hemi-field. Recommended abbreviation is "PREPs (HF)." These responses are best suited for the evaluation of chiasmatic and retrochiasmatic function (2,3,6,10).

Designation of components. Normal response components to monocular hemi-field stimulation (2,3) (Fig. 3) include the following:

1. N75, P100, and N145 over the midline and the ipsilateral occipital areas.
2. P75, N105, and P135 over the contralateral occipital region (as well as the contralateral posterior temporal area, when explored).

B. Stimulation

It is recommended that the monocularly presented stimulus consist of high contrast (black and white) checkerboard patterns or gratings with individual checks or bands subtending a visual angle of 50 min to 1.5° at the subject's eye. Although patterns of these dimensions are best suited for peripheral hemi-field stimulation, the use of more than one size, including smaller sizes or higher spatial frequencies, is recommended, especially for evaluating parafoveal field defects. Hemi-field width should subtend a visual angle greater than 10° and preferably greater than 16°. Fixation point should be in the non-stimulating visual field, lateral to the center of the inner edge of the pattern, such as 1° from it (cf. p. 17). Stimulus parameters and subject conditions should otherwise be the same as for full-field stimulation (pp. 23–24).

C. Recording

Number of trials to be averaged. It is recommended that about 200 trials be averaged.

Recording electrode placements. In a substantial proportion of subjects, the N105 component contralateral to the hemi-field stimulated is better developed over the posterior temporal than the occipital area. Thus, it is suggested that two electrodes be added to the four leads employed for detecting responses to monocular full-field stimulation. These should be placed as follows:

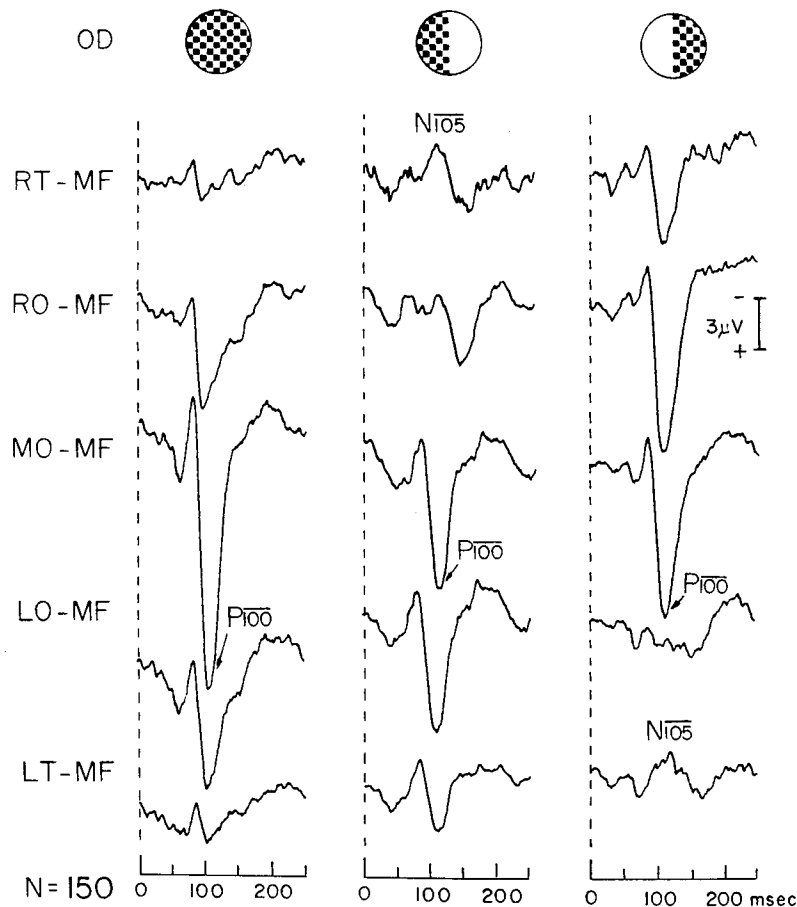


FIG. 3. Left to right: Cerebral pattern reversal-evoked potentials (PREPs) to full-field, left hemi-field, and right hemi-field stimulation of the right eye in 25-year-old normal woman. Stimuli consisted of black and white checkerboard patterns with individual checks subtending a visual angle of $1^{\circ} 4'$ at the subject's eye. Full-field and hemi-fields subtended visual angles of 22° and 10° in the horizontal plane, respectively. Point of fixation was central for full-field, and 1° lateral to the inner edge of the pattern for hemi-field stimulation.

Electrode Nos. 5 and 6: Over the right and left posterior temporal areas (RT and LT), 10 cm lateral to the midline occipital electrode (MO).

Montages. When no more than four recording channels are available, the following four derivations are suggested for studying the responses to *monocular right hemi-field stimulation*:

Channel 1: Right occipital (RO)-midline frontal (MF)

Channel 2: Midline occipital (MO)-midline frontal (MF)

Channel 3: Left occipital (LO)-midline frontal (MF)

Channel 4: Left posterior temporal (LT)-midline frontal (MF)

Similarly, the following montage is suggested for recording the responses to *monocular left hemi-field stimulation*:

Channel 1: Right posterior temporal (RT)-midline frontal (MF)

Channel 2: Right occipital (RO)-midline frontal (MF)

Channel 3: Midline occipital (MO)-midline frontal (MF)

Channel 4: Left occipital (LO)-midline frontal (MF)

Other recommended recording conditions are identical to those specified for full-field pattern reversal stimulation.

D. Analysis of Results

Potentials to be recognized are those most commonly demonstrated in normal individuals, i.e.:

1. The $N\overline{75}$, $P\overline{100}$, and $N\overline{145}$ waves over the midline and the ipsilateral occipital areas. Of these components, the $P\overline{100}$ is the most consistent, as with full-field stimulation.

2. The $P\overline{75}$, $N\overline{105}$, and $P\overline{135}$ waves over the contralateral occipital and posterior temporal areas. These components are smaller in amplitude and show greater inter- and intra-individual variability than those observed over the midline and the ipsilateral occipital areas. The $N\overline{105}$ wave is the most commonly observed.

Awareness of the apparently paradoxical distribution of the major ($P\overline{100}$) response component over the occipital region ipsilateral to the monocularly stimulated hemi-field as well as of the polarity and topography of the contralateral responses is essential to the interpretation of test results.

Measurements. The following measurements should be taken on the response to monocular half-field stimulation:

1. Latency and amplitude of ipsilateral components, especially the $P\overline{100}$.
2. Latency and amplitude of contralateral potentials, especially the $N\overline{105}$ component.

E. Criteria for Clinically Significant Abnormality

At present, the only reliable criterion of abnormality of responses to monocular hemi-field stimulation (2,3,6,10) is the absence of any discernible scalp responses, both ipsilaterally and contralaterally to the hemi-field stimulated, as opposed to normal responses to stimulation of the other hemi-field. Abnormalities of waveform or latency of the responses to hemi-field stimulation should be interpreted with caution.

