Principles and Practice of Clinical Electrophysiology of Vision

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PART X

Visual Evoked Cortical Potentials

51

Visual Evoked Cortical Potentials: Basic Recording

G. F. A. Harding

Visual evoked cortical potentials are relatively easily recorded by noninvasive procedures due to the close proximity of the visual cortex to the surface of the scalp. The method of recording the visual evoked cortical potential is similar to that outlined earlier. The electrophysiological technique is concerned with amplifying the potential differences between two electrodes and their connection to the amplifier, and care must be taken to reduce extraneous potentials as well as those emanating from the biological system but not currently studied.

ELECTRODES

The mode of application of the electrodes is governed by the need to produce a low resistance between the tissue and the electrode. This resistance is generally reduced to around <5 kΩ to allow the potential difference generated by the source to be effectively applied to the amplifier. Visual evoked potentials (VEPs) are usually recorded by utilizing standard electroencephalographic (EEG) electrodes of the silver disk or "stick-on" type. The silver disk is usually coated with silver chloride. The electrode is either attached to the scalp by means of collodion adhesive applied round the rim of the electrode, the adhesive being dried by a stream of air from an air gun, or alternatively, particularly in the United States, bentonite paste is used to hold the electrodes to the scalp. A more recent development is the use of Blenderm tape, approximately 2.5 cm being taped over the electrode and the hair holding the electrode firmly in place for the normal length of a VEP recording. The disk electrode has a hole in the cupped part through which a blunt hypodermic needle can be inserted both for scarifying the skin and inserting electrode jelly into the cup.

The electrodes may be removed after use by pulling off the Blenderm tape or by dissolving the collodion with acetone. Care should be taken in the latter case because the solvent is an irritant to eyes and throat. Electrodes do have a finite life (usually between 60 and 100 recordings) usually due to breakdown at the joint between the electrode and the lead. All electrodes should be chlorided to prevent artifacts. Chloriding is normally carried out by electrolysis following the cleaning of the electrode. The electrodes form the anode in a 5% saline solution, with the cathode another piece of silver, conveniently an old electrode. A 1.5-V battery is connected, and usually approximately 1 minute of chloriding will produce a mauve-brown coating of silver chloride. The electrodes must always be washed after chloriding and after each application. It is sometimes possible to draw blood during the scarifying process, and the risks of cross-infection must always be considered.

ELECTRODE PLACEMENT

All electrode placement systems in current use depend on measurement taken from points on the skull referred to as bony landmarks. For evoked potential (EP) studies of the visual cortex the inion is always an essential location. The inion is the long ridge just above the base of the skull. It is slightly below the visual cortex[4, 14] but is the most convenient landmark in a posterior-anterior direction. Unfortunately, there is no midline protuberance at the back of the skull, so the midline has to be determined by measures taken from the nasion (just above the nose) or the two cochas (preauricular depressions just in front and toward the top of the outer ears). After determining this midline landmark it is relatively easy to construct a measurement system for the placement of electrodes.

Some placement systems operate on fixed measurements from this landmark. The term *fixed* means that the measurements are a constant irrespective of head size. The system recommended by the group at the National Hospital utilizes such a technique. Electrodes are placed 5 cm above the inion at 2.5, 5, and 10 cm each side of the midline.[9] Such a system is, of course, useless on children, and it is questionable whether the position of the electrodes relative to the visual cortex is the same for a small woman and a large man. Although such placement systems are acceptable as long as the position of the electrodes are clearly defined, one must realize that no full studies have been performed on their anatomical location over the surface of the cortex.

The most commonly used system on which such studies have been performed is the International 10–20 system. All measurements are taken from the bony landmarks previously described (nasion, inion, and two cochas), and all locations of electrodes are a percentage of the measurement distance. The system is therefore usable for all head sizes. In addition, the system allows for electrodes to be placed intermediate to the standard positions and yet still be defined by the electrode naming system, which again relates to their anatomical position.

At the First International EEG Congress in London in 1947, it was recommended that an attempt be made to standardize the placement of electrodes for EEG examinations so as to facilitate comparison of records taken in different laboratories and to improve communication of results in the literature. Jasper was appointed to study this problem and report his recommendations to the Second International Congress in Paris in 1949. He found that only minor differences existed between several British and American systems of electrode placement, although the placement designations used (numbers, letters, etc.) were entirely different. It was therefore felt that it should be possible to design a compromise system incorporating the advantages of the various systems then in use so that common agreement would be reached and an international standard formulated.

