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Translation

EVOKED POTENTIALS IN PSYCHOLOGY AND PSYCHOPHYSIOLOGY

By

E.M. Rutman

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EVOKED POTENTIALS IN PSYCHOLOGY AND PSYCHOPHYSIOLOGY

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CONTENTS

General Problems of the Method

Morphology and Neurogenesis of EP's to Stimuli of Different Modalities

Use of EP's in Psychology and Psychophysiology

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ANNOTATION

This book generalizes basic knowledge on the method of reporting evoked potentials (EP) from the human scalp, accumulated in the 30 years of its existence. The greatest emphasis is placed on the basic results of research employing EP in psychology and psychophysiology in the last 5-10 years. The difficulties, limitations, and possible future uses of the method are examined. Much attention is devoted to current methods for analyzing recorded EP, and to the neurogenesis and functional meaning of individual components. Basic information is given on the morphology of EP to widely employed stimuli.

This publication is intended for psychologists and psychophysiologists, and it will also be of interest to neurophysiologists, psychologists, and neurologists.

Six tables, 21 figures, 642 bibliographic references.

FOREWORD

The recording of evoked potentials (EP) from the human scalp has opened a new, irreplaceable "window into the brain." The method, which was first used in 1947, came into broad use in the 1960's, and it is still developing swiftly today. On one hand it is being used to solve an ever-increasing range of problems in the most diverse areas of psychology and psychophysiology, while on the other hand research on the nature of EP's and on their relationship to cerebral structures and functions is continuing. Concurrently the methods for recording, processing, and analyzing EP's are being improved, and new methods are arising. The literature illuminating all of these directions has become unfathomable. And yet a researcher who wishes to employ this method or determine the suitability of its application to concrete problems must have the possibility for quickly and, at the same time, sufficiently fully acquaint himself with today's ideas about the nature of EP's, with the existing methods for processing and analyzing them, and with the basic results. The objective of this monograph is to afford such a possibility.

The book consists of three parts. The first examines the method's general problems, with considerable attention being devoted to complex and not entirely clear ones (neurogenesis, variability, assessment methods, and so on). It briefly presents the history of the development and supersession of ideas about the neurogenesis of EP components with the objective of emphasizing the importance of maintaining a critical attitude toward published data and caution when interpreting one's own results, and the necessity for psychologists and psychophysiologists to constantly be within the mainstream of current neurophysiological research on the nature of EP's, and to maintain an awareness of present ideas concerning the relationship between oscillations recorded from the scalp and the activity of brain structures. A significant fraction of this part is devoted to current methods of analyzing and mathematically processing EP's, multidimensional analysis in particular, which is recently enjoying increasingly greater use.

The second part contains basic information on the morphology and neurogenesis of modally specific components of EP's in response to auditory, visual, and somatosensory stimuli. It provides normative data on the morphology of EP's arising in response to the basic forms of stimuli used in experimental research, and it examines changes occurring in EP's in connection with modally nonspecific characteristics of stimulation, such as stimulus probability and the duration of interstimulus intervals.

The third part provides a brief review of a number of research directions in psychology and psychophysiology making use of EP, and it examines the basic achievements, the possible causes of failures, and the prospects of subsequent research.

Because several monographs fully or partially devoted to the EP method and its use in a number of areas have been published (5,23,30,76), a number of problems that are illuminated sufficiently well in these books are not treated here, thus making fuller examination of others possible. As a consequence the depth to which the material is covered is to a certain extent nonuniform, but as a whole the presentation appeared suitable and justified.

The author expresses deep gratefulness to I. V. Rabich-Shcherbo for his help and his friendly participation in the work on this book.

GENERAL PROBLEMS OF THE METHOD

CHAPTER I

THE METHOD FOR RECORDING AVERAGED EP'S FROM THE SCALP

Determination of EP's. Sensory EP's, Motor Potential, the E-Wave

The term "evoked potential" is applied in neurophysiology to potential oscillations in any division of the nervous system, arising in response to an external influence and existing in a relatively strict temporal relationship with it. EP's are recorded from the human scalp by ordinary electrodes and amplifiers used to obtain electroencephalograms (EEG)--recordings of brain bioelectric activity taken from the scalp (36,76). Potential oscillations--manifestations of so-called spontaneous, or background, brain bioelectric activity--are known to be constantly present on the human scalp apart from any sort of external stimuli. Thus EP's arise on the background of spontaneous oscillations. Therefore an EEG reflects concurrently both potential oscillations elicited by an external stimulus and spontaneous (or background) manifestations of bioelectric activity. Inasmuch as the amplitude of responses to external stimuli is lower as a rule than the amplitude of the oscillations of background bioelectric activity, single responses to a stimulus are usually indistinguishable on the background of the latter.

Registration of EP's became possible owing to the use of various techniques for isolating a signal from noise. Evoked activity is interpreted in the first approximation as oscillations "suspended" in spontaneous activity (368), though in fact a rather complex relationship does exist between the EEG and EP's. The technique for isolating EP's from the general pattern of bioelectric activity is based on the premise that repetition of a stimulus elicits repetition of a similar response, while spontaneous background activity is random. Therefore summation of a sufficient number of EEG segments covering the moment of stimulus presentation should result in isolation of the response to the stimulus, no matter how small it is in comparison with the background (random) activity (Figure 1). In light of the above, EP's recorded from the human scalp can be defined as the sum of individual responses evoked by repeated stimuli, where each response taken separately is not necessarily distinguishable (368).

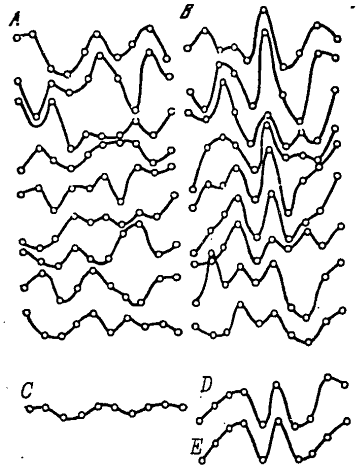

Figure 1. EEG Averaging, With an Artificial Signal Mixed With Artificial Noise as the Example: The background EEG (*A*) is synthesized out of a sequence of 90 random numbers from 0 to 10, which were used to create nine 1-second EEG segments. Segments representing a background EEG coupled with a response to a light flash (*B*) are created by the addition of an artificial EP (*E*) with an average of 0 and a standard deviation of 10 to each EEG segment. Averaging (*C*,*D*) is achieved by summing the values of all curves at particular points in time, followed by division of the sum by the number of curves (116).

The term "evoked potentials" is also used to describe potentials that are not responses to external stimuli. Chronologically, techniques for isolating a signal from noise were first used to record responses of a nerve to electric stimulation, and later to record responses of the brain to external stimuli; in both cases potentials evoked by external stimuli were involved. Meanwhile the possibility for employing the technique for isolating a signal from noise to extract information from the human EEG was found to be much broader.

In fact, it became possible to use these techniques to isolate, from EEG's, changes in potential that are rather rigidly associated in time with some fixed event. The latter could include a person's response, or some sort of fluctuations in his autonomic functions, and not necessarily the action of a sensory stimulus. In particular, scientists were able to record oscillations associated with the activity of the motor zone of the cortex. (a motor potential) and with a particular state which can be described as intention, anticipation, or readiness (the E-wave). These oscillations are recorded on the basis of the same principle of isolating a signal from noise that is applied to responses to sensory stimuli. The only difference in the case of a motor EP is that we sum the EEG segments not after the stimulus, but rather before the motor response, the moment of which can be determined from a myogram or from a resulting movement. The moment a pushbutton is pressed (or an EMG response) serves as the point of reckoning in the same way that the moment of stimulus delivery is used in relation to sensory EP's (reverse averaging). Thus a number of authors (242,306; Vaughan, et al., 1968; Deeke, 1969) have recorded a certain sequence of oscillations before initiation of movement, some of which are most highly pronounced above the motor zone of the cortex corresponding to the projection of the group of muscles responsible for the movement.