Standardized Protocol for Cerebral Flash-Evoked Potentials

A. Terminology

Definition and abbreviation. Transient cerebral flash-evoked potentials, to be referred to herein simply as flash-evoked potentials, are electrophysiologic responses of visual and possibly other cortical areas to flash stimulation at low rates. Recommended abbreviation is "FEPs." Because flash-evoked potentials are less sensitive than pattern reversal-evoked potentials to dysfunction of the visual projection pathways, the latter have become the responses of choice for evaluating these disorders. Thus, the use of flash-evoked potentials is recommended primarily in the following individuals: (a) subjects with refractive errors precluding the visual resolution of the pattern stimuli;

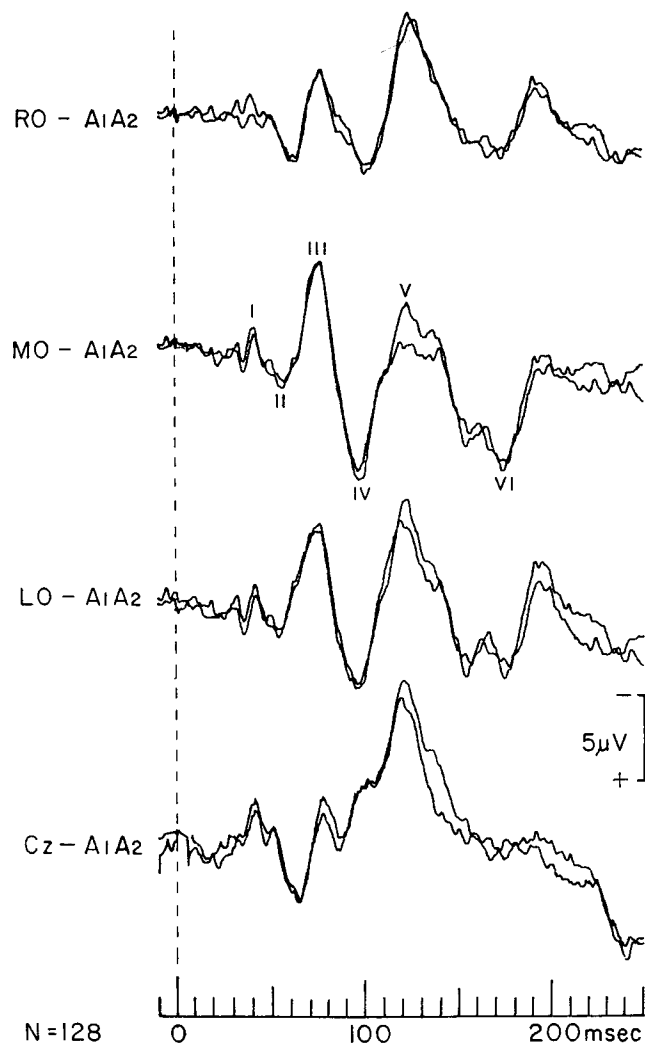


FIG. 4. Cerebral flash-evoked potentials (FEPs) to stimulation of the right eye in 56-year-old normal man. Strong (16 ft-L) white flashes from full-field (ganzfeld) stimulator were delivered at 1/sec in the presence of steady background light (10 ft-L).

(b) individuals with opacity of the ocular media causing visual blurring; and (c) uncooperative subjects, including children and mentally subnormal individuals who do not reliably fixate pattern stimuli.

Designation of components. Flash-evoked potentials, elicited with the subject's eyes open, typically consist of a sequence of six major waves alternately scalp-negative and scalp-positive relative to an interconnected ear reference. These occur over a period of 250 msec and have been labeled I, II, III, IV, V, and VI (12) (Fig. 4). In a significant proportion of subjects, one or more of these waves is replaced by several faster potentials. Moreover, the latency of each individual wave displays considerable inter-

individual variability. These characteristics often make it difficult to identify individual response components with certainty.

B. Stimulation

Stimuli generally consist of brief flashes from a photostimulator lamp located about 30–45 cm in front of the subject's eyes. It is suggested that the stimulus be delivered in the presence of moderate ambient light and that the patient's eyes be open. Stimulus rates of 0.5–1/sec are suggested. The use of a ganzfeld stimulator (p. 18) is recommended and may improve the consistency of results.

C. Recording

It is recommended that recording electrodes be placed on the scalp as follows:

Electrode No. 1: Over the midline occipital region (MO), 5 cm above the inion.

Electrode Nos. 2 and 3: On the right and left occipital regions (RO and LO), 5 cm lateral to MO.

Electrode No. 4: Over the vertex (position Cz of the 10-20 system).

Electrode Nos. 5 and 6: On the earlobes (positions A₁ and A₂ of the 10-20 system).

The ground electrode should be placed over the head, for instance on the midline frontal area (position Fz of the 10-20 system).

Montage. A montage consisting of the following derivation is suggested for a four-channel system:

Channel 1: Right occipital (RO)-interconnected ears (A₁A₂).

Channel 2: Midline occipital (MO)-interconnected ears (A₁A₂).

Channel 3: Left occipital (LO)-interconnected ears (A₁A₂).

Channel 4: Vertex (Cz)-interconnected ears (A₁A₂).

Except for the different placement of some electrodes, recording conditions are identical to those described for pattern reversal-evoked potentials to full-field stimulation.

D. Analysis of Results

Potentials to be recognized. Records are analyzed to identify those potentials that are more consistently demonstrated in normal adults, i.e., waves I through VI. Measurements to be taken include latencies as well as amplitudes of individual components. The latter should be measured from baseline for wave I and from the previous peak for the subsequent waves.

E. Criteria for Clinically Significant Abnormality

Because of considerable inter-individual variability of flash-evoked potentials, the only reliable criterion of clinically significant abnormality is the absence of any demonstrable responses to monocular stimulation. Other alterations, including changes in form and latency and differences between the responses to stimulation of either eye, must be interpreted with extreme caution.

Demonstration of flash-evoked potentials, either alone or in conjunction with infra-orbitally recorded electroretinograms, in small children suspected of being blind provides evidence that some visual input reaches certain cortical areas. However, whether these visual impulses arise within the macula or the peripheral retina and how they are processed by the brain cannot be established. Thus, these responses should not be equated with conscious visual perception and do not provide information on the patient's vision and visual prognosis.

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Recommended Standards for Short-Latency Auditory Evoked Potentials*

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I. INTRODUCTION

These guidelines are limited to the neurologic applications of short-latency auditory evoked potentials, i.e., to the use of these responses to detect and approximately localize dysfunctions of the auditory projection pathways. The audiologic applications of these potentials, which require the utilization of frequency-specific stimuli to assess and quantify hearing function, are excluded from consideration.

II. TERMINOLOGY: DEFINITIONS, ABBREVIATIONS, AND DESIGNATION OF COMPONENTS

Short-latency auditory evoked potentials (SAEPs) are early electrical responses of the auditory pathways which occur within 10–15 msec of an appropriate acoustic stimulus in normal subjects. This generic term encompasses two categories of events: the “electrocochleogram” and the “brainstem auditory evoked potentials.”

The electrocochleogram (ECoChG) consists of electrical responses of the cochlea and the auditory nerve to acoustic stimulation. These include: (a) the cochlear microphonic; (b) the summing potential; and (c) the auditory nerve compound action potential. The *cochlear microphonic* (CM) and the *summing potential* (SP) are cochlear receptor potentials. The *auditory nerve compound action potential* (AP) is the whole-nerve action potential generated by primary auditory nerve fibers.

*The Committee acknowledges a debt to Drs. Starr and Don, who organized a seminar on standards of auditory evoked potentials held in February of 1982 at Laguna Beach, California. Some of the standards proposed at that meeting are included in the present recommendations.

