VISUAL EVOKED RESPONSES IN MAN:
NORMATIVE DATA*

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Introduction

The fundamental importance of the characteristics of the cerebral electrical response to a simple pulse of light in man is evidenced by the number of workers who have provided information about its features from conventional recordings. Detailed description awaited the development of more powerful analytical tools. With the recognition of the usefulness of photographic superimposition, correlational analysis, and summation techniques (Dawson, 1947; Brazier and Casby, 1951, 1952; Dawson, 1954; Barlow and Brazier, 1954; Brazier and Barlow, 1956), the way was opened for a new phase in the examination of the complexities of cerebral organization. The major features of the visual evoked response have now been outlined by Cigánek, Cobb, Dawson and others. Studies which have included an analysis of latency and polarity of individual components of the response are listed in TABLE 1.

The present study was designed to furnish additional information about response morphology, particularly as it might vary in relation to recording site, with the hope that it might lead to an increase in the clinical application of the technique. Also, a preliminary survey of possible relationships between major features of the response and such normal variables as age, eye color, refractive error, color blindness, pupil size, subjective estimate of light intensity, prior night's sleep, alpha frequency, alpha amplitude, and alpha persistence was undertaken.

Material and Methods

A total of 130 adults were studied as part of a periodic intensive health appraisal program, a continuing activity of the University of Michigan Health Service (Tupper and Beckett, 1958). Ophthalmological and neurological consultations were obtained when medically indicated. The series was terminated when 100 subjects without demonstrable ocular or neurological disease had been processed. Subjects were not rejected for minor refractive errors. Information about handedness, use of glasses, color blindness, duration and adequacy of sleep, time of last meal, regular medications and eye color was also recorded at the time of the electroencephalogram (EEG). Ages of the 100 individuals ranged from 28 to 72 with the average being 48.1 years. Ninety-four were males; six, females.

All subjects received a routine EEG. This was followed by the stand-

TABLE 1

REPRESENTATIVE STUDIES OF SURFACE VISUAL EVOKED RESPONSES

author	designations	area	surface polarity and latency (msec) 0—50—100—150—200—250
CRUIKSHANK, 1937	ON EFFECT OR EVOKED POTENTIAL	OCCIPITAL	60——100 TO PEAK
MONNIER, 1952	b, c, d, e	OCCIPITAL	N, P, P, N
COHN, 1952	BY POLARITY & LATENCY	OCCIPITAL	P, P
COBB & MORTON, 1952	BY POLARITY & LATENCY	OCCIPITAL	P, P
BANCAUD et al., 1953	LE POTENTIAL VERTEX (V)	VERTEX	55——95 TO ONSET
BRAZIER & BARLOW, 1956	BY POLARITY & LATENCY	OCCIPITO-PARIETAL	P, N
LARSSON, 1956	NON-SPECIFIC RESPONSE	VERTEX	50——90 TO ONSET (SOMATOSENSORY) "SHORTER" (AUDITORY) 60——80 (VISUAL)
CALVET, et al., 1956	BY POLARITY & LATENCY	OCCIPITAL	40-50 TO ONSET, 0.1 c/sec OSCILLATIONS
BRAZIER, 1957	EARLY & LATE RESPONSES	OCCIPITAL	?N P N, N
COBB & DAWSON, 1960	BY POLARITY & LATENCY	OCCIPITAL	P N, N
CIGÁNEK, 1958 a,b,c; 1959, 1961	PRIMARY RESPONSE, SECONDARY RESPONSE, AFTER DISCHARGE	OCCIPITO-PARIETAL	N (1), P (II) N (III), P N (IV,V,VI), N P (VeVII) (VIII) N
CONTAMIN & CATHALA, 1961	RÉPONSES ÉLECTROCORTICALES	OCCIPITAL, VERTEX, SOMATOSENSORY	P N, P N, N P, P
TEPAS et al., 1962	0-A, 0-B	OCCIPITAL	N, P

ardized evoked response study which required 30 minutes of the total two hour period. The subjects sat in a comfortable chair with the face of the flash lamp 5 cm. from the open eyes. Background light intensity was set at approximately one ft. candle. The lamp (Grass Model PS2) was fitted with commercial opal glass which improved diffusion and eliminated internal lamp detail. It reduced light intensity by 20 per cent from the basic rating of 200,000 peak candles. The light intensity was selected to be as bright as could be reasonably tolerated by the average individual. The great majority of the subjects rated the light as "moderately" or "very" bright. Four subjects felt it was "extremely" bright. A doublewalled encasement eliminated audible lamp "click."