An E-wave was revealed with the recording (by means of a constant current amplifier) of slow oscillations arising in the period between a preparatory stimulus and a triggering stimulus in a situation calling for motor reactions occurring over constant intervals. A negative potential deviation that arises regularly in response to a preparatory signal and grows at a varying rate depending on the length of the interval between the preparatory and triggering signals was recorded (518). In this case the external signal is used as a time "marker" associating development of the process at the basis of the E-wave (or reflected within it) with a certain moment in time. (which is necessary for summation). The accumulated data on the E-wave implied an association between it and states that can be described as intention, readiness, anticipation, and attention (492).

Potential oscillations arising at the moment an expected stimulus is missed have also been recorded. Weinberg et al. (525) suggested the term "emitted events" or "emitted (generated) potentials" to designate such oscillations, since they arise not in response to an external stimulus but rather in connection with anticipation of a stimulus or a reaction. Vaughan (1969) suggested the term "event-related potentials" to designate any bioelectric responses recorded with the help of techniques for isolating a signal from noise. These terms have not as yet established themselves in the literature, and motor potentials and other bioelectric oscillations not associated directly with an external stimulus are often interpreted as variants of the EP.

This book will examine only sensory and associative EP's--that is, bioelectric oscillations arising in the human brain in response to stimulation of afferent sensory systems and associated with reception and processing of sensory information contained within the stimulus.* As a rule when we refer to the

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* This book does not examine so-called steady state potentials, described in detail in Regan's book (394), and stable auditory potentials (Picton et al., 1978).

recording of EP's from the scalp, we imply responses obtained by one of the techniques for isolating a signal from noise, and not singular responses. For the sake of brevity we will use the term "evoked potential"--EP--irrespective of precisely what technique for isolating a signal from noise was used to obtain it, if the situation does not call for any special remarks. In cases where we will be dealing with "raw" EEG recordings made following a stimulus, we will refer to singular EP's. (The situation is generally somewhat paradoxical, since a single EEG recording made following a stimulus does not in a sense contain a "pure" response to the stimulus--that is, an EP; instead, it represents the sum of the response and background activity.) As a rule, recent works deal with EP's obtained as a result of summation, or of summation and averaging. The differences will become clear later on, and as a rule they are inconsequential in relation to analyzing and interpreting the results.

The Method of Summation and Averaging

The summation and averaging method is used to isolate a signal--an event strictly associated in time with a stimulus, from noise--events not having a strict temporal relationship to the stimulus (this division of EEG "events" into signal and noise does not necessarily correspond to their "signaling" significance to the work of the brain). The averaging principle was employed for signal isolation back in the last century by Laplace, while Dawson (179) was the first to use it to register responses in the nervous system. Application of the averaging method to EP's is based on a number of assumptions that are not in fact entirely valid. A certain degree of inadequacy of the averaging assumptions manifests itself in the discrepancy between the real averaging results and the theoretically expected results, but it is not so great as to make the averaging method unacceptable.

According to the axioms of averaging, a response to a stimulus, S, is interpreted as a constant with zero variability. Noise (that is, a spontaneous EEG) is interpreted as a random stationary uncorrelated process described by the value of its average, n, which, given a sufficient number of trials, tends toward zero: $E(n) = 0$, and by its variance, σ^2.

Let us examine how a signal is isolated from noise by means of summation and averaging under the conditions described above. Assume we have a set of N EEG segments after a stimulus $f(i)$. What would be the arithmetic mean of the sum of these segments $f(i)$? In keeping with the premises presented above,

$$\bar{f}_i = \frac{1}{N}\sum_{k=1}^{N} f_{ik} = \frac{1}{N}\sum_{p=1}^{N} (S_{ik} + n_{ik}),$$

where S is signal intensity and n is noise intensity. Hence

$$\bar{f}_i = \frac{1}{N}\sum_{k=1}^{N} S_{ik} + \frac{1}{N}\sum_{p=1}^{N} n_{ik} = \bar{S}_i + \bar{n}_i,$$

and inasmuch as $\bar{S}_i = S_i$, then $\bar{f}_i = S_i + \bar{n}_i$ (in view of an axiom of averaging--the constancy of the response to the stimulus and the additive nature of signal and noise). The mathematical expectation of the average of the sum of EEG segments may be expressed as

$$E(\bar{f}_i) = S_i + E(\bar{n}_i) = S_i + E(n).$$

Inasmuch as the mean of the noise is zero, $E(f_i) = S_i$. This means that when we approach the limit, given a sufficiently large N, summation should produce a signal without noise artefacts in the averaged EP for any real n. Inasmuch as the mean of the noise is presumed to be zero, the share of noise artefacts depends on its variance:

$$\sigma^2(\bar{f}_i) = \left|\frac{1}{N^2}\sum_{k=1}^{N}\sum_{p=1}^{N} E(f_{ik}f_{ip})\right| - E^2(\bar{f}_i) =$$
$$= \frac{1}{N^2}\sum_{k=1}^{N}\sum_{p=1}^{N}\{E(S_{ik}S_{ip}) + E(n_{ik}n_{ip})\} - S_i^2.$$

Since we assume that noise segments $n(t)$ do not correlate with one another, when $k \neq p$, $E(n_{ik}n_{ip}) = 0$, and so

$$\sigma^2(\bar{f}_i) = S_i^2 + \frac{1}{N}E(n_i^2) - S_i^2 = \frac{1}{N}\sigma^2(n_i) = \frac{1}{N}\sigma^2(n).$$

This means that when we average N EEG segments following a stimulus, the expected mean of the amplitude at each moment in time would be equal to the amplitude of the reaction to the stimulus (signal), and that the variance would be $1/N\sigma^2(n)$. In other words while the mathematical expectation of the mean of the signal, S_i, is the same both for a singular EEG recording following the stimulus and for the sum of N EEG segments, averaging causes the mathematical expectation of the variance to decline in proportion to the number of singular reactions averaged. Inasmuch as the mean of the noise is zero, the ratio of signal to noise, S/n, can be defined as the ratio of the signal's mathematical expectation to the mathematical expectation of the variance of noise. Then if for a singular recording $S/n = S_i/\sigma(n)$, for an averaged EP derived from N EEG segments, $S/n = S_i/\sqrt{N}\sigma(n)$. The latter formula shows that the signal/noise ratio increases as $\sqrt{N}$ in response to averaging.

However, this entire line of reasoning would be fully valid only on the condition that all axioms upon which the averaging method is based are valid. But this is not the case. In particular, the premise that there is absolutely no correlation exhibited in noise is wrong, for which reason averaging would lead to a lesser increase in the signal/noise ratio than shown above. Were we to interpret the EEG as noise with a Gaussian distribution filtered within a particular frequency band (the extreme variant of this would be a narrow frequency band within the alpha-rhythm zone), then an increase in the signal/noise ratio proportionate to $\sqrt{N}$ would be possible only at the limit, and for practical purposes this increase will always be smaller. Possible influence of noise correlation upon the EP, the influence of the alpha-rhythm in particular, was specially studied in a number of works. Ruchkin (416) used a mathematical model to examine interaction between a signal and noise having the characteristics of an alpha-rhythm, and he came to the conclusion that aperiodic stimulation could reduce noise correlation in EEG segments being averaged. A mathematical model has also been used to analyze the variance of an EP as a function of N in cases where steady noise is superimposed over the reaction (265). It has been demonstrated that introduction of aperiodicity into stimulation changes the function describing the relationship between variance and N in the same way that replacement of noise in a narrow frequency band by noise with a very broad frequency spectrum does; in this case the variance becomes proportional to $1/N$. However, on examining a real EP recording situation, the authors concluded that the natural irregularity of the alpha-rhythm is sufficient to make the difficulties associated with delivering aperiodic stimulation outweigh its merits. Only in some cases, when special stimulation conditions promote an increase in the correlation of noise segments--for example when the signal is delivered at a particular moment within the alpha-rhythm, can introduction of aperiodicity into the signal be found to be suitable.