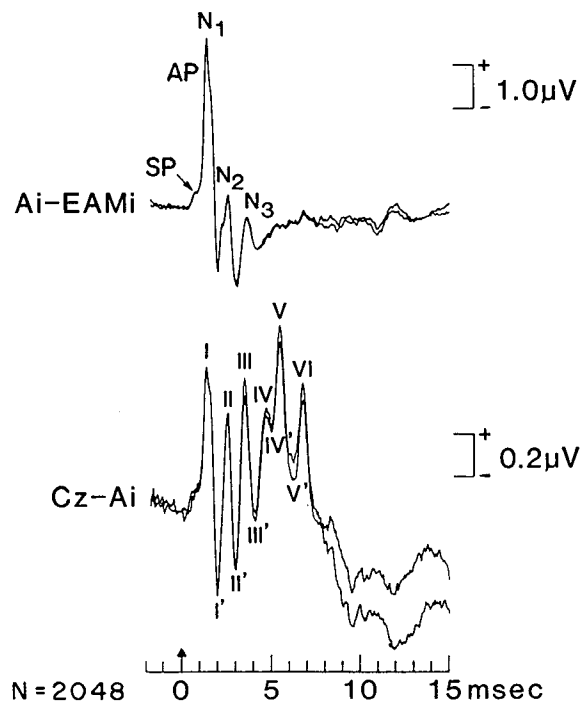


FIG. 5. Top: Auditory nerve compound action potential (AP) recorded by noninvasive external auditory meatus electrode. **Bottom:** Brainstem auditory evoked potentials (BAEPs). Responses were obtained simultaneously on 22-year-old normal man. Stimuli consisted of alternating rarefaction and condensation broadband clicks delivered to the right ear at 8/sec and 120 dB pe SPL with masking of the contralateral ear by white noise at 60 dB pe SPL. Zero in time calibration and arrow indicate onset of the electrical waveform of the click.

Brainstem auditory evoked potentials (BAEPs) are responses of the auditory nerve, brainstem, and, possibly, higher subcortical structures to acoustic stimulation.

Both terms, "electrocochleogram" and "brainstem auditory evoked potentials," are somewhat inappropriate in that: (a) the most prominent component of the "electrocochleogram" arises from primary auditory nerve fibers rather than from cochlear structures; and (b) the first component of the "brainstem auditory evoked potential" does not arise in the brainstem but in the auditory nerve, and the latest components may originate above the brainstem. In spite of these objections, both terms are recommended as standard terminology because they are widely used and understood by all in the field.

The relevance to neurologic diagnosis of the cochlear microphonic and the summing potential of the electrocochleogram is not established at present. Thus, these two events will be excluded from these recommendations.

It is suggested that in the circumstances defined in this report, the main ear canal-negative component of the auditory nerve compound action potential (AP) be labeled N1 (Fig. 5, top) and the subsequent negative waves be designated N2 and N3. The "vertex-positive" components of BAEPs should be designated by the Roman numerals I

through VII and the "vertex-negative" components following each vertex-positive wave should be labeled I' through VI' (Fig. 5, bottom). It should be noted that, in the context of these recommendations, the terms "vertex-positive" and "vertex-negative" only imply positivity of one electrode (at the vertex) relative to another electrode (over the earlobe or mastoid process) and should not be construed as indicative of the polarity of each electrical event. The limitations of this polarity designation are evident in the labeling of the earlobe-negative wave I of BAEPs as a "vertex-positive" wave. It is also suggested that the designation "wave V" be applied to this component whether or not it is preceded by a discernible wave IV.

III. STIMULUS

It is recommended that "broad-band" clicks, the acoustic energy of which is spread over a wide range of audio-frequencies, be used for the neurological applications of auditory evoked potentials. These clicks should be generated by driving with a 100 μ sec rectangular pulse (single monophasic square wave) a standard audiometric ear-speaker having a relative flat frequency spectrum such as a TDH49 or equivalent. The sound pressure waves so produced consist of a first and major wave, followed by smaller, highly damped oscillations of alternating polarity that may last up to a total of 2 msec or longer. The waveform of the driving pulse, to be referred to as the click's "*electrical waveform*," can be viewed by displaying on an oscilloscope screen the output of the pulse generator. The sound pressure waves, to be designated the click's "*acoustical waveform*," can be examined by coupling the ear-speaker to the microphone of a "sound level meter" via a standard "earphone coupler" or "artificial ear" and displaying the meter's electrical output on an oscilloscope screen. To the extent that the artificial ear approximates the acoustic transfer characteristics of the human external auditory meatus, this acoustic waveform mimics the stimulus applied to the tympanic membrane.

Many other types of acoustic stimuli are used for eliciting BAEPs, such as tone bursts, tone pips, filtered clicks, single-cycle clicks, etc. Most of these stimuli have frequency spectra that are more restricted than those of broad-band clicks, i.e., are "narrow-band" stimuli best suited for audiological applications of BAEPs. No standards are recommended in this rapidly developing area.

Stimulus Polarity

The polarity of the first and most prominent wave of the acoustic waveform of the click (as distinct from that of the electrical pulse driving the ear-speaker) determines whether a negative or positive pressure is applied in front of the ear-speaker diaphragm. Those clicks in which the first and major acoustic wave applies negative pressure in front of the ear-speaker diaphragm are referred to as "*rarefaction*" clicks. Those clicks in which the first and most prominent acoustic wave applies a positive pressure in front of the ear-speaker diaphragm are referred to as "*condensation*" clicks. It should be recognized that these polarity designations are, to some degree, arbitrary, since acoustical polarity may be reversed during transfer through the ear canal (1). Click generators must be capable of delivering rarefaction only, condensation only, and alternating

rarefaction and condensation clicks. For acoustical transients, such as tone pips, the first acoustical wave of which is not the most prominent, a meaningful polarity designation is impossible.

Stimulus Rate

Stimulus rates employed vary widely from 5 to 200/sec, depending on test applications. Waves I, II, VI, and VII are reduced in amplitude at rates higher than 10/sec. Thus, stimulus rates of 8–10/sec are especially suited to resolve these peaks.

Stimulus Intensity

It is recommended that click intensity be acoustically *calibrated* in “decibels peak-equivalent sound pressure level” (*dB pe SPL*). Sound pressure level measurements use as a reference level (0 dB) 20 micropascals (μPa) which equal 0.0002 dyne/cm^2 .[†] A click’s peak-equivalent SPL is the SPL of a pure tone, the peak-to-peak amplitude of which matches the peak-to-peak amplitude of the click’s acoustic waveform. The calibration of the stimulus delivery system should be repeated at least every 6 months. Each laboratory should be capable of converting its intensity measures into equivalent values obtained with other methods, i.e., expressed in “decibels above normal hearing level” or *dB HL* (the average hearing threshold of a group of normal young adults tested by the same laboratory under conditions identical to those used for recording BAEPs clinically) or in “decibels above sensation level” or *dB SL* (the subject’s individual hearing threshold). Stimulus intensities employed generally range between 40 and 120 dB pe SPL.

Monaural Versus Binaural Stimulation

Clicks should be delivered monaurally, i.e., to one ear at a time (7).

Contralateral Masking

It is recommended that the contralateral (non-stimulated) ear be masked by white noise at 60 dB SPL to eliminate “crossover” responses, i.e., bone-conducted responses originating in this ear. Although not necessary in every situation, it is recommended that contralateral masking be included in the routine test protocol to avoid its inadvertent omission when it is required.

IV. RECORDING

System Bandpass

Recommended system bandpass for BAEP recording is 10–30 to 2,500–3,000 Hz (–3 dB) with a filter roll-off not exceeding 12 dB/octave for the low frequencies and 24 dB/octave for the high frequencies. Whenever this test is performed in the presence

[†] A dyne is the force necessary to give acceleration of 1 cm/sec to 1 g of mass.

of irreducible EMG and mechanical artifacts, the low frequency cutoff may be raised to 100–200 Hz.

Analysis Time

Analysis time should be no less than 15 msec from stimulus onset, i.e., not including pre-stimulus baseline, if any.

Number of Trials to Be Averaged

It is suggested that about 1,000–4,000 individual trials be averaged. With presently available instrumentation, 2,000 trials are preferred. However, it should be recognized that future improvements in averaging algorithms may reduce this requirement.