The procedure was devised to provide systematic data from 14 regions over the head, face and neck. Data analyzed in the present study was recorded from the following electrode positions: left infra-orbital; left frontal; left and right central; left, right and midoccipital; and cervical. The infra-orbital lead was placed on the inferior margin of the orbit. Frontal and central leads were four cm. from the midline, the frontal being three cm. above the eyebrow, the central being on the interaural plane. Occipital leads were 3 cm. above the inion with the laterally placed leads being three cm. from the midline. The cervical lead was 6 cm. below the inion. Combined ears were used as a reference except during runs especially included to evaluate the suitability of various reference sites. Four areas were compared simultaneously. Analysis periods were either 250 or 125 msec. Light flashes were randomized and presented 1/4–6 sec. to a total of 50 (n_r 50) or 1/.5–1 sec. to a total of 300 (n_r 300). Pupil size was measured immediately before and after the initial five minute run.

The forms of the averaged responses were computed by the Mnemotron CAT and photographed by a Hathaway oscilloscope camera which uses 6 inch wide sensitized paper. Four channels of the Grass model IV-BS electroencephalograph were employed as pre-amplifiers. Upper frequency attenuation was 40 and 80 per cent of full signal amplitude at 100 c/sec. for the two filter settings selected. Reduction of high frequency input was found useful to decrease the background "noise" which appeared to be largely due to muscle tension artifact. Low frequency response was linear to 1 c/sec. Phase shift was less than 1 msec. over the 10–100 c/sec. frequency range with the upper filter setting. Comparison of data gathered simultaneously with both settings revealed that the greater filtering resulted in added peak delays of from 1 to 5 msec. (86 per cent between 1.25 and 3.75 msec.).

Evaluation of photically evoked responses requires consideration of extracerebral sources of potential changes that may also be systematically time-related to the stimulus. These may affect the form of the cerebral event as recorded from a scalp electrode irrespective of whether the second electrode is placed close to it on the scalp or at some distant relatively inactive (in respect to cerebral potentials) site. It is axiomatic that voltages generated at any point within the head affect *to some de-*

gree a voltage differential recorded between two points upon it. Fortunately, the sources of major deflections are well known. Other sources of more subtle "contaminants" may yet be discovered.

Periorbital electrodes record three extracerebral events or series of events that can be identified by their latencies, distributions, and polarities—the electroretinogram, local photomyoclonic responses, and the corneo-retinal field shift associated with blinking. The cervical muscles form a fourth significant source of possible response distortion.

Inspection of the group data and separate studies of individual questions with a noncephalic reference have shown that (1) infraorbital-ear, supraorbital-ear, and ear-cervical linkages are useful indicators of the morphology and distribution of the major artifacts; (2) the ears are satisfactory reference sites; (3) while the electroretinogram is virtually constant from subject to subject, periorbital and cervical myoclonic responses and the corneo-retinal field shift vary widely in degree; (4) periorbital responses do not ordinarily constitute a source of ear reference "contamination"; (5) cervical responses are clearly recognizable in about 10 per cent of normal adults but rarely constitute a serious artifact (by distortion of the occipital response); and (6) the corneo-retinal field may extend to central and parietal electrodes and attenuate and alter latencies of surface negative vertex sharp waves in subjects with active blink reflexes.

In order to ascertain the frequency with which major deflections occurred at specific latencies following the stimulus, major deflections were identified and ordered according to their relative amplitudes. Three distinct peaks (surface negative) and three troughs (surface positive) could be readily identified in most instances. These were designated first, second, and third order components. Major waves were frequently "notched" resulting in two closely spaced deflections less than 20 msec. apart. In this event, the higher deflection was selected. Occasionally, third, or, rarely, second order deflections could not be distinguished, particularly in infra-orbital and frontal derivations. Inasmuch as amplitude of activity recorded by the posterior cervical control lead was low relative to that from scalp leads, only two deflections for each polarity were scored.

An alpha index was derived by counting the number of times alpha activity exceeded 20 microvolts at the instant of the stimulus during the initial n_r 50 accumulation period. The scores ranged from 0 to 28 with an average of 6.3. Alpha frequency was determined from eyes closed record, being based on counts of 10 one second epochs, five each from the initial and final occipital-ear runs. Consistency studies indicated frequency analysis was not necessary for adequate measure of this variable. Maximum alpha amplitude was estimated from epochs of greatest alpha elaboration in increments of 10 microvolts, the range being from 10 to 80 microvolts, average—40 microvolts. The eyes-closed resting alpha amplitude was positively related to the eyes-open alpha index.