Nor is the notion of the additive nature of signal and noise entirely valid either: A stimulus alters a spontaneous EEG (148). Another idea at the basis of the averaging technique--that a stable relationship exists between signal and noise--is also contrary to fact (121,394). This is especially significant in cases where singular trials to be subjected to the averaging technique are recorded over such a long period of time that tiring, sleepiness, sleep, and other similar phenomena develop--that is, when the subject's state changes so much that both the spontaneous EEG and the responses to the stimulus change.

Incidentally the idea of reaction constancy, also at the basis of the averaging technique, is apparently not entirely correct in principle (see Chapter VI). For practical purposes averaged EP's always contain significant noise artefacts, and change in the signal/noise ratio does not always change strictly in proportion to $\sqrt{N}$. Empirical research on this problem has produced highly variable results. For example Perry and Childers (368) present a figure in their book which shows linear increase in the amplitude of a visual EP with growth in N from 120 to 960 in the presence of rhythmical stimulation at a frequency of four flashes per second. Recording auditory

EP's, Milner (344) found the amplitude of the EP's to increase in proportion to N only at frequencies not greater than 1 stimulus in every 7.5 seconds; beginning at a frequency of 1 stimulus every 3 seconds, further growth in stimulation frequency caused an increasing change in this dependence, and at a frequency of 2 stimuli per second the EP amplitude increased in proportion to $\sqrt{N}$..

The question arises as to what is the least number of summed EP's that would be needed for the averaging technique. A researcher trying to find an answer to this question perpetually finds himself between Scyla and Charybdis: An increase in the number of signal deliveries necessary to reduce the proportion of noise in the recorded EP is inevitably associated with an undesirable increase in experiment duration. EP characteristics change depending on the state of the subject, and under otherwise equal conditions the probability of this change grows as the research time lengthens. In this connection when we attempt to correct for variability of EP's associated with too small a number of summed responses (that is, a large proportion of noise), from a certain moment on we witness a concurrent increase in EP variance due to fluctuations in the subject's state. Perry and Childers (368) write in their visual EP analysis handbook that in most cases summation of 50-100 reactions would be enough to obtain stable averaged EP's. Ellingson et al. (209), who studied variability of visual EP's in adults and children, note that the variability and form of EP's derived from summation of 32 responses differ little from the same EP characteristics when 50, 60, and 100 responses are summed. At the same time there are indications that 500 responses must be summed to register early components of EP's to light flashes (359).

In principle, the number of stimulus repetitions necessary to acquire a sufficiently distinct EP depends on the ratio of the oscillation amplitude of the potential evoked by a single stimulus delivery to the oscillation amplitude of background activity (in other words on the signal/noise ratio). Inasmuch as an EP consists as a rule of several oscillations of different amplitudes, the minimum number of stimulus deliveries required for isolation of an EP depends on the particular component in which the researcher is interested: The greater the amplitude of the component under analysis, the fewer stimulus deliveries he could get by with to register an EP. Here are some simple computations. For example, when 100 responses are summed, according to the formula $S/n = S_i/\sqrt{N}\sigma(n)$ the signal/noise ratio should increase by a factor of 10. In reality this number would be smaller. On this basis, knowing the approximate amplitude of the components that have to be registered and the amplitude (variability) of background activity, we can approximate the needed number of summations.

Inasmuch as the mean of the noise amplitude does not reach zero for practical purposes, and since it depends on a number of conditions (for example whether the eyes are open or closed, the difficulty of the assignment, and so on), Perry and Childers (358) recommend always recording, in parallel with the EP and as a control, the same average number of EEG segments in the absence of the stimulus. This makes it possible to obtain what could be called the real mean of the noise in the given conditions (technically speaking, such registration is extremely simple--summation and averaging are performed in precisely the same way as with stimulus delivery, except that the stimulus itself is not presented.) Figure 2 shows an example of such a recording.

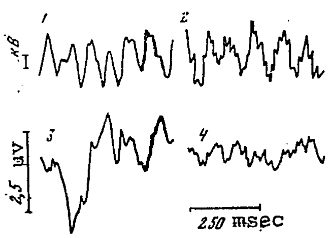

Figure 2. Isolation of a Visual EP (Signal) From an EEG (Noise):
1--EEG together with an EP to a singular stimulus;
2--background EEG (stimulus is not presented);
3--summed visual EP to 150 stimulus presentations;
4--control (summation of 100 EEG segments in the absence of a stimulus) (368)

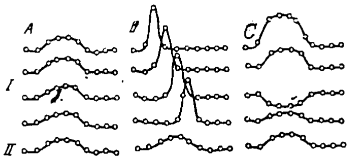

Figure 3. Demonstration of the Possibility for Obtaining Identical Averaged EP's By Summing Different Singular Responses: *A*--Constant reactions; *B*--variable latent times; *C*--variable amplitudes; I--singular EEG reaction, II--averaged EEG reactions (116)

What can be treated as the criterion for presence of a signal (a response to a stimulus) in a comparison of such recordings? Perry and Childers (368) believe that the main criterion of signal presence is a signal-to-noise ratio not less than 2. It can be easily determined by visual comparison of EP's and a corresponding control recording. It would not for practical purposes be difficult to obtain a ratio of 4:1 and more by increasing the number of summations or the intensity of the stimulus, or by changing background activity, as well as with the help of frequency filters.

To answer the question as to the minimum necessary number of stimulus deliveries, the researcher usually relies upon visual analysis of recorded EP's, attempting to obtain EP's of distinctive shape that are sufficiently stable with repeated registration. Understandably the same number of summations may be fully sufficient to isolate some components and entirely inadequate in relation to others of lower amplitude (see Figure 9 below).

The *S/n* ratio is a good sign of signal isolation itself, but it says nothing about the degree of correctness, precision. As Regan notes (394), it is enticing but dangerous to interpret the shape of a wave, obtained by averaging, necessarily as the result of summation of *N* identical evoked potentials in response to singular stimuli (Figure 3).

It is clear from the above that given the availability of a set of EEG amplitude values following stimulus deliveries (for example, having a tape-recorded EEG and an analog-digital converter), we could perform the averaging operation with any sort of computer. EP registration based on the cross-correlation method may be more convenient to some tasks (227). Easier methods of EP registration can also be employed: algebraic summation of responses on magnetic tape, accumulation of responses on photographic film, and the method developed in the 1960's by Ertl et al. (see 23,394; Shagass 1974).

Though not broadly accepted yet, selective averaging is very promising (372). It essentially entails the averaging of not all singular responses to stimuli, but only those which satisfy certain requirements (a previously established "template"). Selective averaging opens some fundamentally new perspectives in the use of EP's. As an example after selectively averaging EP's having a certain component with particular characteristics, we could see what sort of correlations are revealed with the characteristics of other components. These correlations might not be revealed with nonselective averaging.

CHAPTER II

MONOPOLAR AND BIPOLAR EP RECORDING TECHNIQUES

Division of recording techniques into monopolar and bipolar is highly conditional, inasmuch as the so-called indifferent contact points are in fact active, and not neutral, as is theoretically presumed in monopolar registration. Nevertheless it can be assumed as an approximation that monopolar recording provides an impression of absolute changes in potentials in the vicinity of the active electrode, while bipolar recording provides information on changes occurring in the difference between the potentials at the two points being studied. Bipolar registration may reveal more-local and smaller changes in potential than monopolar registration. At the same time the absolute value of the potential obtained with bipolar registration is often lower than that obtained with monopolar registration, which means that a larger number of responses must be summed. Another advantage of monopolar registration is greater intra- and interindividual stability than with bipolar recording (166). It is probably in part a product of the fact that significant changes in EP's accompanying slight changes in electrode position are more typical of bipolar recording (especially in relation to early components). According to Benett et al. (98) movement of an electrode 3 cm upward, to the right, or to the left of the occipital protuberance did not cause significant changes in an EP to light, recorded monopolarly.