Certain basic principles were laid down as follows:

1. Positions of electrodes should be determined by measurement from standard, easily detectable landmarks on the skull. Measurements should be proportional to skull size and shape, as far as possible.
2. All parts of the head should be covered by standard designated positions even though not all may be used in a given examination.
3. Designations of electrode positions should be in terms of the underlying brain areas (for example, parietal, occipital, etc.) rather than by numbers so that communication would become more meaningful to the nonspecialist.
4. Anatomical studies should be carried out to determine those areas of cortex likely to be found beneath each of the standard electrode positions in the average person.

Ten-Twenty Method of Measurement

The anterior-posterior midline measurements are based upon the distance between the the nasion (the dip at the top of the nose) and the inion (the lowest point of protuberance at the base of the skull) over the vertex in the midline (Fig 51–1). Along this line

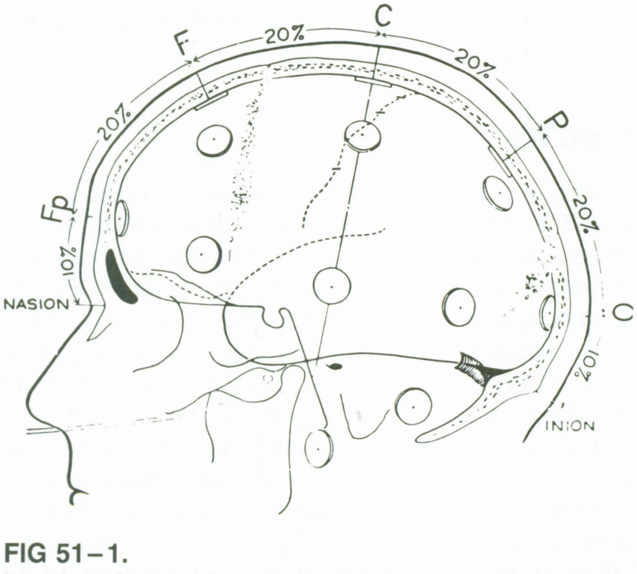

FIG 51–1.
Location of electrodes when using the international 10–20 system. This figure shows a lateral view of the skull and shows the divisions of the line from nasion to inion and the percent distances between the frontal pole *(Fp)* and the frontal *(F)*, central *(C)*, parietal *(P)*, and occipital *(O)* electrodes (From Jasper HH: *Electroencephalogr Clin Neurophysiol* 1958; 10:370–375. Used by permission.)

are five points designated frontal pole (F_p), frontal (F), central (C), parietal (P), and occipital (O). The first point (F_p) is 10% of the nasion-inion distance above the nasion; the second point (F) is 20% of this distance back from the point F_p, and so on, in 20% steps back from the central, parietal, and occipital midline points (thus the name 10–20 system). These divisions are illustrated in Figure 51–1. It will be noted that this places the vertex or central electrode just half the distance between the nasion and inion.

Lateral measurements are based upon the central coronal plane (Fig 51–2). The distance is first measured from left to right preauricular points, which are felt as depressions at the root of the zygoma (cheekbone) just anterior to the tragus (the small flap of skin and cartilage projecting over the orifice at the anterior of the external ear). These points were chosen by Jasper because they seemed easier to determine with accuracy than the external auditory meati. The lateral measurement line should pass through the predetermined central point at the vertex when making this measurement. Ten percent of this distance is then taken from the temporal point up from the preauricular point on either side. The central points are then marked 20% of the distance above the temporal points, the vertex electrode (C_z) being placed midway between the preauricular depressions.

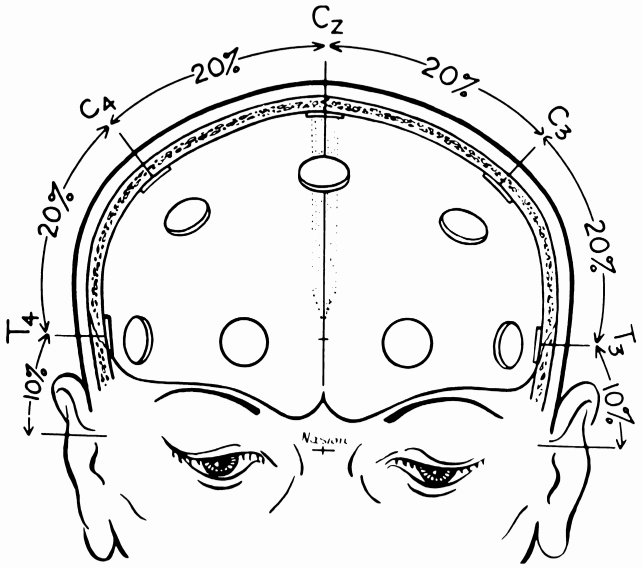

FIG 51–2.
Frontal view of the skull with the lateral locations of the 10–20 system. The division of the line between the right and left preauricular depressions and the percent distances between the temporal (T_3 and T_4, central (C_3 and C_4), and vertex (C_z) electrodes are shown (From Jasper HH: *Electroencephalogr Clin Neurophysiol* 1958; 10:370–375. Used by permission.)