The latency distributions of first, second, and third order events recorded

from infraorbital and frontal regions are presented as reference informa-
tion in FIGURE 1. Early components of the electroretinogram were detect-
able in all subjects at both locations with the same polarity. These were
followed by a series of periorbital twitch responses, largely falling within
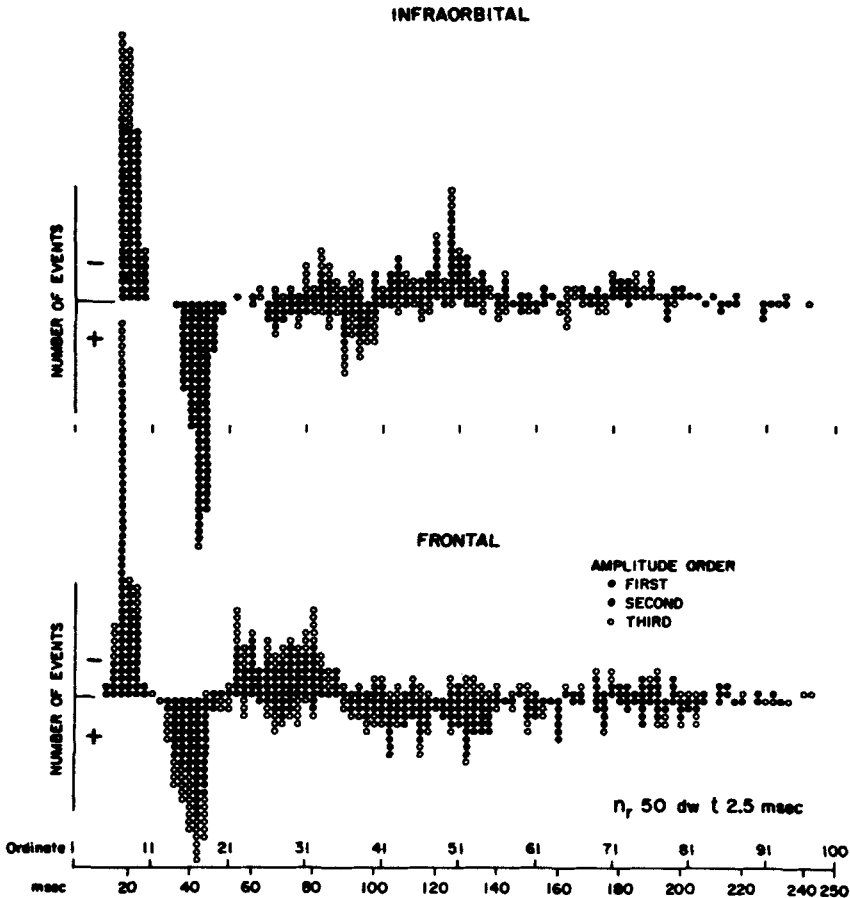the 50–100 msec. range, most evident in the frontal region. The component

FIGURE 1. Latencies of first, second, and third order deflections for 100 subjects,
left infra-orbital and left frontal regions. In five subjects who had extremely active
blink reflexes the latency of the frontal surface positive component of the blink arti-
fact could not be determined because its amplitude exceeded the range of the re-
cording system. Eyes open. Each score is the average of 50 responses. Random flash,
1/4-6 sec. Analysis time 250 msec. Address dwell time 2.5 msec.

which reflects upward rotation of the eyeball and is recognizable by out-
of-phase relationships between the two recording sites was variable in
peak latency. In the majority of instances, it fell within 100–150 msec.
In the frontal region it was often possible to detect a low amplitude deflec-

tion arising from the base of the blink artifact which could be identified as a frontally distributed vertex sharp wave.

Results

Morphology. FIGURE 2 illustrates response patterns for central, parietal, and occipital regions, based upon latency and amplitude measurements of waves I, II, III, IV and V for 100 subjects. The designations I, II, and III parallel those of Cigánek.* Waves IV and V were the remaining major