On the whole, the two techniques should be thought of as supplementary, and not competitive, since, judging from experiments in which they were used together, bipolar recording is found to be more informative in some cases (359,393), while monopolar recording is found to be more informative in others (404).

It would be pertinent to cite two studies as a precaution against mistaken interpretations. In the first (512), it was discovered that the amplitude of bipolarly recorded EP's to visual structures presented in half of the visual field is greater in the right temporal region than in the left, irrespective of the side stimulated. The authors assessed their results as evidence of a special role played by the right hemisphere in perception of spatial information. An investigation of monopolarly recorded EP's to the same stimuli (Shagass et al., 1976) did not reveal interhemispheric differences in amplitude. An analysis of the distribution of the amplitudes of components recorded from different points on the scalp revealed a larger gradient in the right hemisphere, which is what was responsible for the greater amplitude observed by Vella et al. with bypolar recording.

The practical criterion used to select the point for the indifferent electrode is absence of stable EP's at this point, when recorded "bipolarly" using a series of other points, also tentatively indifferent. Usually the indifferent electrode is placed on the earlobe, in which case it is recommended that it be located on the side opposite that of the active electrode (245,321). At the same time there are data showing that the ear electrode is not indifferent. When EP's are recorded with an ear electrode paired with another electrode presumed to be indifferent (usually noncephalic), some subjects exhibit regular changes in potential in response to a light flash (260,314) and stimuli of other modalities (463). In addition to the earlobe and the mastoid process, the nose or the bridge of the nose is used as the location of the indifferent electrode (Allison et al., 1962), which according to Stowell (1972) is inappropriate in the case of somatosensory EP's.

Noncephalic location of the indifferent electrode is also employed. A so-called thoracic indifferent electrode is used to record EEG's.(470). It was concluded from a special study that a thoracic electrode is preferable to an ear electrode only for the recording of visual EP's; it does not have advantages over an ear electrode in the two other modalities (314).

Comparing different locations of the indifferent electrode (earlobe, neck, nose, back, and so on), Broughton (112) concluded that it is best to place the indifferent electrode on the earlobe, though activity of intracerebral origin and myogenic potentials may doubtlessly be recorded in this area following light and sound stimuli.

Considering the above, it would apparently be suitable to use the ear electrode to record auditory and somatosensory EP's, and a thoracic electrode for visual EP's. Incidentally we cannot fail to note that a tremendous quantity of doubtlessly valuable results have been obtained with the indifferent electrodes in the vicinity of the earlobe or the mastoid process, and that the location of the indifferent electrode apparently becomes significant only when it comes down to determining the source of the registered oscillation (see Chapter VII) (303).

A standard system for locating "active" electrodes to record EP's similar to the international 10/20 system does not exist: All we can do is mention the locations used most often in relation to each modality. Standardization will probably come along in the future (at least in relation to some particular set of objectives and situations). (Let us recall that prior to creation of the international 10/20 system, electrodes used to record EEG's were also arranged differently by different laboratories).

The choice of electrode location depends first of all on the components in which the researcher is mostly interested and on the sort of stimuli employed. Early EP components (in the first 60-100 msec) are expressed predominantly in the cortical projection zone corresponding to the stimulus modality. Auditory EP's, the early components of which are expressed no worse and, according to some data, even better in the parietal area than in the temporal area, are an exception. Late EP components (occurring after 100 msec and more) are registered sufficiently clearly over the entire scalp. Thus when early components are to be studied, placing the electrodes in the cortical projection zones corresponding to the modality of the stimuli employed is usually recommended (321).

The points on the scalp at which electrodes are located for optimum registration of different components differ slightly in concrete studies.

Shagass' recommendation of placing the electrode at the point where the component under analysis exhibits its greatest amplitude may be used as the most general rule (this is the most widespread technique for locating the electrode) (76). It should be recalled, however, that components of similar form and latency in different divisions of the brain may have different origins, and therefore the registration point at which the greatest amplitude is recorded within the given time period may not always be the point at which the component under analysis is expressed best (if we define this component as a potential oscillation having a hypothetically known source). In addition to the 10/20 system (276), an atlas (184) and a method developed by Remond (397) can be used to determine electrode locations.

There are no unambiguous, universal recommendations for the choice of both bi- or monopolar registration and electrode location, nor can there be such recommendations. It is important to remember that in a number of cases the electrode locations and the recording technique may turn out to be the decisive factor, and changes that are not revealed at all or are poorly revealed by one recording technique may manifest themselves distinctly with the other. When a researcher is unable to conduct preliminary studies to resolve these questions in relation to the basic objectives of his own work, Perry and Childers (368) advise using those points of contact that have been employed in other studies performed in the given area. This would at least make is easier to compare the results. Of course this does carry the danger of limiting oneself to an acceptable but in no way necessarily the best technique.

Some data and recommendations, "retrieved" from concrete studies, on locating active electrodes in correspondence with stimulation modality are presented below.

Judging from the works of Benett et al. (98) small differences in the location of the active electrode are inconsequential in relation to monopolar recording of EP's to light flashes. They recorded EP's to light flashes at four points: Over the occipital protuberance, 3 cm above it, and to the right and left of it. An analysis of results based on a group of 50 persons revealed very slight differences associated with electrode position. Different data exist as well. Perry and Childers (368) studied visual EP changes connected with amblyopia (disturbance of visual acuity without apparent structural disorders in the visual system). When EP's were recorded from only one point in the occipital region, EP changes correlating with clinical manifestations of visual disturbances were revealed in 20-50 percent of the subjects. Then when EP's were recorded from four points in the occipital region instead of one, EP changes were detected in all amblyopia cases. The fact that visual EP's that are usually very similar within the limits of the occipital region may change in different ways in the presence of amblyopia affords the grounds for attempts at seeking EP changes by similar techniques in psychophysiological and psychophysical research. Changes in electrode position are more significant with bipolar than with monopolar registration.

With bipolar recording, the greatest amplitude of early components, P74 in particular, is noted not in the occipital but in the parietal region, and even somewhat forward of it, while when the electrode is moved to the occipital protuberance the amplitude drops to zero (153,352).

Giblin (243) recorded reactions of greatest amplitude to electrocutaneous stimulation of the wrist at a point on the head located on a line running between the external auditory meatus and a point 2 cm forward of the vertex, 7 cm from the mediosagittal line. He suggests that this point on the scalp is located above the projection zone of the hand in the postcentral gyrus. This agrees with the recommendation given by Broughton (112), who believes that the points C_3 and C_4 of the international 10/20 system (276) are located above Rolando's fissure near a region which, when directly stimulated, produces an irritant sensation in the innervation reaction of the median nerve of the contralateral hand. Correspondingly, points intermediate between C_z and C_3 and between C_3 and T are above the projection zones of the face and lower limbs. (Electrode application points determined on the basis of the 10/20 system of points are more reliable because they account for individual head dimensions.)