The anterior-posterior line of electrodes over the temporal lobe, frontal to occipital, is determined by measuring the distance between the frontal pole midline point (as determined above), through the temporal position of the central line, and back to the midoccipital point (Fig 51–3). The occipital electrode position was then marked 10% of the distance from the midline at the back. The posterior temporal positions then fall 20% of the distance from the occipital electrodes, respectively, along this line, as shown in Figure 51–3.

The remaining midparietal (P_3 and P_4) electrodes are then placed along the parietal coronal lines equidistant between the midline and temporal line of electrodes on either side, respectively.

Electrode separations are approximately the same for all pairs in the anteriorposterior direction, and coronal lines of electrodes are also approximately equally spaced.

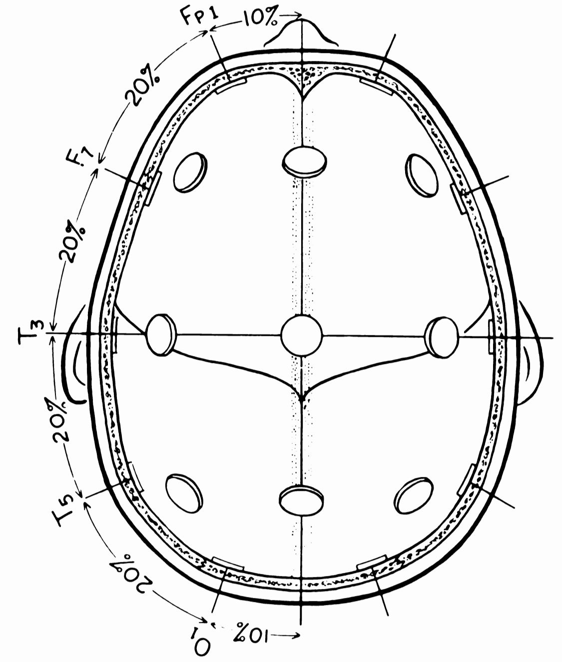

FIG 51–3.
Superior view of the skull with the circumference location of the 10–20 system. The divisions are made from the frontal pole to the occiput, and percent distances are given to the left frontal pole (F_1) and the frontal (F_7), midposterior-temporal (T_5), and the occipital (O_1) electrodes (From Jasper HH: *Electroencephalogr Clin Neurophysiol* 1958; 10:370–375. Used by permission.)

Ten-Twenty Designations of Electrodes Positions

Traditional anatomical terms were employed to designate electrode positions over the various lobes of the brain, with the exception of the central region, which is, strictly speaking, partly frontal (Brodmann's area 4) and partly parietal (Brodmann's area 3). It represents the cortex in the vicinity of the rolandic fissure, both precentral and postcentral, and is often called the sensorimotor area.

In order to differentiate between homologous positions over the left and right hemispheres it was decided to use even numbers as subscripts for the subject's right hemisphere and odd numbers for the subject's left hemisphere. F_{p2}, F_4, F_8, C_4, P_4, T_4, T_6, and O_2 become standard positions on the lateral aspect of the right hemisphere, while F_{p1}, F_3, F_7, C_3, P_3, T_3, T_5, and O_1 become standard lateral positions over the left hemisphere. These numbers were selected to allow for intermediate positions (e.g., P_1, P_5) for specific localization studies. Electrodes on the midline in the frontal, central, and parietal regions were designated F_z, C_z, and P_z (z for zero, O is already used for occipital). The complete system of placements with designations is shown in Figure 51–4.

When the electrode positions were agreed upon, anatomical studies were carried out by Jasper to determine the cortical areas over which each electrode would lie. He utilized two methods: (1) metal clips placed along the rolandic and sylvian fissures at surgery were used to identify these fissures in x-ray studies of the skull after the EEG electrodes had been applied. (2) Electrode positions were carefully marked on the head of cadavers, drill holes placed through the skull, and the cortex marked in each position before the brain was removed for examination.