Electrode Type and Placement

It is recommended that recording electrodes be placed as follows:

1. Over the left and right earlobes (A_1 and A_2 positions of the 10-20 system of EEG electrode placement) or the left and right mastoid processes to be designated M_1 and M_2 .
2. On the scalp at the vertex (Cz position of the 10-20 system). The ground electrode may be placed anywhere on the body. For convenience, it is recommended that it be placed on the head, for instance, on the scalp in a midline frontal location (position Fz of the 10-20 system).

Montage

A montage consisting of the following derivations is suggested for BAEP recording with a two-channel system:

Channel 1: Vertex-ipsilateral earlobe or mastoid (Cz-Ai or Mi).

Channel 2: Vertex-contralateral earlobe or mastoid (Cz-Ac or Mc).

When only one recording channel is available, we recommend the following derivation:

Vertex-ipsilateral earlobe or mastoid (Cz-Ai or Mi).

V. ANALYSIS OF RESULTS

Components to Be Recognized

Records are analyzed primarily for the presence of waves I, III, and V.

Measurements

Measurements must include the following:

1. Wave I peak latency.
2. Wave III peak latency.
3. Wave V peak latency.
4. I-III inter-peak interval.

5. III-V inter-peak interval.
6. I-V inter-peak interval.
7. Wave I amplitude.
8. Wave V amplitude.
9. Wave V/I amplitude ratio.

Peak latencies, i.e., absolute latencies, must be measured from the leading edge of the driving pulse (electrical waveform of the click). Peak amplitudes are measured from pre-stimulus baseline (when one is available) or from the immediately preceding or following peak of opposite "polarity."

VI. CRITERIA FOR CLINICALLY SIGNIFICANT ABNORMALITY

In most laboratories, it is customary to interpret as abnormal peak latencies, inter-peak intervals, and amplitude ratios that are beyond 2 or 2.5 standard deviations of the mean of an age-matched control sample from the normal population. The implications of the choice of limits of normality, the limitations inherent in the use of the standard deviation for comparing results obtained in individual patients to population norms, and the possible use of alternative measures are discussed on pp. 12–13 of these guidelines.

Abnormal BAEP measures do not necessarily imply altered retrocochlear function. At present, criteria for *retrocochlear dysfunction* include the following:

1. Absence of all BAEP waves I through V, unexplained by extreme hearing loss.
2. Absence of all waves following wave I or wave III.
3. Abnormal prolongation of the I-V inter-peak intervals.
4. Abnormal diminution of the V/I amplitude ratios, especially when accompanied by other abnormalities.
5. Abnormally increased differences between the two ears (interaural differences) as regards the I-V inter-peak interval, when not explained by unilateral or asymmetric middle and/or inner ear dysfunction determined by appropriate audiometric tests.

There are at present insufficient data to justify interpreting any BAEP alterations not listed above as suggestive of retrocochlear dysfunction.

VII. MINIMAL TEST PROTOCOL

It is recommended that for neurologic applications, minimal BAEP testing should consist of responses to summed rarefaction and condensation clicks delivered monaurally at intensities of 90–120 dB pe SPL, preferably 115 or 120 dB pe SPL and at rates below 25/sec. The contralateral ear should be masked by white noise at 60 dB SPL.

VIII. DESIRABLE ADDITIONAL TECHNIQUES: DESCRIPTION, PROTOCOL, AND RATIONALE

Recording of Wave N1 of the Electrocochleogram (ECochG) from the External Auditory Meatus

In certain circumstances, especially in individuals with hearing deficits, wave I is too small in amplitude to be clearly detected by surface earlobe or mastoid electrodes. Be-

cause this potential is an essential benchmark for BAEP measurement, it is important that some technique be available for recording it from a location closer to its source, the auditory nerve. An external auditory meatus (EAM) placement is recommended. Either a "plastic-leaf" electrode (2,3), which places a silver ball within 2–4 mm of the tympanic membrane or a needle electrode inserted under the skin of the ear canal (8) may be used for these recordings. The introduction of "transtympanic" electrodes that penetrate the tympanic membrane and come to rest against the promontory of the middle ear requires specialized otologic skills and is not recommended for neurologic studies. Impedances of EAM electrodes may be as high as 500 k Ω (at 30 Hz). Thus, preamplifiers with sufficiently high input impedance must be employed for recording from the EAM.

Montage

A montage consisting of the following two derivations is recommended for a two-channel system:

Channel 1: Ipsilateral earlobe or mastoid-ipsilateral external auditory meatus (Ai or Mi-EAMi).

Channel 2: Vertex-ipsilateral earlobe or mastoid (Cz-Ai or Mi).

This montage makes it possible to detect wave N₁ of the ECoChG in channel 1 and BAEPs in channel 2. Wave N₁ of the ECoChG is the main component of the auditory nerve compound action potential (AP). This wave is the same potential that is termed wave I in BAEP records but generally greatly exceeds it in amplitude. When only one recording channel is available, we recommend the following derivation that combines ECoChG and BAEP potentials:

Vertex-ipsilateral external auditory meatus (Cz-EAMi).

Protocol

Simultaneous ECoChG and BAEP testing is conducted in the same conditions described for recording BAEPs alone.

Measurements

The following requirements are recommended:

1. N₁ peak latency.
2. N₁-III inter-peak interval.
3. N₁ inter-peak interval.

These measurements may add to or replace those of wave I latency, and I-III and I-V inter-peak intervals. It should be noted that the amplitude of N₁ is influenced to a major degree by the position of the recording electrode in the EAM. Thus, interaural differences in this parameter should receive little consideration.

Recording at Multiple Intensities

Whenever BAEP, or combined ECoChG-BAEP, recording at a single stimulus intensity produces evidence of a retrocochlear disorder, additional information can be obtained by recording at other intensities.

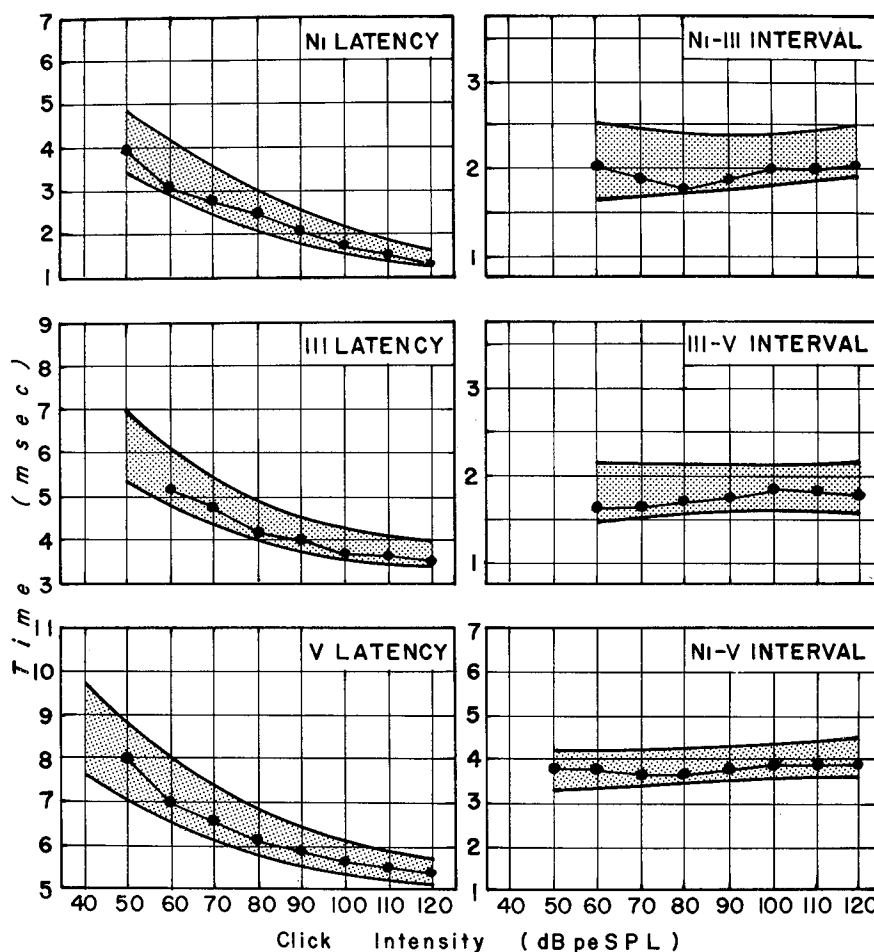


FIG. 6. Latency-intensity (LI) functions for waves N_1 of the ECochG and waves III and V of BAEPs and their inter-peak intervals. Same subject and ear as in Fig. 1. Limits of shaded areas represent two standard deviations of the mean of a control sample consisting of 20 normal subjects of both sexes, aged 10–29 years (from G. E. Chatrian, unpublished data).