Published data on the greatest expressiveness of reactions to tactile stimulation are close to data cited for electrostimulation. Thus with monopolar recording, maximum early reactions to tactile stimulation of the hand are observed in a small area 17.5-19 cm in back of the nose and 7.5-9 cm to the side of the midline, in the direction contralateral to the stimulated side (226). When electrodes are located in any direction beyond the limits of this area, the amplitude of early responses drops significantly. For some reason bipolar registration of EP's is used more often than monopolar registration in relation to tactile stimulation. A special study by Nakanishi et al. (354) showed that reactions to tactile stimulation are best expressed with bipolar recording in most subjects when one electrode is located on line C corresponding to the projection zone of the stimulated area, and the second is located at a point midway between the first point and the F point with the corresponding number. As an example when EP's to stimulation of a finger of the right hand are to be recorded, the electrodes are placed at points C_4 and C_4-F_4. The crown is usually recommended and used to record auditory EP's; the temporal region is used more rarely, though if we consider data indicating that the temporal component of an auditory EP reveals itself when the temporal region is used (539), it would be desirable to record auditory EP's in the temporal region as well.

CHAPTER III

DESCRIPTION OF AN EP

An EP recorded in graphic form is a complex curve, the nature of which depends on the modality and intensity of the stimulus, the recording technique and the conditions, the state of the individual, and other such factors. Figure 4 shows EP's to visual stimuli recorded at different points on the scalp of the same person. Individual oscillations, referred to as components in the previous discussion, are commonly isolated from the complex EP curves. As a rule the components are isolated "by eye"--different authors isolate different numbers of oscillations as individual components. Oscillations that are sufficiently persistent in repeated EP recordings and which express themselves most distinctly in most people are usually isolated. Each component may be described by its latent period (from the moment of stimulus delivery to the moment of peak amplitude), its polarity, and its amplitude. After this the entire EP may be described as the succession of components contained within it. However, inasmuch as the latent periods and amplitude of components vary depending on the recording conditions, it has become the practice of designating the components by letters or numbers. Different authors have used different systems to designate components (Figure 5).

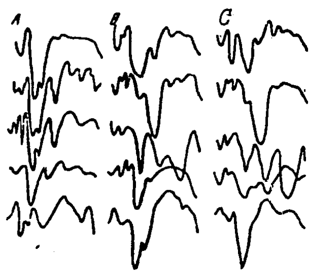

Figure 4. Averaged Visual EP's in the Visual (*A*) and Somatosensory (*B*) Regions and in the Vicinity of the Crown (*C*) of Five Subjects: Analysis interval--500 msec. Positivity--downward (238)

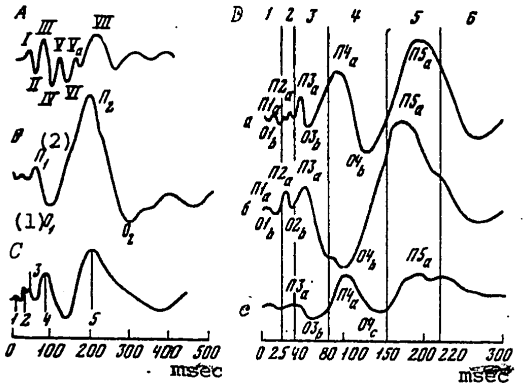

Figure 5. Examples of Different Designations of EP Components: *A*--visual EP, bipclar registration (144); *B*--auditory EP, monopolar registration (174); *C*--somatosensory EP (Goff et al., 1962); *D*--for any modality (245): *a*--somatosensory EP (P_3); *b*--auditory EP (C_2); *c*--visual EP (N 2). The 300 msec interval following the stimulus is divided into six parts numbered in order from the moment of stimulus delivery. Each component is designated by a capital letter corresponding to its polarity, a number corresponding to the interval, and a lower case letter indicating its serial position among other components of "its" temporal interval. For practical purposes this system has not established itself in the literature.

Key: 1. N 2. P

The inconvenience of such description techniques revealed itself very quickly. Implicit in any system of component designation is the supposition that every component reflects the activity of certain brain structures or systems, and it was precisely this supposed "origin" of the component that was "labeled" by a letter or number, relatively independently of variations in characteristics such as latent time and amplitude. Comparing his results with those obtained earlier, every researcher attempted to designate the components of the EP he recorded in accordance with some previously suggested designation system (if he did not suggest his own). But real characteristics necessary and sufficient for identification of the components were unavailable, labeling was done arbitrarily to some extent, and this sometimes became a source of errors.

A typical example of errors of this sort can be found in the scheme for describing visual EP's suggested by Ciganek (144) (Figure 5*A*). The author isolated a number of components in an EP to a light flash, he designated them by numbers, and he tentatively associated them with particular structures or systems (in subsequent years these associations were changed rather significantly). Ciganek's description was one of the earliest descriptions of an EP, and as a consequence many researchers established an association with it, in a manner resembling "imprinting": They tended to designate monopolarly registered EP's in accordance with Ciganek's scheme, which was created for EP's registered bipolarly.

It is difficult to understand how such a designation system could be suitable, inasmuch as when we are dealing with simultaneously occurring potential oscillations of similar shape recorded bipolarly and monopolarly, we have no assurance at all that they reflect the activity of the same systems. It would not be difficult to show that different authors compare knowingly different components of monopolarly registered EP's with the same components of Ciganek's scheme. As an example Nakamura and Biersdorf (1972) recorded an EP in response to illumination of the visual field by red light consisting of components N54, P74, N96, P114, and N146. They identified oscillations N54, P74, and N96 as oscillations 2, 3, and 4 in Ciganek's scheme. At the same time Fil'chikova (70), for example, who recorded an EP monopolarly, designated, as Ciganek's components 3 and 4, oscillations N80-100 and P110-240--that is, oscillations of opposite polarity in comparison with "identically named" components in the work of Nakamura and Biersdorf. This example illustrates the unsuitability of using Ciganek's classification to label components at least in terms of monopolar EP's. Another significant source of errors may be identification of components in accordance with their serial numbers. In this case if early components of a small number of responses to be summed or of responses having low intensity are not recorded (which is highly probable), subsequent components would be interpreted as early ones with longer latent times, and the designations of all the components would be displaced.

Examples of such errors have already been examined in the literature. For example Zenkov et al. (1974), who recorded visual EP's from patients suffering visual tract lesions and normal individuals, describe a decrease or disappearance of early components and a shortening of the latent times of subsequent components beginning with oscillation P44 in patients. Comparing their results with others indicating elongation of latent times in the presence of visual tract lesions, the authors concluded that early components were identified in the former incorrectly: Later components were assumed to be early ones with a longer latent time, but in fact the early components were absent.

In this case it would be difficult to resolve the issue with complete certainty, but we can examine a more persuasive example cited by Prescott (386). Using data cited by Ertl et al., he demonstrated how incorrect identification of components led to the conclusion that the latent times of components in EP's recorded from persons with a high IQ are shorter than those of persons with a low IQ. The only basis used to identify a component was its serial number--that is its place in line in the given EP. In this case a component arising in one of the subjects at a moment about 80 msec following the stimulus is interpreted as being identical to a component with a latent time of about 225 msec in other subjects. However, were we to turn to normative data, for example that of Beck and Dustman (97), for similar stimulation conditions, we would see that the third component of an EP to a light flash has a latent time of 68.1 msec with a standard deviation of 13.5 msec, while the seventh oscillation has a latent time of 236 msec and a standard deviation of 28.3 msec.

It is entirely obvious that we cannot assume (without any special proof) that oscillations with latent times of 80 and 225 msec, recorded from different persons, are the same component.

Mistaken identification leads to incorrect interpretations and conclusions, which upon superficial analysis of a study could easily generate many false impressions. As an example differences in EP's in response to presentation of visual structures were revealed in Gorev's interesting work (15) depending on whether or not the subject was able to recognize the structure presented to him. The EP recorded in response to presentation of the visual structures consisted of the following sequence of oscillations: N130-170, P210-240, N240-300, N330-390, N400-520. The author identifies them correspondingly as oscillations III, IV, V, VI, and VII in Ciganek's scheme. Analyzing the obtained results, he compared his data describing changes in the N240-300 component with published data on changes experienced by Ciganek's component V, and he considered the latter in his interpretation of the results. However, Ciganek's oscillation V has a latent time of less than 200 msec, which is not close to even the minimum latent time of N240-300.