Brains in which there were gross lesions or local atrophy were excluded. Although some variability was found, the position of the two principal fissures were within about 1 cm of that shown on the figures, provided the head measurements were carefully made and the brain was free of gross distortion due to expending or contracting lesions. Due to the obliquity of the rolandic fissure, the upper central electrodes usually lie precentral while the lower ones are postcentral.

In the author's experience, in any particular case it is impossible to be sure of the location of the central electrodes and their relationship to the rolandic fissure. This problem presumably arises from individual variations in brain location with respect to skull landmarks, and likewise it is impossible to ascertain whether the midline electrodes F_z, C_z, and P_z are placed on the midline, over the right hemisphere, or over the left hemisphere of the brain. These problems are, of course, reduced in intrapatient or serial studies since care in measurement will guarantee that the electrode location is replicated on each subsequent occasion, and thus any location error will be constant.

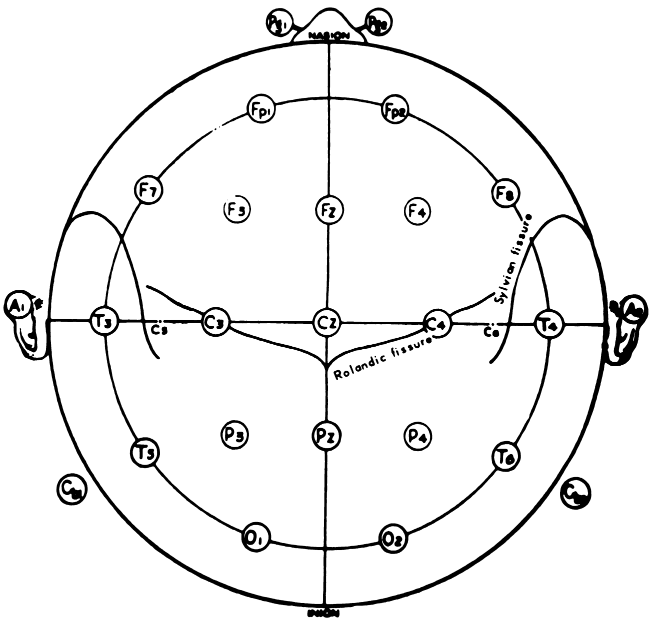

FIG 51–4.

Figure shows a plan view of the 10–20 designated positions on the scalp and their relationship to underlying fissures. The letters refer to regions over which the electrodes lie, thus, F_p refers to frontal pole, F refers to frontal, C refers to central, P refers to parietal, O refers to occipital and T refers to temporal. Even numbered electrodes are on the right and odd numbered electrodes on the left. It should be noted that the nomenclature allows for half distance electrodes to be placed in between those designated, thus P_2 for instance, would appear at half the distance between electrodes P_z and P_4 and electrode O_4 would appear at half the distance between electrode O_2 and electrode T_6.

For studies of the visual cortex it is possible to locate additional electrodes at O_z (at the midline) and at O_3 and O_4 (midway between O_1 and T_5 and O_2 and T_6, respectively), and these positions have been used in many studies[5, 11]; electrodes may also be located midway between the occipital and parietal positions, i.e., OP_2 and OP_1.

A further interesting modification has been proposed by Drasdo and Furlong.[6] In this technique the position of the poles of the 10–20 system are relocated to allow a more sensitive measurement across the area to be studied. Thus for studies of the visual cortex the polar positions are moved from the nasion and inion to the vertex. The system still allows a measurement system proportional to head size and is constructed on the basis of models of the visual cortex, but it must be said that true anatomical studies have not been performed. However the system does have advantages for topographical studies in that all 19 electrode sites may be packed into a relatively small area, with little assumption being made in the interpolation that of necessity occurs in brain mapping. In addition, various points on the coordinate system coincide with those of the 10–20 system. Because the system utilizes equal coordinate intervals, standard brain mapping packages may be used. This system would appear to have advantages for studies involving stimuli subtending small visual angles (3 degrees or less), but great care must be taken in the choice of the reference electrode site.

Once the electrodes are in position, the method of connection to the amplifier must be considered. For all amplifiers used in electrophysiology there are always two inputs, that is, the amplifier amplifies the potential difference between a pair of electrodes. Signals in common between the two inputs are rejected. These inputs are shown by EEG conventions—the "black" lead and the "white" lead. Within this convention and in common with all electrophysiology there are two basic types of electrode linkage, known as "reference" and "bipolar" recording.