Test Protocol

It is recommended that BAEPs or combined ECochG-BAEPs be recorded at progressively lower intensities from 120 dB pe SPL to below the electrophysiologic threshold, i.e., an intensity at which no BAEP wave is detectable any longer. Ideally, this should be accomplished in steps of 10 dB. However, for clinical testing it is more practical to descend in 20 dB steps and to subsequently ascend to fill in the gaps, if time permits. Two coherent averages should be obtained at the highest as well as at near-threshold intensities.

Measurement and Plotting of Latency-Intensity (Input-Output) Functions

Measurements to be made include the following:

1. Wave I (or N_1) peak latency.

2. Wave III peak latency.
3. Wave V peak latency.
4. I (or N₁)-III inter-peak intervals.
5. III-V inter-peak interval.
6. I (or N₁)-V inter-peak interval.
7. BAEP threshold, approximated by taking the midpoint between the lowest intensity at which the BAEP response is detected and the highest intensity at which the BAEP response is no longer demonstrated.

Measurements 1 to 6 above are plotted on a graph opposite stimulus intensity and the individual points are joined by a line. "Latency-intensity" ("input-output") functions are thus obtained for each of the six parameters examined (Fig. 6). Comparing to normal standards multiple measures obtained at a single intensity greatly increases the power of the test (4,5). Measurement of BAEP thresholds further contributes a rough approximation of overall BAEP function.

Recording at High Stimulus Rates

Recording BAEPs or combined ECoChG and BAEPs at stimulus rates of 70/sec or more may produce clinically relevant information. For example, it may facilitate the identification of wave V and, if done at different intensities, may provide an estimate of peripheral auditory function in situations where behavioral audiometry is not possible.

Separately Recording Rarefaction and Condensation Responses

Whenever the magnitude of the click artifact permits it, it is recommended that BAEP or BAEP and ECoChG responses to rarefaction and to condensation clicks be separately recorded and assessed. Differences between rarefaction and condensation responses may occasionally reveal clinically useful information (6).

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Recommended Standards for Short-Latency Somatosensory Evoked Potentials

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I. INTRODUCTION

Short-latency somatosensory evoked potentials (SSEPs) are early electrophysiologic responses of the somatosensory pathways to appropriate stimulation. Various types of stimuli can be applied to a number of body sites to elicit these potentials. However, brief electrical pulses delivered to major mixed nerve trunks at easily accessible locations generally are employed for their clinical study. In normal subjects, these responses mostly occur within 25–50 msec of the stimulus. The present recommended standards are limited to short-latency somatosensory evoked potentials to stimulation of the median nerve at the wrist for the upper extremity, and of the common peroneal nerve at the knee and the posterior tibial nerve at the ankle for the lower extremity.

II. GENERALITIES

Stimulation and Grounding

Type and Placement of Stimulating Electrodes

EEG disc or needle or EMG stimulating electrodes may be employed to elicit SSEPs. However, the use of EEG disk electrodes with impedances of 10 k Ω or less is recommended to reduce discomfort and stimulus artifact. The placement of the stimulating electrodes varies according to the nerve trunk to be stimulated.

Stimulus Isolation and Subject Grounding

To contribute to the subject's safety and minimize stimulus artifact, the stimulator output must be isolated from ground via an appropriate stimulus isolation unit. A large band or plate electrode placed between stimulating and recording leads and connected to ground will help reduce stimulus artifact and enhance safety in the event of isolator failure by restricting the flow of current to the subject's limb.

Stimulus Parameters

Monophasic rectangular pulses (square waves) of 200–300 μ sec duration (or at least no longer than 500 μ sec) are recommended. A stimulus rate of about 4–7/sec, not an integral of 60 Hz, is suggested. Stimulus intensity should be sufficient to produce a visible and moderately vigorous muscle twitch. When no twitch can be elicited, as in cases of severe peripheral neuropathy, the stimulus should be delivered at an intensity known in the individual laboratory to produce a visible, moderately vigorous muscle twitch in the average subject. It is important that the extremity stimulated be visible to the technologist at all times to permit observation of the twitch.

Right and left nerve trunks should be stimulated independently. However, when monitoring spinal cord function during surgery, bilateral stimulation may be helpful to enhance the amplitude of spine and scalp responses.

Type of Stimulator

Either a constant current or a constant voltage stimulator may be used. Whether one type of stimulator is superior to the other is debatable. There are advantages and disadvantages to both types of stimulators and neither is superior in all applications. In situations in which it may be difficult to maintain sufficiently low and stable electrode impedances, such as in intraoperative recordings, a constant current stimulator is preferred.

Designation of Response Components

It is recommended that typical normal response components be designated according to their apparent polarity and peak latency in normal control subjects (p. 23). It should be noted that in the context of these recommendations, positive or negative polarity of any wave in any derivation only implies positivity or negativity of the electrode connected to the input terminal 1 of the differential amplifier relative to the input terminal 2, and should not be construed as indicative of the polarity of the underlying electrical event.

Recording

System Bandpass

Recommended recording system bandpass for SSEP recording is 5–30 to 2,500–4,000 Hz (–3 dB), preferably 20–3,000 Hz, with filter roll-off slopes not exceeding 12 dB/octave for the low frequencies and 24 dB/octave for the high frequencies.

Analysis Time

Recommended analysis time varies according to the nerve trunk stimulated. Delaying the onset of analysis by a few (1–5) msec after stimulus onset is acceptable to avoid displaying the stimulus artifact.

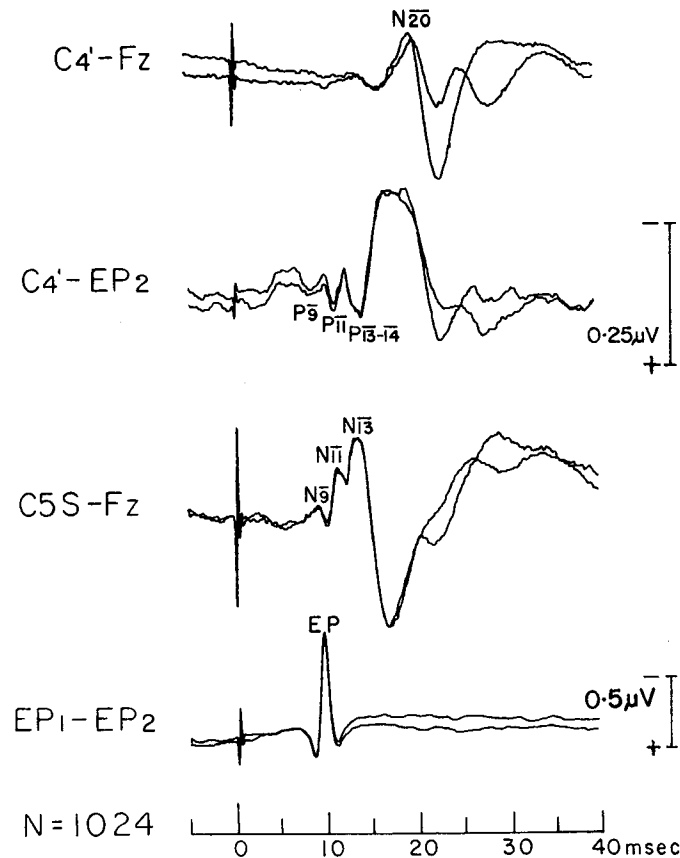


FIG. 7. Short-latency somatosensory evoked potentials (SSEPs) to left median nerve stimulation at the wrist in 24-year-old man. Stimulus consisted of monophasic square waves of 200 μ sec duration repeated at 5.4/sec. Muscle twitch causing abduction of the thumb was observed. In this and following figures, zero in time calibration corresponds to stimulus onset.