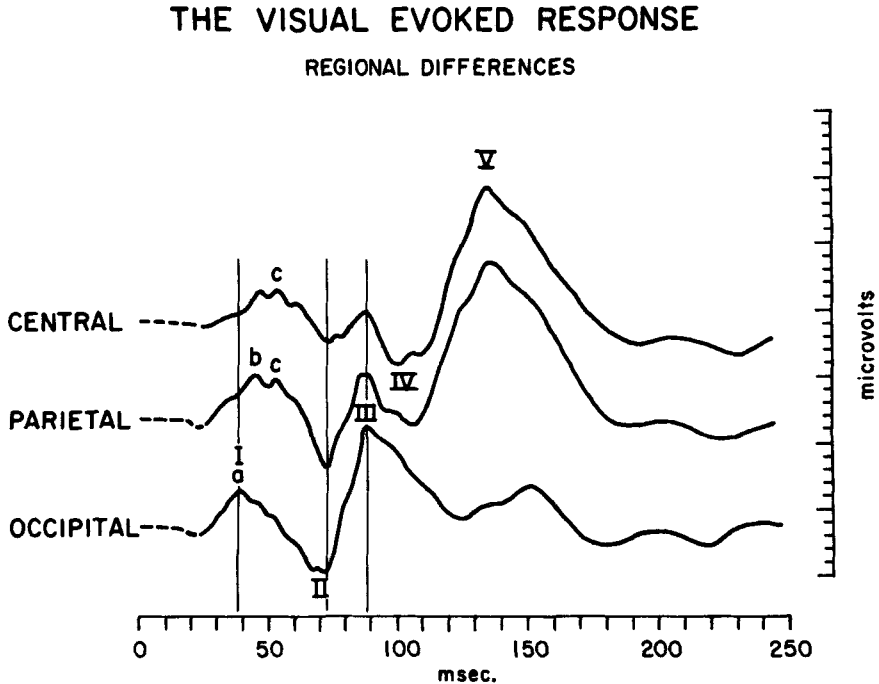## THE VISUAL EVOKED RESPONSE

REGIONAL DIFFERENCES

FIGURE 2. Semi-diagrammatic representation of group findings based upon latency and amplitude data obtained from 100 subjects.

deflections. Amplitude of the initial positive-negative deflection (I) averaged 3.7 microvolts for the occipital region, 4.7 for the parietal. The limb from I to II averaged 6.7 and 7.4 microvolts respectively. These waves tended to be slightly more prominent in the parietal region. In contrast, the occipito-parietal wave (II-III) was usually of greater voltage over the occipital region, average voltages being 11.3 and 7.6 for the two areas (TABLE 2). Its amplitude was higher in the occipital region as compared

* It cannot be assumed, however, because of procedural differences, that these waves are electrophysiologically identical. The designations, I, II, and III, are similar to those of Cigánek in respect to occipital polarity sequence of major deflections. Electrode arrangement and light intensity are highly important in determining the exact form of the recorded response.

TABLE 2

AMPLITUDES OF MAJOR DEFLECTIONS
(microvolts)

| | Occipital | | | | | | Parietal | | Central | |
| | 1 | | 2 | | 3 | | 4 | | 5 | |
	Average	Range	Average	Range	Average	Range	Average	Range	Average	Range
Initial positive wave to I	3.7	1-10	4.4	1-11	4.0	1-9	4.7	1-11	—	—
I-II	6.7	1-20	6.0	1-17	6.0	1-17	7.4	1-28	—	—
II-III	11.3	1-42	7.8	1-22	7.4	1-20	7.6	1-36	—	—
IV-V	—	—	—	—	—	—	12.3	1-33	13.6	3-39
Overall	—	—	—	—	—	—	14.7	5-37	14.3	4-39

1, 4, 5—100 subjects, n_r 50, flash rate 1/4-6 sec.
2—50 subjects, n_r 300, ear reference, flash rate 1/.5-1 sec.
3—50 subjects, n_r 300, cervical reference, flash rate 1/.5-1 sec.

with parietal in 83 per cent of the subjects. Amplitude of wave III was dependent upon flash rate, being attenuated by flash rates faster than 1/sec. (TABLE 2).

The vertex sharp wave was measured for central and parietal regions only, inasmuch as it was inconstant in the occipital region. Amplitudes were similar for the two areas, the central average being 13.6 microvolts, the parietal being 12.3. Maximum trough-peak voltages may be found in TABLE 2.

Wave I peak latencies were usually earlier in the occipital than in the parietal and central regions. For purposes of discussion three peaks have been labeled *a, b* and *c* within the general latency range of the initial negative wave. Peak *a,* which was ordinarily identified within a range of 30 to 42.5 msec., was prominent over the occipital region. Peak *b* falling between 37.5 and 50 msec. was parietal-dominant while peak *c* (47.5–55 msec.) was equally represented in central and parietal regions. Wave II had a common base deflection for the three regions but in the occipital area a slightly earlier surface positive deflection often formed a notched configuration while in the central region a similar configuration arose because of the presence of a slightly later wave. Peak latencies of the vertex sharp wave were not appreciably different between central and parietal areas.