Obviously, until such time that we arrive at an efficient technique of component identification which would permit us to determine and designate, with sufficient certainty, components in accordance with their morphogenesis and (or) functional significance irrespective of the EP registration conditions, any description of an EP in which components are not described by their latent times, polarity, and amplitude would more likely serve as a source of error than as a means of economical description (57,245).

The recording conditions must also be indicated in an EP: electrode locations, stimulation characteristics, number of responses summed, and so on. All of these EP characteristics (latent time, polarity, and amplitude of the component in known recording conditions) must be "gleaned" from the literature to the extent possible, so as to permit comparison of the data irrespective of the description system employed. When describing EP's, it would be simplest of all to designate individual components by a letter indicating its polarity and a number expressing the latent time before the peak. As an example a positive oscillation with a latent time of 200 msec would be designated as P200, while a negative oscillation with a latent time of 250 msec would be designated N250. Of course it would be best to indicate not only the average but also the limiting values of the latent times, or the mean together with the standard deviation (for example P190-215, N240-253, or P200 ± 9.7).

Discussing component identification, we should note the following. The commonly accepted practice today is basically to interpret oscillations of similar shape and polarity, arising simultaneously or almost simultaneously on different points of the scalp, as a component of the same nature--that is, as a reflection of the same process, though the validity of this approach has never been proven and it is not intrinsically obvious. On the contrary we have data showing, for example, that P200 oscillations recorded in the occipital anterocentral region differ in nature, and that in certain conditions they behave differently (312,498). Similar hypotheses have been stated in relation to component P300 (464) and other components (Goida et al., 1975). In this connection I would like to emphasize that similarly appearing simultaneous oscillations recorded at different points on the scalp may be both a manifestation of the activity of one common source that is physically conducted to all points, and a reflection of the activity of different independent structures. Figuratively speaking, if at a certain moment after the doorbell is rung all of the windows of the house are illuminated by light of the same nature simultaneously, we cannot say whether this light is coming from a chandelier in the center of a large hall containing numerous windows, or that the light is from numerous lamps that were turned on simultaneously in different rooms, each having its own window and, finally, we are not sure whenther there is a master switch, or a special attendant in each room who turns on the light in reponse to the bell. It would also not be difficult to imagine the entire range of possible combinations of a general system of "ceiling" lighting and individual table lamps, and of large halls and small rooms, and the range of different floor plans and uses of the large house we are trying to learn about from changes in window illumination in response to different external influences.

CHAPTER IV

EP PROCESSING AND ANALYSIS TECHNIQUES

As Bitinas validly noted (8), the most important question for the researcher, and perhaps the one that causes him the greatest torment, is that of what to measure.

No matter what objective is pursued in research involving the use of EP's, as a rule, simple assertion of differences based on a visual assessment is not enough for attainment of the objective. The range and (or) nature of the differences must be indicated, and if the significance of the difference is to be evaluated, quantitative characteristics must be presented. There are two ways to do this. One is to select individual EP characteristics (intuitively or on the basis of some predetermined conditions), represent them quantitatively, and them use them in accordance with the rules of unidimensional statistical analysis. This is precisely what was done in the bulk of EP research in the initial period following the arisal of the averaging method. It gradually became clear that it would be suitable to seek a relationship between a set of external influences and a set of EP characteristics, and not between individual characteristics. The methods of multidimensional analysis afford a possibility for such explorations. They are what make up the second way, and they are being used now with increasingly greater frequency. Let us begin with an examination of the first way.

Techniques for Reducing Data for Subsequent Application of Unidimensional Statistical Analysis

Simple visual assessment of an EP (given in digital or graphic form) permits us to distinguish only identical and different EP's, and to indicate, in sufficiently simple cases, the range and magnitude of differences. However, differences arise to different extents in different EP's, subjective influences are unavoidable in their assessment and, finally, the possibility for visual comparison and assessment are limited by the modest number of EP's which a person can simultaneously perceive and assess. And yet because of the variability of EP's, every researcher tries to obtain as large a sample of EP's as possible. This is why tentative visual assessment of an EP must be followed as a rule by selection of characteristics permitting quantitative representation and subsequent analysis.

At the dawn of the method's development, the most widespread technique, if not the sole one, for quantitative representation of EP's was visual isolation of individual components and determination of their latent times and amplitude. This was precisely the technique used to reveal a number of dependencies between EP's and the characteristics of the experimental situation (intensity of the stimuli, their meaningfulness), the subject's state, and so on.

However, difficulties that were not always surmountable arose. One of the main ones was identifying the components (see Chapter III). Individual oscillations in a complex curve, described by the latent time of its peak and by its polarity, are singled out as EP components. Given significant changes in the shape of an EP, even one recorded from the same subject (for example when falling asleep), it is sometimes difficult to determine whether we are dealing with significant changes in the latent times of components of constant nature, or with disappearance of some components and appearance of others. Identification of components is even more difficult when we compare the EP's of different individuals. But comparison of changes in the EP's of a group of subjects is precisely what many problems need for their solution. Two approaches can be taken in this regard. One is visual (often intuitive) identification of the components of different EP's and subsequent assessment of their latent times and amplitudes. The other approach is to measure amplitude not at the time of a given component's peak, but rather at strictly defined times following stimulus delivery, irrespective of whether this moment occurred at the summit, in the valley, or in a transitional area of the component.

A shortcoming of the first technique is its unavoidable subjectivity and the errors possible in component identification. The second method is free of the subjective factors of component identification, and the moment of measurement is strictly fixed within it in relation to the entire population of EP's, but in this case phenomena of entirely different nature may be compared as identical changes. The problem is that the latent times of EP's recorded from different people vary, and thus different components may fall within the same "temporal cross section." Moreover the amplitude of components of different nature within a given "temporal cross section" may change in opposite directions within a given situation under study, as a result of which changes are not detected when a group assessment is made. It might perhaps make sense to some researchers to select groups of subjects with sufficiently similar EP's with components that can be identified with certainty. It also makes sense to use these techniques in combination with one another: first a visual analysis and isolation of the principal components in each EP of the population at hand, and then determination of total amplitudes within strictly defined temporal intervals corresponding to the most distinct and stable components, ones that are similar in the greater part of the EP's of the population under analysis.

As an example Adams and Benson (79), who found that all components were not clearly expressed in most of their subjects, defined the amplitude as the difference between the greatest negativity in the 100 ± 20 msec period and the greatest positivity in the 200 ± 20 and 300 ± 50 msec periods. Of course the success of such measurements depends on the correctness with which the temporal intervals are selected. Understandably the difficulties of component identification also reveal themselves at their fullest in an assessment of the latent times of EP components. It should be noted that the latent times of the components of the same person are a tremendously more stable indicator than is amplitude.

One broadly employed technique is to assess different EP indicators "on the whole" (this is in a certain sense a "broadside method"). As an example we can determine the sum of the amplitudes of all individual components irrespective of their shape, quantity, and so on, or we can determine the amplitude from the maximum positive oscillation to the maximum negative oscillation (the greatest spread of the EP), irrespective of when the maximum oscillation is observed following stimulus delivery. It should be considered, however, that when the conditions change, the maximum positive (or negative) oscillation of the EP may decrease in size, and then another oscillation (with another latent time) would become the maximum oscillation. Amplitude determined by the procedure described above would be interpreted as a manifestation of changes in the same indicator, even though what was previously measured was the amplitude between two other peaks. Thus this method can be used only to assess EP's with sufficiently stable latent times for the maximums of their positive and negative components.