Number of Trials to Be Averaged

The number of trials to be averaged varies according to the nerve trunk stimulated.

Recording Electrodes and Montages

Standard disk EEG electrodes are suitable for recording these responses. Their placement and the recommended montages depend on the nerve trunk stimulated.

III. SHORT-LATENCY SOMATOSENSORY EVOKED POTENTIALS TO STIMULATION OF THE UPPER EXTREMITY

Short-latency somatosensory evoked potentials to electrical stimulation of the upper extremity can be elicited by excitation of the median nerve at the wrist or of the digital

nerves. Stimulation of the median nerve at the wrist is recommended because it elicits the most reliable responses.

Stimulation of the Median Nerve at the Wrist

A. Terminology

Temporal features and abbreviation. Short-latency somatosensory evoked potentials to electrical stimulation of the median nerve at the wrist (1,2,4-7) occur within 25 msec of the stimulus in normal subjects. Suggested abbreviation is MN-SSEPs.

Designation of components. Normal short-latency response components to median nerve stimulation are designated P₉, P₁₁, P₁₃, P₁₄, N₂₀, and P₂₃ in records taken between scalp and noncephalic reference electrodes, and N₉, N₁₁, N₁₃, and N₁₄ in cervical spine-scalp derivation (Fig. 7). It should be emphasized that potentials having opposite polarity but similar latency in spine-scalp and scalp-noncephalic reference derivations do not necessarily have identical generator sources.

B. Stimulation

Placement of stimulating electrodes. With the subject in the supine position the cathode (negative stimulating electrode) should be placed between the tendons of the palmaris longus and of the flexor carpi radialis muscles, 2 cm proximal to the wrist crease. These tendons can be easily visualized when the subject flexes the wrist in the palmar direction against manual dorsiflexion by the technologist. The anode (positive stimulating electrode) should be applied 2-3 cm distal to the cathode, or on the dorsal surface of the wrist.

Subject grounding. A plate electrode on the palmar surface of the forearm or a band electrode around the forearm is suggested as a ground lead.

Motor effects of stimulation. Stimulation of the median nerve at the wrist should produce visible muscle twitch causing abduction of the thumb.

C. Recording

Analysis time. Analysis time should be 40 msec from stimulus onset, i.e., not including pre-stimulus baseline, if any. Whenever no scalp potentials are apparent during this time, it is recommended that longer analysis times be used, such as 60 and 100 msec, before inferring that the scalp components of the responses to median nerve stimulation are absent.

Number of trials to be averaged. Averaging about 500-2,000 individual trials is suggested.

Recording electrode placement. It is recommended that recording electrodes be placed as follows:

Electrode Nos. 1 and 2: At Erb's point on each side, i.e., within the angle formed by the posterior border of the clavicular head of the sternocleidomastoideus muscle and the clavicle, 2-3 cm above the clavicle. The clavicular head of this muscle is readily visualized when the subject flexes his head against manual pressure on the forehead by the technologist. (Stimulation of Erb's point produces abduction of the arm and flexion

of the forearm on the arm.) Left and right Erb's point electrodes should be designated EP1 and EP2, respectively.

Electrode No. 3: On the cervical spine, over the C5 or C2 processes, i.e., two or five spines, respectively above C7. This last process is easily identified as the most prominent spine at the base of the neck, when the neck is flexed. C5 and C2 spine electrodes should be referred to as C5S and C2S, respectively.

Electrode Nos. 4 and 5: Over the scalp of each side, 2 cm posterior to the C3 and C4 positions of the 10-20 International System of EEG electrode placement. These electrodes should be referred to as C3' and C4'.

Electrode No. 6: Over the midline frontal region of the scalp (Fz placement of the 10-20 system).

Electrode Nos. 7 and 8: Over the earlobe of each side (positions A₁ and A₂ of the 10-20 system). These two electrodes are optional.

Montage. A montage consisting of the following derivation is suggested for a four-channel system:

Channel 1: Scalp (C3' or C4')-scalp (Fz) or contralateral earlobe. Components P₁₃₋₁₄ and N₂₀ are recorded in this derivation.

Channel 2: Scalp (C3' or C4')-Erb's point (contralateral). Waves P₉, P₁₁, P₁₃₋₁₄, and N₂₀ may be detected in this derivation.

Channel 3: Neck (C5S or C2S)-scalp (Fz). Components N₉, N₁₁, N₁₃, and N₁₄ may be seen in this derivation.

Channel 4: Erb's point ipsilateral to the side of stimulation-Erb's point contralateral to the side of stimulation.

D. Analysis of Results

Components to be recognized. Records are analyzed to identify those potentials that are most consistently demonstrated in normal individuals. These include the following:

1. In ipsilateral-contralateral Erb's point derivation: Erb's point potential.
2. In neck-scalp derivation: wave N₁₃, N₉, N₁₁, and N₁₄ are not clearly identified in some normal subjects.
3. In scalp-noncephalic reference (contralateral Erb's point) derivation: P₉, P₁₃₋₁₄, and N₂₀. P₁₁ is not consistently recorded in normals.
4. In scalp-scalp or scalp-ear derivations: P₁₃₋₁₄ and N₂₀.

Measurements. A *body measurement* essential to assess median nerve SSEPs is the distance (in cm) from the stimulating cathode to Erb's point on each side.

The following *latency measurements*, to be computed from the leading edge of stimulating pulse, are recommended to evaluate these responses:

1. Peak latency of Erb's point potential in the Erb's point derivation (negative or preceding positive, peak).
2. Peak latency waves of P₉ and P₁₃₋₁₄ in the scalp-noncephalic reference derivation.
3. Peak latency of N₁₃ component in the neck-scalp derivation.
4. Peak latency of the N₂₀ wave in the scalp-ear or scalp-scalp derivation.

If the peak of a potential cannot be identified with certainty, as it is sometimes the

case with the P13-14 component which may be bifid, lines can be drawn over the ascending and descending slopes of the potential and the intersection of the lines taken as the peak.

Using the above measurements, the following *conduction times (in msec) and velocities (in meters per second, m/sec)* can be determined:

1. *Conduction velocity in peripheral afferent nerve fibers*, which is computed by dividing the distance between the stimulating cathode and Erb's point by the latency of Erb's point potential.

2. *Conduction time through brachial plexus and cervical cord*, measured by the time elapsed between Erb's point potential and wave N13 and/or components P9 and P13-14.

3. *Conduction time from cervical cord/lower brainstem lemniscal pathways to cortex*, indicated by the time interval between components N13 and N20 and/or P13-14 and N20.

4. *Conduction time from brachial plexus to cortex*, measured by the time elapsed between Erb's point potential and the N20 wave and/or components P9 and N20.

It should be noted that the generators of components N13 in spine-scalp and P13 in scalp-noncephalic reference derivations may not be identical. Wave N13 may be a composite potential reflecting "near-field" activity from the cervical cord and "far-field" activity from brainstem lemniscal pathways. Component P13 is presently believed primarily to reflect "far-field" activity arising from brainstem lemniscal pathways.