An attempt has been made to develop a basis for comparison of normal and deviant responses by tabulating frequency of occurrence of major deflections at latency intervals following the stimulus. This data provides an answer to the question: "What is the probability, in a normal subject, that a peak potential will fall at a specific point in time?" For the occipital region (FIGURE 3), the highest negative deflection was ordinarily the occipito-parietal wave (80–120 msec.) although in a sizable number of subjects a wave falling between 120 and 160 msec. was the dominant event. The later wave was often synchronous with the vertex sharp wave but in many instances was an apparently distinct still later event. The relative areal amplitudes of the vertex sharp wave were highly variable from subject to subject and assumed a major role in determining the configuration of the occipital response. There appeared to be an interaction between the negatively-going occipito-parietal wave and the positively-going initial component of the vertex sharp wave (IV), which was noticeable particularly in the parietal region. Wave I was the first order event in 10 of the subjects. Wave II was a highly constant feature of the response although not necessarily one of the three most prominent events.

The initial positive wave, while probably averaging less than one microvolt in amplitude was, none the less, the second or third order positive deflection in 28 subjects. Doubt remains as to the origin of this component. FIGURE 4 reveals that it was evident in approximately the same number of subjects with either combined ears or the midcervical region as reference locations, favoring its cerebral origin. This data, derived from averages of 300 responses is noteworthy in that no improvement of latency ranges was evident. It is also of interest that the latency of the initial peak
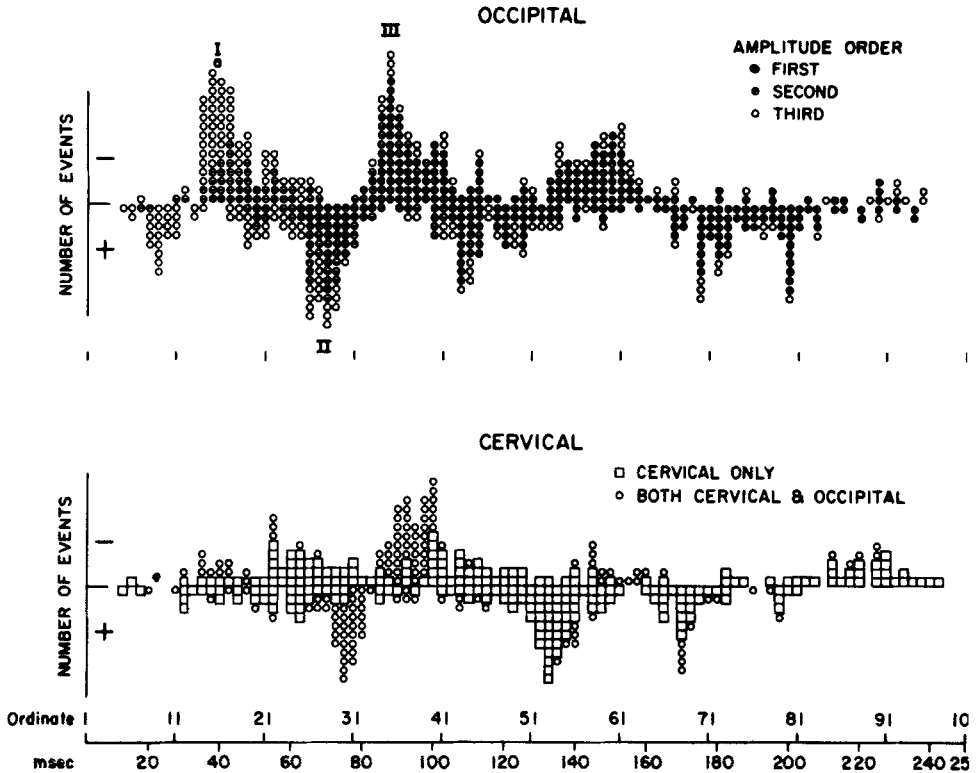
FIGURE 3. Latencies of first, second, and third order deflections for 100 subjects, left occipital region. Deflections in the cervical region were cross-matched with those recorded in the occipital area to determine which were common to both. Waves I, II, and III were detected by the cervical lead at greatly reduced amplitudes (cervical less than 20 per cent of occipital). The remaining events were assumed to represent either cervical muscle responses or low amplitude ocular and cerebral responses recorded at the ear. The consistent downward deflections in the 120–150 msec. range appeared to be instrumentally inverted vertex sharp waves.

(Ia) was the same in the tabulation of data obtained using a midoccipital placement as that recorded with a lead placed 3 cm. laterally.

The vertex sharp wave was the dominant event in both central and parietal regions (FIGURE 5) followed by waves III and I, wave III being more usual in the parietal region. It is of interest to note that when wave I occurred as the highest deflection, it was likely to occur late in the wave I cluster.