In reference recording the black lead of the amplifier is normally connected to the electrode over the active source to the investigated, for example, over the visual cortex. The white lead is connected to an electrode over a reference point, which if possible should be inactive, at least in terms of visual stimuli. If more than one amplifier is used (each is commonly referred to as a "channel") it is essential that the reference electrode be common to the white lead of all amplifiers. In this situation the recordings are referred to as common reference recording. If the reference is truely inactive, each channel should only record the activity under the active electrode. For VEPs utilizing common reference recording, either the F_z (frontal midline) electrode or linked ear electrodes are used as a reference. Studies have unfortunately shown that the earlobe is within the potential field of the VEPs.[9, 16] Recently it has also become apparent that the F_z electrode proposed as a reference by Halliday and his coworkers is also highly active, not with the VEP as such, but by a signal of opposite polarity that occurs almost simultaneously with the major positive component of the VEP evoked by both flash and pattern[13] (Figure 51–5, Plate 5). Because of these severe difficulties recent interest has revived the use of both average reference recording and noncephalic references.

The average reference system was first developed by Offner[17] and Goldman.[8] The technique produces a theoretical average reference point. All active electrodes are connected through resistors of equal value to a common point in the amplifiers or the electrode selection system. The potential at this point will therefore be an algebraic sum and should approximate zero. Thus one can select any active electrode, and the amplifier will record the potential difference between this electrode and the average of all the other electrodes on the head. As in reference recording, the active electrode is connected to the black lead and the average reference to the white. Unfortunately, in practice the system has some disadvantages. In the first place if a very large potential occurs at a small number of electrodes, it appears out of phase on the other channels since it contributes disproportionately to the average, thereby increasing the risk of biological artifact. In addition,

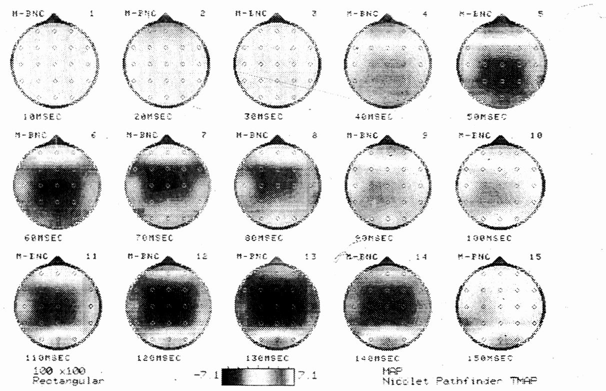

FIG 51–5.
Distribution of activity across the scalp in 10-ms steps from flash stimulation. The brain maps indicate electrode positions according to the 10–20 system, and each electrode is referred to a balanced noncephalic reference. The diagram shows the group average responses from normal middle-aged adults. It can be seen that between 50 and 80 ms there is a clear negativity in the frontal regions that is unaccompanied by any change in the occipital derivations. A little later, maximally around 120 and 130 ms there is a clear positive P2 component developed in the occipital derivations that coexists with a marked negativity seen in frontal derivations. The fact that the earlier N75 component seen in the frontal regions does not coexist with the posterior component suggests that this may well be independent of activity in the occipital region. **(See also Color Plate 5.)**

since the amplifiers only record the difference between an electrode and the average of the other points, it is not suitable for a densely packed electrode configuration such as that proposed by Drasdo and Furlong.[6] However, it must be said that in terms of studies of topographical distribution of potentials over the whole head it has much to commend it.

Noncephalic references have a long history and great theoretical advantages. Since they can be placed on the body, they are unlikely to be influenced by any cephalic activity. The difficulty is getting rid of the artifact of the electrocardiograph (ECG). Stephenson and Gibbs[18] first developed a technique of balancing out the ECG artifact. Two electrodes are positioned, one on the right sternoclavicular point and the other over the seventh cervical vertebra. A variable resistor network allows adjustment so that the ECG will be of opposite polarity at each electrode and can be canceled out. In studies in our own laboratory this technique has been most useful when studying topographical distribution. However, difficulty is experienced in canceling the ECG artifact if the patient is sitting. This idiosyncratic difficulty appears to be related to the body build of the subject, and it is of course well known that in the short and portly the heart is pushed laterally by the diaphragm, particularly when sitting. No such difficulties are experienced in a prone patient or subject, but this means, however, that most stimuli have to be presented through a silvered-surface mirror system.