D. Criteria for Clinically Significant Abnormality

At present, the only reliable criteria of abnormality of short-latency somatosensory evoked potentials to stimulation of the median nerve at the wrist are:

1. The absence of those potentials which are consistently recorded in normal subjects. These include: the Erb's point potential in the Erb's point derivation; the N13 wave in the neck-scalp derivation; and components P13-14 and N20 in scalp-noncephalic lead and scalp-scalp or scalp-contralateral earlobe derivations.

2. Exceedingly slow peripheral conduction velocities and increased conduction times through brachial plexus and cervical cord and from cervical cord/lower brainstem lemniscal pathways to cortex.

Most laboratories regard as abnormal conduction velocities and conduction times that are beyond 2.5 or 3 standard deviations of the mean of an age-matched control sample from the normal population. The implications of the choice of any given normal limit, the limitations inherent in the use of the standard deviation for comparing results in individual patients to population norms, and the possible uses of alternative measures are discussed on pp. 12-13.

Because absolute latencies are directly influenced by arm length, they cannot be used as a criterion for abnormality. The amplitude of short-latency somatosensory evoked potentials to median nerve stimulation shows considerable variability in normals. Thus, these responses must not be regarded as abnormal on the basis of diminished amplitude alone. Similarly, morphologic peculiarities of individual peaks unaccompanied by prolongation of inter-peak intervals do not represent at present acceptable evidence of clinically significant abnormality.

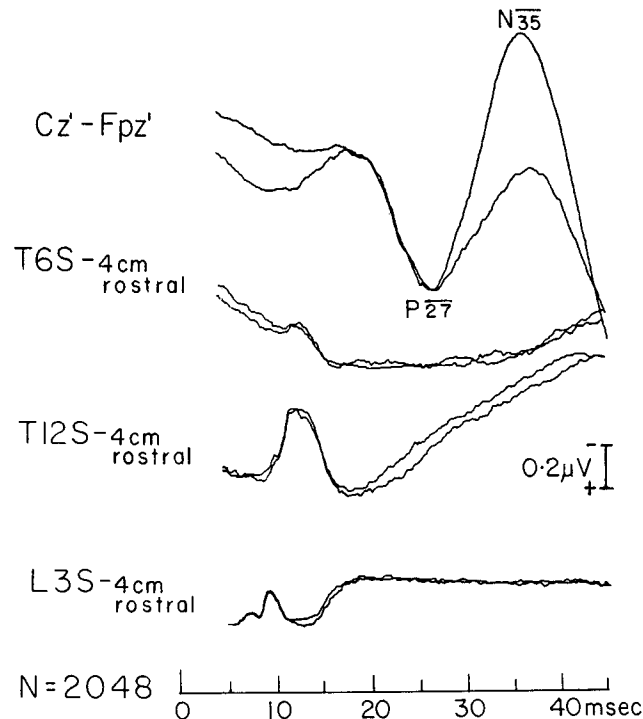


FIG. 8. Somatosensory evoked potentials (SSEPs) to stimulation of the right common peroneal nerve at the knee in 20-year-old normal woman. Stimulus consisted of monophasic square pulses of 200 μ sec duration repeated at 7/sec. Muscle twitch caused plantar flexion and eversion of the foot. Note 5 msec delay between stimulus and sweep onset.

IV. SHORT-LATENCY SOMATOSENSORY EVOKED POTENTIALS TO STIMULATION OF THE LOWER EXTREMITY

The field of short-latency somatosensory evoked potentials to stimulation of nerve trunks in the lower extremity is undergoing rapid evolution. Whether the common peroneal nerve at the knee or the posterior tibial nerve at the ankle is to be stimulated may depend on the circumstances as well as on personal preference.

Stimulation of the Common Peroneal Nerve at the Knee

A. Terminology

Temporal features and abbreviation. Short-latency somatosensory evoked potentials to stimulation of the common peroneal nerve at the knee (3,12–14) occur within 40 msec of the stimulus in normal subjects. Recommended abbreviation is CPN-SSEPs.

Designation of components. It is suggested that individual response components (Fig. 8) be designated as follows:

1. Spine components: L3 and T12 spine potentials.
2. Scalp components: P27 and N35.

B. Stimulation

Placement of stimulating electrodes. With the subject in the prone position, the cathode should be placed over the lateral portion of the popliteal fossa, just medial to the tendon of the biceps femoris muscle and inferior to the leg crease. The tendon of the biceps femoris is readily visualized when the subject flexes his leg against manual extension by the technologist. The anode should be located 3 cm distal to the cathode.

Subject grounding. A plate electrode over the posterior aspect of the mid-thigh or a band electrode around the mid-thigh is recommended as a ground lead.

Motor effects of stimulation. Stimulation of the common peroneal nerve at the knee should produce a visible muscle twitch causing plantar flexion and eversion of the foot.

C. Recording

Analysis time. An analysis time of 40–60 msec from stimulus onset is recommended. If no scalp potentials are apparent during this time, it is suggested that a longer analysis time be used such as 100 or 200 msec before inferring that the scalp components of the response are absent.

Number of trials averaged. It is recommended that about 1,000–4,000 individual trials be averaged.

Recording electrode placement. The electrodes for recording these responses should be placed as follows:

Electrode No. 1: Over the L3 spinous process, i.e., one spine above a line joining the iliac crests of the hip bones. This electrode should be referred to as L3S.

Electrode No. 2: 4 cm rostral to L3.

Electrode No. 3: Over the T12 spinous process, i.e., three spines above the L3 spine. This electrode should be designated T12S.

Electrode No. 4: 4 cm rostral to T12S.

Electrode No. 5: Over the T6 spinous process, i.e., two spines above the line joining the lower border of the scapulae when the arms and shoulders are relaxed. This electrode should be termed T6S.

Electrode No. 6: 4 cm rostral to T6.

Electrode No. 7: Over the scalp on the midline, 2 cm posterior to the Cz position of the 10-20 system. This electrode should be referred to as Cz'.

Electrode No. 8: Midway between positions Fpz and Fz of the 10-20 system. This electrode should be designated Fpz'.

Montage. A montage consisting of the following derivations is suggested for a four-channel system.

Channel 1: Cz'-Fpz'.

Channel 2: T6S-4 cm rostral to T6S.

Channel 3: T12S-4 cm rostral to T12S.

Channel 4: L3S-4 cm rostral to L3S.

D. Analysis of Results

Potentials to be recognized. Records are analyzed to identify those potentials that are most consistently demonstrated in normal subjects. These include the following:

1. In spine derivations: L3, T12, and T6 spine potentials.
2. In scalp-to-scalp derivations: Components P27 and N35.

It should be noted that the T6 spine potential is not consistently recorded in normals and that the amplitude and latency of the N35 scalp component varies with the state of the subject.

Measurements. The following *body measurements* must be taken:

1. Distance from stimulating cathode on each leg to L3 spine electrode.
2. Straight line distances from the L3, T12, and T6 spine electrodes to the Cz' scalp lead.

The following *latency measurements* (to be computed from the leading edge of the stimulating pulse) are suggested to evaluate common peroneal nerve SSEPs:

1. Peak latencies of L3, T12, and T6 spine potentials (negative peak).
2. Peak latency of the first major positive scalp potential (P27).

Using the above measurements, the following *conduction velocities* (in m/sec) should be computed:

1. *Conduction velocity in peripheral afferent nerve fibers*, which is determined by dividing the distance between the stimulating cathode and the L3 spine electrode by the latency of the L3 spine potential.
2. *"Conduction" velocities from spine to scalp* that are computed by subtracting the latency of the L3, T12, and T6 spine potentials from the latency of the P27 scalp potentials and dividing the corresponding spine-scalp distances by these differences.