Consistency of response pattern. Test-retest data (n, 50) was available to evaluate the stability of selected measures in occipital and central regions within a single examination for 50 subjects (TABLE 3). Concurrence of measurements between trial one and trial two indicated a high consistency for these points. Data gathered to compare response form at accumulations of 100, 200, and 300 responses was not formally treated but

LATENCIES OF WAVES I, II & III
OCCIPITAL
50 SUBJECTS

(a)   POST. CERVICAL REFERENCE
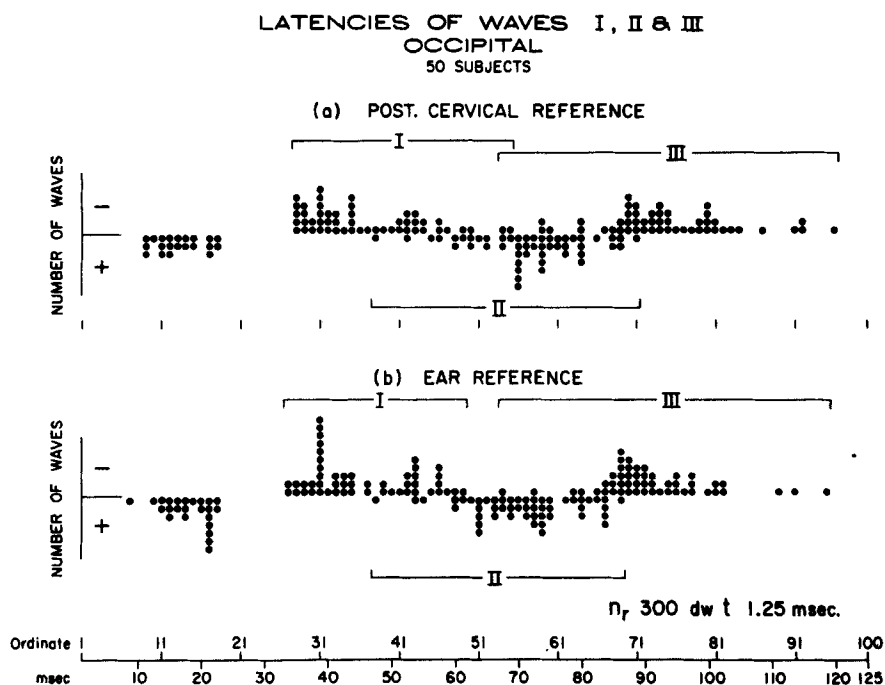
(b)   EAR REFERENCE

n_r 300 dw t 1.25 msec.

FIGURE 4. Comparison of latencies of waves I, II, and III recorded simultaneously by a midoccipital lead 3 cm. above the inion paired with (a) a reference lead 6 cm. below the inion and (b) conventional linked ears. Instances in which the initial positive phase of the vertex sharp wave spread to the occipital region were identified and eliminated from the tabulation. Each value represents the average of 300 responses. Random flash, 1/.5-1 sec. Analysis time 125 msec. Dwell time 1.25 msec. System rise time less than 1 msec.

inspection of these curves from 50 subjects gave the impression of virtual identity of pattern for the successive read-outs. Four subjects were examined from 5 to 16 times over periods of 1 to 15 months. This data also gave evidence of great stability of pattern for a given individual.

Difference between test and retest patterns. While consistency between the features of the two averaged patterns studied was high, none the less, significant differences emerged (TABLE 3). For the occipital region, latency measurements for waves II and III were slightly but significantly later for the second of the two samples whereas amplitude of wave III did not change. In the central area, latency of the vertex sharp wave was not appreciably different while amplitude was lower for the second trial.