After we identify the components or select the points in time at which the amplitudes are to be measured, we still must decide how to measure amplitude. Amplitude is measured either from peak to peak (from the peak of the preceding component to the peak of the required component), or from the so-called EEG base line, which is usually defined as the mean amplitude of the background EEG within a small time interval prior to stimulus delivery. This technique accounts for the polarity of amplitude changes. Each of these techniques has its merits and shortcomings. Measurement of amplitudes from a base line is suitable at least because simultaneously occurring opposite changes in a positive and a negative component may lead a researcher measuring amplitudes from peak to peak to believe that the amplitude is constant. This is perhaps why measurements of the components by the two techniques--from peak to peak and from a base line--reveal significant differences only with the second technique (523).

At the same time oscillations of the base line (which are fully possible, and which are associated with the influences under analysis) would be perceived as changes in the EP, and moreover, for example, a negative "valley" at the summit of a positive wave that does not cross the base line would be described as a positive oscillation with this technique. Jeffreys and Axford (282) noted periodic change in the value of the base line beneath all electrodes simultaneously (the base line was defined as the mean of the EEG in the first 40 msec following stimulus delivery). The authors emphasized the importance of simultaneously determining that value of the base line and of the EP being analyzed. Both techniques should obviously be used together.

Amplitude is also measured from an arbitrary zero line--that is, from a certain line drawn a certain distance away from the EP, determined following some particular rule for all EP's of the population under analysis. As an example this line could be placed a certain distance away from the base line. Such a definition of amplitude makes it possible to interpret the EP as "the edge of a fence," and it is convenient for comparison of component shape without considering component polarity. Sometimes the amplitude of all components is determined relative to the most pronounced, usually positive component, the peak of which is adopted as the zero point. This technique is also convenient for comparison of EP shape and of changes in the amplitudes of different components; we need only remember that changes in the amplitudes of all components may in this case be the result of changes in the amplitude of the "reference" positive oscillation, the peak of which is adopted as the conditional zero point.

Significant scatter of amplitudes recorded from different individuals may have a significant influence upon statistical assessments of differences in interindividual (group) comparison of EP's. Moreover according to the existing notions this scatter may not have functional significance (amplitude may be the product of, for example, the thickness of bone or of soft tissues of the head, and so on). In these cases it would make sense to eliminate or minimize amplitudinal differences, while maintaining the shape of the EP's. This can be done by means of normalization; for example we can employ a technique referred to by its author as "amplitude scaling" (274). This technique consists of the following. The maximum amplitude--that is, the amplitude between maximum positive and negative oscillations--was determined in each individual averaged EP; then all other amplitude values associated with all other points in time, determined relative to a prearranged isoelectric line, were established as percentages of the maximum amplitude. The "scaled" individual EP's obtained in this fashion were averaged. The standard deviation was determined in relation to each point in time in the group-averaged EP's, in addition to the averaged deviations from the isoelectric line, and the sum of these values for all points in time served as a measure of interindividual EP variability.

A tendency to develop techniques for automatic assessment of EP parameters, amplitude in particular, is typical of the present stage of EP research. In this aspect it would be sensible to examine the work of Soskis and Shagass (456) as an example. They defined amplitude as the standard deviation from the mean, but they determined the mean not for the whole EP but rather for individual time intervals of the EP, selected on the basis of a preliminary visual analysis in such a way that the mean deviation for the given time period would reflect the amplitude of this period's component to the best extent. Such determination of means separately for different time segments reduced the influence of the mean's variations in different segments upon the characteristics of each separate interval. Their analysis of EP's to a light flash was based on 25-75, 75-150, and 25-200 msec periods. Concurrently they determined the amplitude from a small visually isolated negative peak, situated within a segment from 90 to 160 msec, to the peak of the positive oscillation preceding it. The latter had to be a peak, and not a "valley" on the descending side of a negative oscillation. Its latent time fluctuated within 72-132 msec for 92 EP's to light flashes of four intensities.

Amplitude measured in this fashion exhibited high correlation with the standard deviation obtained by automatic analysis in the 75-150 msec period in relation to all four studied intensities ($r = 0.89$, $P = 0.01$). Such high correlation was obtained by Soskis and Shagass in similar research on somatosensory EP's. In the end, the authors concluded that when the research involves the dependence of EP amplitude on stimulus intensity, preference should be given to automatic determination of amplitude on the basis of the standard deviation from the mean in preselected time intervals.

A valuable advantage of this technique is the absence of subjectivity in resolving the peak issue. However, adequate selection of the time interval to be used to determine standard deviation has great significance in this case. Thus for example the standard deviations determined in the work above for the 25-200 msec period did not exhibit correlation with peak-to-peak amplitudes. The reason for this lies in the fact that regularly occurring changes in the 75-150 msec period (which were the cause of correlation exhibited in this period) are "eclipsed" by amplitudinal fluctuations in adjacent time intervals that are random in relation to the studied dependence.

Hull (272) created an algorithm for automatic identification of components in an EP to a light flash. First of all he proposed certain rules for isolating independent components (in distinction from noise--that is, insignificant oscillation of potential on the ascending or descending "side" of the EP component). The positive (negative) peak of the component is defined as the point having a positive (negative) amplitude greater than any at neighboring points within the limits of a particular time interval--a "window" on the curve with the given peak at its center. The width of the "window" depends on the difference in amplitude between the maximum positive and maximum negative points of the given EP in the period extending 200 msec after the light flash, and it is one-tenth of this difference, as measured from a paper recording of the EP.

Having thus determined the peaks (components) in each EP to a light flash, Hull computed the frequency of arisal of peaks in every 10 msec interval following the stimulus, with a consideration for polarity in the period extending for 11 to 280 msec following stimulus delivery. Five normal distributions of frequencies were thus obtained for each polarity. An early negative oscillation of low amplitude with a latent time of 11-20 msec and a positive oscillation with a latent time of 25-45 msec were often observed, the amplitude depending on stimulus intensity. Stability of shape, breadth, and location of the mode of the distributions that were related to the four intensities employed were noted for the next six components; the least-distinct limits were observed in the distributions of peaks occurring after the dimmest flash. Having determined the statistical means for four intensities, Hull created an algorithm for automatic determination of peaks in every subject in relation to each intensity; in accordance with this algorithm, a peak was defined as the point of greatest amplitude of particular polarity within the limits of indicated time intervals.

Peaks were identified by this algorithm in 67-100 percent of the cases depending on the component and the intensity, and automatic identification was not inferior to visual identification. P175 and N85 oscillations served as the "markers." The former was distinguished by the greatest amplitude, and the latter was characterized by the narrowest monomodal distribution. The P175 oscillation was identified in 100 percent of the cases, and its latent time increased significantly as the intensity declined. Use of this same oscillation as a "marker" was also suggested in another work (209). Any component other than P175 could be absent from individual subjects (in the general case, or with the weak intensity). P105 and N120 oscillations often arose at points appearing to be within the descending phase of the N85 oscillation, and Hull noted that they gave the impression of a fast oscillation with a period of 30-70 msec superimposed over a slow oscillation (P175) with a period of 100-140 msec, and that the expressiveness of this phenomenon depends on the relationship between the fast and slow components.

It is impossible to make a definite recommendation today as to which assessment technique to employ--it would be better to use several together. It is very important to consider the technique used to assess amplitude and identify components when analyzing published data. For example an attempt to summarize data obtained by different laboratories, describing the dependence of EP's on stimulus intensity, revealed that researchers referring to comparable results are often dealing with identical amplitude changes pertaining to entirely different components, and that in the few works in which the amplitudes of all components were measured simultaneously, changes occurring in different components exhibit different natures depending on stimulus intensity (58).

We have examined the most widely employed EP characteristics, though they are not at all the sole possible ones. Others can also be used: area beneath the curve, the length of the EP segment as determined with a curvimeter, the length of the EP as a whole or of its individual components, the ratio of amplitudes or areas of positive and negative components, the ratio of amplitudes of individual components, and so on.