Because the conduction velocity from L3S to T12S is highly variable in normal subjects, its measurement is of little utility.

E. Criteria for Clinically Significant Abnormality

These include the following:

1. Absence of both spine and scalp responses in recordings utilizing analysis times as long as 100 or 200 msec.
2. Exceedingly slow conduction velocities below 2.5 or 3 standard deviations of the mean of an age-matched control sample from the normal population. The implications of the choice of any given normal limit, the limitations inherent in the use of the standard deviation for comparing results obtained in individual patients to population norms, and the possible use of alternative measures are discussed on pp. 12–13.

The absence of a spine potential in the face of demonstrable scalp responses of normal latency should not be interpreted as abnormal. Similarly, changes in amplitude and form of individual response components do not represent reliable criteria for abnormality.

Stimulation of the Posterior Tibial Nerve at the Ankle

A. Terminology

Temporal features and abbreviation. Posterior tibial nerve-evoked short-latency somatosensory evoked potentials (3,8–11) occur within 50 msec of the stimulus in normal subjects. Suggested abbreviation is PTN-SSEPs.

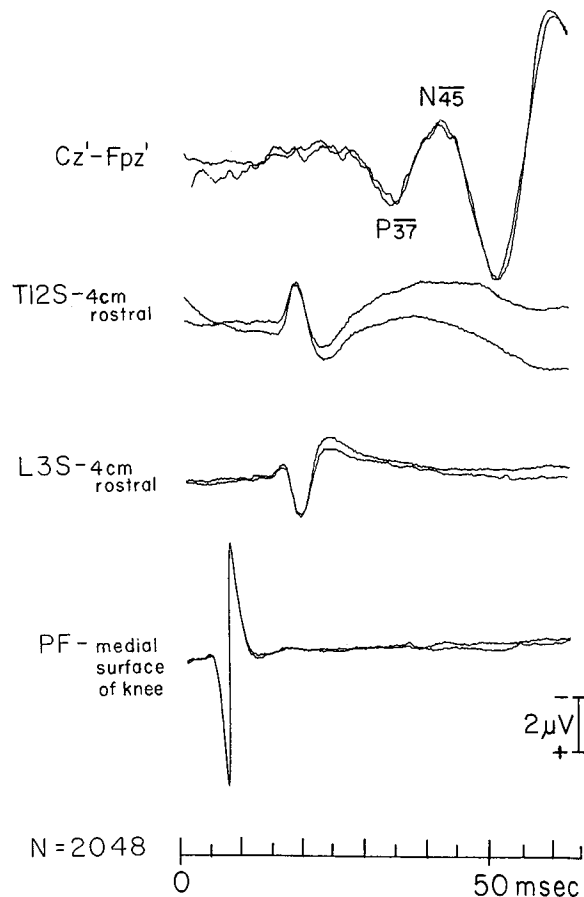


FIG. 9. Short-latency somatosensory evoked potentials (SSEPs) to right posterior tibial nerve stimulation of the ankle in 24-year-old man. Stimulus consisted of monophasic square pulses of 200 μ sec duration repeated at 5.4/sec. Muscle twitch caused plantar flexion of the toes. There was a 2 msec delay between stimulus and sweep onset.

Designation of components. It is recommended that individual response components (Fig. 9) be designated as follows:

1. Nerve trunk (tibial nerve) component in the popliteal fossa: PF potential.
2. Spine components: L3 and T12 potentials.
3. Scalp components: P $\overline{37}$ and N $\overline{45}$ waves.

B. Stimulation

Placement of stimulating electrodes. With the subject in the supine position, the cathode should be placed midway between the medial border of the Achilles tendon and the posterior border of the medial malleolus. The Achilles tendon is readily visualized when the subject flexes his foot at the ankle in the plantar direction against manual extension by the technologist. The anode should be located 3 cm distal to the cathode.

Subject grounding. A band electrode around the calf is recommended as a ground lead.

Motor effects of stimulation. Stimulation of the posterior tibial nerve at the ankle should produce a visible muscle twitch causing plantar flexion of the toes.

C. Recording

Analysis time. An analysis time of 60–80 msec from stimulus onset is suggested. If no scalp potentials are detected during this time, it is recommended that a longer analysis time be used such as 100 or 200 msec before inferring that the scalp components of the response are absent.

Number of trials to be averaged. It is suggested that about 1,000–4,000 individual trials be averaged.

Recording electrode placement. The electrodes for recording these responses should be placed as follows:

Electrode No. 1: Over the tibial nerve in the popliteal fossa, 4–6 cm above the popliteal crease, midway between the combined tendons of the semi-membranous and semi-tendinous muscles medially and the tendon of the biceps femoris laterally. These tendons are readily visualized when the subject flexes his leg at the knee against manual extension by the technologist. (Stimulation of the tibial nerve in this location produces plantar flexion of foot and toes.) This popliteal fossa electrode should be designated PF.

Electrode No. 2: On the medial surface of the knee.

Electrode No. 3: Over the L3 spinous process, i.e., one spine above the line joining the iliac crests of the hip bones. This electrode should be referred to as L3S.

Electrode No. 4: 4 cm rostral to L3S.

Electrode No. 5: Over the T12 spinous process, i.e., three spines above the L3 spine. This electrode should be referred to as T12S.

Electrode No. 6: 4 cm rostral to T12S.

Electrode No. 7: Over the scalp on the midline, 2 cm posterior to the Cz position of the 10-20 system. This electrode should be designated Cz'.

Electrode No. 8: Midway between positions Fpz and Fz of the 10-20 system. This electrode should be referred to as Fpz'.

Montage. A montage consisting of the following derivations is suggested for a four-channel system.

Channel 1: Cz'-Fpz'.

Channel 2: T12S-4 cm rostral to T12S.

Channel 3: L3S-4 cm rostral to L3S.

Channel 4: PF-medial surface of knee.

D. Analysis of Results

Potentials to be recognized. Records are analyzed to identify those potentials that are most consistently demonstrated in normal subjects. These include the following:

1. In the popliteal fossa derivations: PF potential.
2. In the spinal derivations: L3 and T12 potentials.
3. In the scalp-to-scalp derivations: components P37 and N45.

It should be noted that the amplitude and latency of the N45 scalp component may be influenced by the state of the subject.

Measurements. The following *body measurements* should be taken:

1. Distance from stimulating cathode on each ankle to PF electrode.
2. Distance from stimulating cathode on each ankle to each L3 and T12 spine electrode.
3. Straight line distances from each L3 and T12 spine electrode to Cz' scalp lead.

The following *latency measurements* (to be computed from the leading edge of the stimulating pulse) are suggested to evaluate posterior tibial nerve SSEPs:

1. Peak latency of the popliteal fossa potential (initial negative or preceding positive, peak).
2. Peak latency of the L3 and T12 spine potentials (negative peak).
3. Peak latency of the first major positive scalp potential (P37).

Using the above measurements, the following *conduction velocities* (in m/sec) should be computed:

1. *Conduction velocity in peripheral afferent nerve fibers*, which is determined by dividing: (a) the distance between the stimulating cathode and the PF electrode by the latency of the PF potential, and (b) the distance between the stimulating cathode and the L3S electrode by the latency of the L3 spine potential.

2. "*Conduction*" *velocities from spine to scalp* that are computed by subtracting the peak latencies of the L3 and T12 spine potentials from the peak latency of the P37 scalp potential and dividing the corresponding spine-scalp distances by these differences.

Because the conduction velocity from L3S to T12S is highly variable in normal subjects, its measurement is of little clinical significance.

E. Criteria for Clinically Significant Abnormality

Criteria for clinically significant abnormality are the same as for common peroneal nerve-evoked SSEPs.

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