Relationships between subject variables, the occipito-parietal wave, and the vertex sharp wave. These studies of normal physical and physiological variables were of an exploratory nature and major correlations were not anticipated. The results are reported as a matter of record. Because of their relatively high amplitudes and wide amplitude ranges, the occipito-parietal wave and vertex sharp waves were chosen as points of departure.
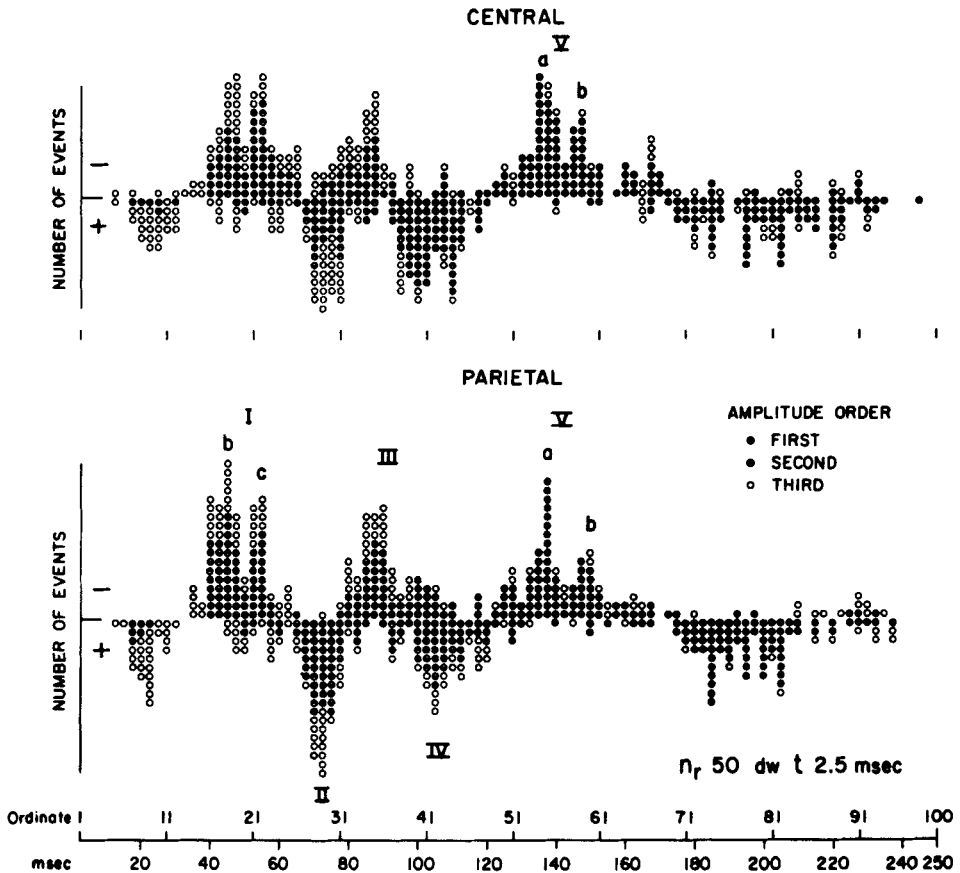
FIGURE 5. Latencies of first, second, and third order deflections for 100 subjects, left central and parietal areas. Joined ears as reference.

Each subject variable was studied in relation to the two response variables for the first 50 subjects by fourfold χ^2s. Those relationships that were possibly significant were then re-examined by Pearson product-moment correlations for both the initial 50 and full 100 subjects.

No relationship emerged between the amplitudes of either the occipito-parietal wave or vertex sharp wave and eye color, color blindness, type of refractive error, pupil size, subjective estimate of light intensity, hours of sleep, alpha frequency, alpha amplitude, and the alpha persistence index.

For the first 50 subjects, whose average age was 49.3, age correlated with occipito-parietal wave amplitude, $r = +.41$, $p < .01$. This correlation was $-.07$ for the second 50 subjects, average age, 46.9. The correlation for the combined groups was $+.21$, $p < .05$. Amplitude of the vertex sharp wave did not relate to age.

Attempts to correlate subject variables with wave latencies might be

TABLE 3

TEST-RETEST DATA*

Occipital region				
	1 (Average)	2 (Average)	Correlation (r)	Significance of difference (t)
Amplitude Wave III	10.6μV	10.7μV	.97	0.4, p > .05
Latency Wave II	27.5†	28.6†	.91	6.5, p < .001
Wave III	35.1†	35.8†	.95	3.7, p < .001

Central region				
			Correlation (r)	Significance of difference (t)
Amplitude Wave V	14.6μV	13.4μV	.87	2.7, p < .01
Latency Wave V	56.7*	57.0†	.96	1.5, p > .05

* Fifty subjects.
† Ordinates (2.5 msec. each).

expected to be unrewarding because of the difficulty in selecting a homogeneous population of latency points. Correlations between pupil size and latencies of waves I, II, and III were not significant (however, relationships between pupil size and latencies of specific waves of the electroretinogram were readily established). A low order correlation emerged between latency of parietal wave II and age ($r = +.26, p < .05$).

Discussion

Several considerations lead us to believe that analysis of visual evoked responses, as well as those elicited by other modalities, will be a highly useful addition to the electroencephalographic examination. First, it is reasonable to postulate that the electrophysiological events described are universal, inherent, cerebral processes related directly or indirectly to normal cerebral functioning. Secondly, these events may be described and delimited for the normal population in respect to such quantifiable measures as amplitude, latency, symmetry, and distribution. It may be anticipated that individual waves will also have functional correlates, thereby providing another manner of identification. Thirdly, there is evidence to suggest that information derived from the conventional electroencephalogram may be substantially supplemented in that the number of independent measures is increased. Lastly, because of recent developments in instrumentation (Clynes and Kohn, 1960) a procedure may be devised that is adaptable to the clinical laboratory.

The fact that points representing every subject are not found within

each prominent wave cluster does not indicate that a major event may be absent in a portion of normal individuals. Rather, only that it may not be of the first, second, or third order of magnitude. In this situation, when the event cannot be specifically identified by its amplitude, other criteria become essential.