Bipolar recording is a completely different concept. Under this system both electrodes are assumed to be active, and successive channels or amplifiers are connected to a chain of electrodes. When utilizing this system, except for the ends of the chain, electrodes are connected to the opposite leads of successive amplifiers (Fig 51–6). Thus a single source can be located by the electrode that produced opposite phase signals in adjacent channels. Such systems have been used to enhance components and identify the source.[10, 12, 15] Recently interest has revived in bipolar recording since it is easy to reconfigure the information by using the Hjorth source derivation technique.[3] This technique, instead of trying to identify dipoles within the brain, locates current flow in and out of the scalp. This concept allows easy comparison with the neuromagnetic field.

One further problem remains in VEP recording: which way is up? If the conventions indicated above are followed, positive potentials at the black lead will be represented downward and negative upward. This convention matches that of the EEG but is the opposite of the electroretinogram (ERG), and it is the one most commonly used for flash and pattern-reversal VEPs. For pattern appearance-disappearance most laboratories display positive up and negative down. Uniformity has never been achieved, but it is essential in any published illustration of EPs that there be a clear indication of whether positive is up or positive is down. This can be conveniently provided by a plus or minus sign next to the amplitude calibration bar.

Artifacts that interfere with the recording of the VEP can be separated into two groups: extraneous artifacts generated by electrodes and other electrical sources, including the stimulating equipment, and physiological artifacts generated by the patient.

Extraneous artifacts most commonly experienced in VEP recording are those generated by the electrodes. Most of these artifacts appear as large sudden potential shifts of the baseline of the VEP. Often this is due to changes in electrode-skin interface brought about by movement or by sweating. These artifacts may result in the rejection of large numbers of traces by averagers utilizing automatic artifact rejection when the input exceeds the limit set. If automatic rejection is not used, a single trace *containing* an artifact that is markedly larger than the EP will still influence the average of, say, 32 traces. On multichannel recording, artifacts affecting only one of the active electrodes can be easily recognized; also, artifacts occurring in common between all channels must be originating at the reference electrode. The offending electrode should have its resistance rechecked and additional electrode jelly reinserted. The adherence between the electrode and the scalp should also be investigated. Occasionally the fault is due to corrosion between the silver electrode and the wire of the electrode lead. Such a fault is difficult to recognize, but if the above adjustments have proved useless in removing the artifact, the electrode should be changed. Usually high resistances at any electrode will be recognized by increased line (or mains) interference. This interference matches the line frequency, 60 Hz in the United States and 50 Hz in Europe. If electrode resistances are kept low and the electrode leads and the imput box and lead are kept away from power levels and plugs, no other action is needed to avoid line interference. Although screened rooms are sometimes recommended, they are rarely necessary, and modern equipment will even cope with hostile environments such as operating theaters and intensive care wards.

Biological artifacts are of course not really artifacts

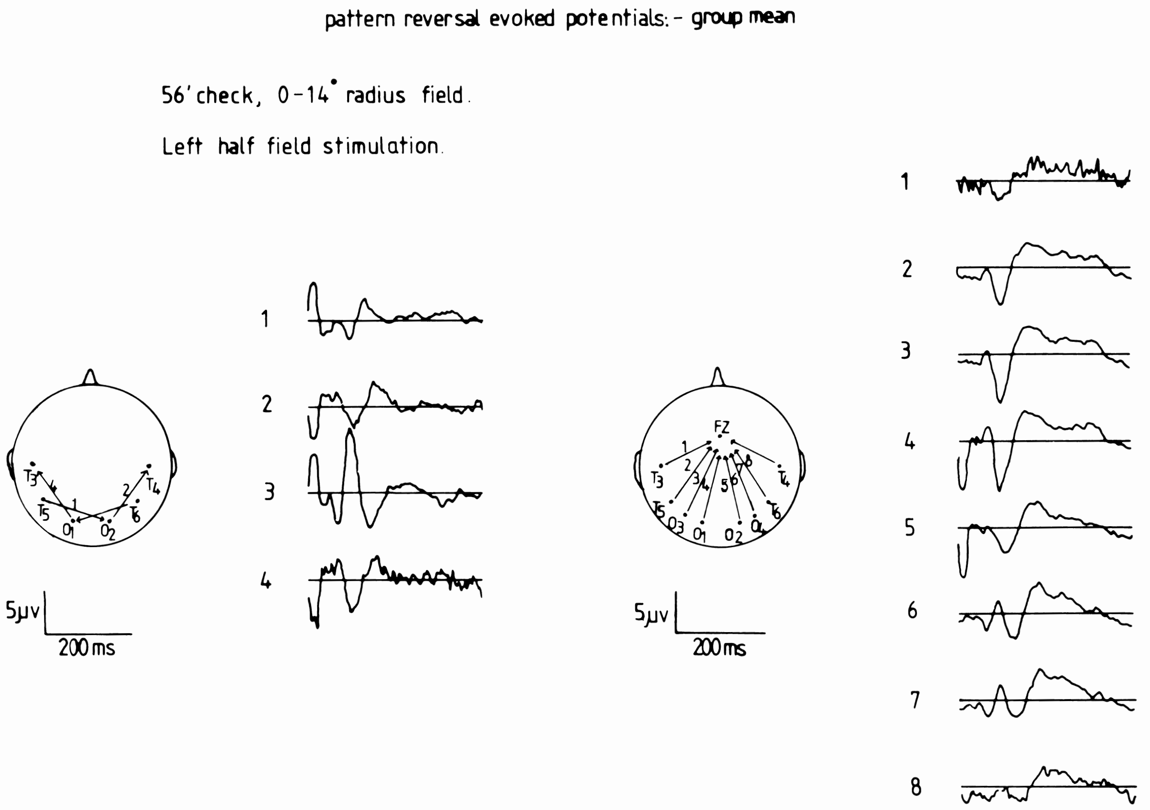

FIG 51-6.

Figure shows the distribution of amplitude of responses according to common reference recording shown in the right column and also on bipolar recording shown in the left column. It can be seen from the montage attached to the right column that all channels are referred to the mid-frontal electrode and that the highest amplitude response to left half field stimulation occurs over the left cerebral hemisphere, that is in channels 2, 3 and 4. On the contralateral side of the head a negativity can be seen in channels 6 and 7. With bipolar derivations shown on the left when the left half field is stimulated, the P100 response can be seen phase reversed (that is opposite way up) between channels 3 and 4 showing that the response is occurring at electrode O_1 which is the common electrode between those two channels. Channels 1 and 2, which both utilize the right occipital electrode, fail to show any such phase reversal. This would be expected from left-half field stimulation since the response will be ipsilaterally at the left occiput. The two techniques, therefore, can be seen to be complementary.

at all; they are genuine signals arising from structures and systems that we are not investigating. Ocular artifact due to eye movement is a common problem. The cornea has a standing positive potential of between 6 to 10 millivolts depending on the level of illumination. Blinking when a flash of light occurs produces a positive-going potential of about 200 μV that occurs at about 200 ms after the flash and lasts for around 250 ms. This potential is easily picked up by frontal electrodes, and as we have seen, the midfrontal electrode is often chosen for the common reference point. Equally, the ERG itself spreads as far as the rolandic fissure. Derivations using the frontal electrode as reference may therefore by contaminated by the ERG producing spontaneous early components in the VEP. Correction of most of the artifacts is relatively easy. Patients need to be instructed not to blink excessively, and for the visual evoked response (VEP) it is usually better to have some low-intensity background lighting when flash stimulation is being given. The position of the reference electrode is also a critical factor, as was seen earlier.

Muscle artifact is a particularly troublesome source of interference. Continuous muscle interference is usually generated by the frontal, temporal, postauricular, occipital, and neck muscles. Movements such as tensing the neck, frowning, clenching the jaw, or swallowing are common problems. The first action to take in these circumstances is to persuade the patient to relax. For continuous artifact such as this where the artifact is unrelated to the stimulus, those instructions are often sufficient. More support for the head may be given and the patient reclined slightly. Instructions to open the mouth often help. Since the frequency of the electromyographic (EMG) activity (20 Hz to 1 kHz) often encompasses those of the VEP, the use of low-pass filters may well affect particular components of the VEP, thus producing shifts in latency. Since the EMG artifact is unrelated to the stimulus, increasing the number of sweeps to be averaged may also be advantageous.

Occasionally stimulus-locked muscle activity may be present. The most commonly seen myogenic response is the photomyoclonic response of the frontalis muscle that was described by Gastaut[7] and Bickford et al.[2] This is a normal response consisting of high-amplitude frontal spikes elicited by high-intensity flash stimulation. Bickford et al.[2] found such responses to be present in 50% of normal subjects, and they are obviously a hazard in reference recording to the frontal electrode.

Very occasionally muscle potentials generated from the neck muscles cause difficulty due to intention tremor. Thus when the patient is asked to look at the light or look at the pattern, a rhythmic muscle potential occurs that obliterates the VEP. In some cases stimulus-locked potentials occur around 75 ms after the stimulus.[1] In other cases only a rhythmic tremor can be recorded (Fig 51–7).