Knowledge of the distribution of a given event aids materially in its identification. For example, multiareal data affords clear separation of the occipito-parietal wave and the vertex sharp wave, two temporally adjacent events that may appear with varying degrees of overlap, particularly in junctional parietal areas. This principal also applies to the identification of the individual components of wave I.

No relationship was found between the amplitude of the occipito-parietal wave and alpha amplitude measured both during the resting tracing and at the time of each stimulus (alpha index). Nor did alpha frequency relate to the amplitude of this event. Thus, the hypothesis that the occipito-parietal wave and the alpha rhythm have a common neural mechanism, suggested by their similar timing and distribution, received no support. Tepas, Armington, and Kropfl (1962) have similarly obtained an insignificant correlation between the amplitude of the occipital evoked response and an alpha index.

In some subjects, rapid deflections of 8–12 msec. in duration form a prominent feature of the response. These have been described by Cobb and Dawson (1960) and are particularly evident during the early phases of the occipital response. How frequent their occurrence and how widespread their distribution must remain unanswered from analysis of records from the scalp because of the relatively low response/noise ratio and the possibility of myoclonic components. It is likely they are, at least in part, neurogenic in origin.

Differences in response configuration from subject to subject did not appear to be attributable, in the main, either to minor procedural variations in the standardized examination or to the subject variables considered. Looking elsewhere, it is reasonable to relate them to factors that determine varying orientations, strengths and degrees of spatial and temporal overlay of discharge fields—cerebral and especially cortical macro- and microstructure, physical and electrical properties of overlying tissues, facilitory and inhibitory effects of interacting neural systems, basic levels of excitability and preferential pathways of inter- and intra-neuronal flow.

It has always been popular to draw analogies between brain mechanisms and the most advanced machine of the era. Today (and we hope with increased accuracy) it is attractive to view the brain as a data processing device concerning itself with orderly examination of information arriving over sensory pathways. The systematic, virtually invariant relationships of many components of the evoked response, in time as well as space, and in sleep as well as during waking, lend support to this concept. Continuing the speculation, the EEG evidence suggests that the earlier steps proceed rapidly while those occurring late in the process

require more time, reasonably a function of increasing complexity of successive operations. The earliest cortical steps occur in the primary receiving area, closely followed by activity in surrounding functionally related cortex. Later events are more diffuse, indicating greater integrative properties. They are also likely to be synchronous over wide regions of the cortex, consistent with activation of cortical-subcortical networks. Concentration of a major late process over motor centers (V) may reflect activity linked to the possibility of a need for activation or inhibition of efferent systems. If the recordable events should be related to operational steps in the brain's data processing mechanisms, it is tenable that analysis of alterations of response patterns could lead to a clearer understanding of the nature of functional disabilities resulting from brain lesions.

Summary

Normative values for amplitudes and latencies of major components of the averaged visual evoked response, obtained from examination of 100 medically screened adults, have been presented for three cerebral regions. Complexity of configuration, regional differences, and intra-individual consistency have been emphasized.

Because of the importance of procedural constants and electrode arrangement in determining the recorded response form, wave identification is in its preliminary stage. The following description and numerical designations apply to scalp-ear or scalp-cervical recordings with methodological variables as outlined. The peak of the initial occipital surface negative wave (I) generally fell within 30–42.5 msec. following the flash. In the parietal region, the initial peak negative deflection tended to be 5–10 msec. later. Wave I appeared to be composed of two or more rapid deflections, its peak amplitude-latency histogram being multiphasic and skewed to the side of longer latency. In about one-half of the subjects, a surface positive wave, which reached its maximum amplitude between 20–30 msec., could be identified preceding Wave I. Wave II, surface positive, culminated between 60–80 msec. Wave III (occipito-parietal wave), surface negative, most commonly attained its peak amplitude between 80–120 msec. Waves IV, surface positive, and V (vertex sharp wave), surface negative, fell within the 90–120 and 120–170 msec. ranges respectively. Waves I and II were usually of greater amplitude over the parietal region while wave III was higher over the occipital area. Waves IV and V were maximal over the central region.

No relationships emerged between either the amplitude of the occipito-parietal wave or the vertex sharp wave and eye color, color blindness, type of refractive error, pupil size, subjective estimate of light intensity, hours of sleep, alpha frequency, alpha amplitude, and an alpha persistence index. Low order correlations were found between the amplitude of the occipito-parietal wave and latency of parietal wave II and age. Retinal, periorbital myoclonic, ocular rotational, and cervical myo-

clonic responses were discussed as possible sources of distortion of cerebral responses.

Acknowledgements

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