Stimulus-induced artifact may also be both extraneous and induced in the patient. Obviously, proximity to TV-type stimulators increases the probability of line interference as well as static interference from the screen. However the stimulus may also induce an inappropriate response as, for instance, when a photostimulator produces an auditory evoked response from the click as the discharge tube is illuminated. Equally, there is often an illumination change related to line frequency in a TV stimulator that should apparently only be producing a pattern change. For both these types of artifact it is worthwhile to carry out a nonstimulus average in which the stimulator is triggered as normal but masked from the subject. Such averaging runs will indicate not only background noise levels but also stimulus-induced artifact.

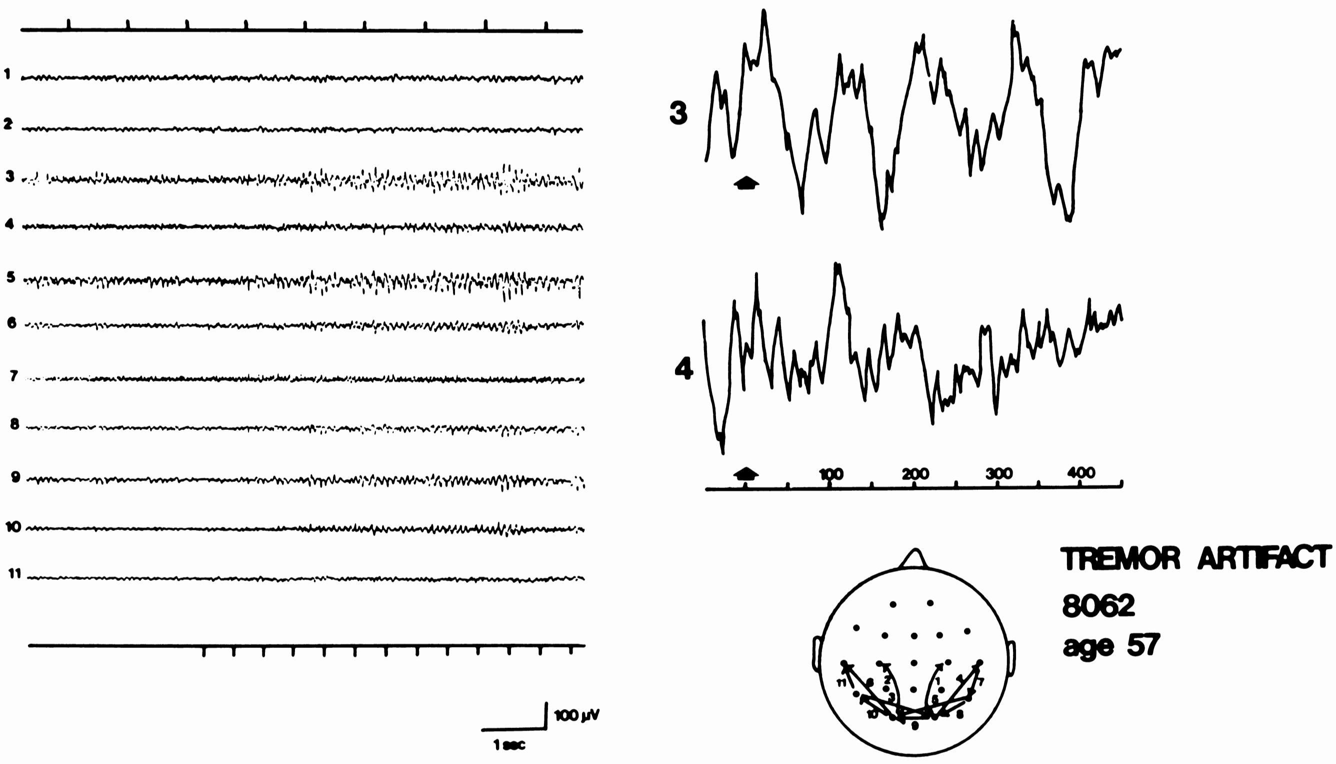

FIG 51–7.
Effect on the VEP recorded from occipital derivations of a sternomastoid tremor. This patient had an intention tremor so that when he was asked to look at the light (flashes are indicated on the *bottom* trace on the left) a clear alphalike wave was seen in the EEG. This wave, when averged, dominated the VEP as seen in the *right* two traces. By placing electrodes over the sternomastoid muscle it was possible to record this tremor, and it later became apparent that the patient was suffering from Parkinson's disease.

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