The choice of particular characteristics is associated with the way the researcher understands the nature of the EP. We can examine, as an example, the approach to quantitative assessment of EP's developed by Gnezditskiy (13).* He interprets an EP as a reflection of the "energy" function of sensory systems, a function having the purpose of keeping the state of brain structures at a particular level necessary for information processing. Fluctuations in an EP are viewed as a reflection of reactive tuning oscillations that keep the cortex at a particular level of activity, or at its "optimum tone." The EP is concurrently interpreted as an integral systemic reaction of the brain. The brain is interpreted as a system having an input (to which the signal is applied) and an output (the recorded EP). An EP reflects the system's transient process in response to an external stimulus. It is hypothesized that an effect such as, for example, a light flash takes the brain system out of equilibrium, to which it tries to return owing to homeostatic mechanisms inherent to the brain, which is reflected by the EP. Following this line of reasoning, the state of the cortex and the quality of the system's homeostatic mechanisms should reflect upon the characteristics of the EP. Depending on the quality of these mechanisms, this transition may proceed quickly or slowly (it may be extended in time), with a significant or an unpronounced deviation from the state of equilibrium, with a periodic or an aperiodic response, and with dominance of its positive or its negative part. We can use parameters such as the area beneath the response curve, the time required to establish equilibrium, and others to evaluate the quality of tuning within the system.

This approach to the nature of EP's is what predetermined the parameters employed to assess EP's. The tuning area, defined as the area contained between the zero line and the curve representing the process, and the tuning time, which reflects the time of transition to equilibrium, were computed in relation to each EP. Response area was determined planimetrically. The zero line was drawn as the average of the noise intensity. A so-called dynamic shape coefficient was computed to describe the shape of the response: the ratio of the area of the positive portion of the response to that of the negative portion, $D = S+/S-$. (The author believes that this variable is close to unity for a periodic response, and that it differs significantly from unity for an aperiodic response. It would be entirely logical to imagine periodic oscillations shifted relative to the zero line and producing a significant deviation from unity.) When combined with the tuning time, the dynamic shape coefficient is interpreted by the author as a certain analog of the damping (attenuation) coefficient used in tuning theory to describe the dynamics of tuning.

These indicators were used to compare EP's recorded from patients suffering different brain afflictions and from healthy individuals, as well as

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* Application of tuning methods to EP research was first suggested in a paper by Ye. Ya. Voytinskiy (VOPROSY PSIKHOLOGII, No 6, 1969, pp 108-110).

subsequent conclusions about the nature of the pathology, made on the basis of the changes occurring in the EP. These indicators made it possible to reveal and quantitatively describe EP changes exhibited by patients in comparison with healthy individuals. It would not be difficult to foresee that whenever any of the components changes, one of the named characteristics should change as well, and the changes could be interpreted as a result of disturbance of cortical-subcortical interactions. In this connection it would be difficult to agree with the opinion of the author that this method of analysis may be thought of as more adequate for studying interaction in the subcortex-cortex system (more adequate than which others?), but this does not reduce the validity and fruitfulness of using this system for describing and quantitatively representing EP's.

We should simply remember that *a priori* interpretation of EP's as a reflection of tuning processes, description of EP changes in terms borrowed from tuning theory, and revelation of differences by means of this system of description do not at all confirm the notion upon which such description is based--that an EP reflects tuning processes and not, for example, coding or processing of information, the state of the subject, and so on. The advantage of the proposed technique for describing and measuring EP's is that it permits us to automate acquisition of isolated numerical parameters, since visual identification of peaks is not required.

And so, the choice of EP characteristics depends upon the initial premises and intuition of the author, and given the uncertainty of our ideas about the nature of EP's, we can only welcome a diversity of approaches, inasmuch as the problem of assessing and comparing EP's boils down, to a significant extent, to that of selecting the characteristics to be recorded.

We must of course also have distinct criteria of component isolation in relation to visual assessment (for example, should an oscillation below a particular magnitude be treated as evidence of a reaction) but in relation to automatic assessment of reactions, development of such criteria is absolutely necessary. This is a very pressing issue, particularly in regard to analyzing EP's to near-threshold stimuli--that is, in a situation where it is important to decide, on the basis of single EP's, whether or not the EEG contains a reaction to the stimulus. After sufficiently stable components are revealed in responses to stimuli known to be suprathreshold and their latent periods are known, the question arises as to what minimum amplitude, at the corresponding moment in time following stimulus delivery, can be evaluated as presence of an oscillation. We can use as our amplitude criterion that mean amplitude of the given component, obtained by averaging a certain number of reactions. However, in this case we will probably lose a number of the reactions, inasmuch as the averaged EP used to select the value of the criterion doubtlessly contained single responses of lower amplitude. Were we to reduce the magnitude of the criterion, we would not omit any of the reactions, or we would omit just a few, but we would necessarily obtain a certain number of false detections. How do we resolve this problem?

One group of authors (361) approached this problem with the Nieman-Pearson strategy: finding a criterion providing a maximum number of detections in the presence of a previously given number of false alarms. The permissible number of false alarms was determined intuitively by the authors on the basis of their clinical experience in threshold determination. Preparatory examination of 11 adults showed that all exhibited sufficiently similar and stable EP's. The characteristics of these EP's related to alertness and sleep were found, after which the presence or absence of a reaction in the initial EEG after the stimulus was determined on the basis of different amplitude criteria.

In particular, to reveal N90 and P170 oscillations, the authors determined the point of maximum negativeness in the 80-100 msec period and the point of maximum positiveness in the 160-180 msec period. The initial recordings were first assessed independently by three experimenters: two of them experienced and one performing such an assessment for the first time. Subsequent analysis was performed only with the undoubtable reactions--those EEG segments that were assessed as reactions by everyone. The experienced experimenters were inconsistent in 5 percent of the cases. We note that when the new experimenter examined the EEG segments containing the "undoubtable reaction," he made his decision as to presence or absence of reactions on the basis of different amplitude criteria. Concurrently, such an analysis was also performed with a corresponding number of EEG segments from which a signal was knowingly absent.

It turned out that a criterion of 8.2 μv does not produce false detections, but it reveals only 73 percent of reactions having an intensity of 45 db, and only 1 percent of reactions with an intensity of 10 db. A criterion of 3.3 μv insured 100 percent detection of reactions at an intensity of 45 db, and 57 percent detection at 10 db, concurrently producing 18 percent false detections. The authors deemed a value of 3.3 μv to be suitable for audiometry in an alert state, noting the need for first conducting a number of studies, particularly ones aimed at replicating the results in another group of adults, and so on.

Determination of EP Similarity-Difference on the Basis of the Correlation Coefficient

The yearning to eliminate the difficulties of identifying EP's and accounting for their characteristics more fully (not just the latent periods and amplitude of component peaks) led to a search for characteristics that would describe the degree of general EP similarity-difference, characteristics which could be obtained on the basis of objectively prescribed, rigid rules. One particular approach was to interpret amplitudes at successive points in the duration of an EP as a set of successive independent trials of one variable. From this approach it would be valid to describe any EP as a set of independent random observations by two values--the arithmetic mean and the standard deviation, and to use the correlation coefficient as an indicator of the degree of similarity existing between two EP's. This approach was used rather extensively, and with its help a number of authors revealed significant differences between EP's in the particular conditions of analysis.

It should not be forgotten, however, that computation of correlation coefficients and establishment of differences on their basis must be accompanied by assessments of the significance of these values. In the case where correlation coefficients are not significant, greater deviations between the actual correlation and that computed would be possible, owing to which the differences between the correponding curves may turn out to be insignificant.

Most of the methods used to evaluate the significance of correlation coefficients are based on the assumption of statistical independence of values taken at different points along the curve, which is of course invalid in relation to EP amplitudes at nearby points. Therefore it would be reasonable to reduce the "number of degrees of freedom" of the EP--that is, to compute a correlation coefficient only on the basis of points between which there is no clear dependence, excluding all other points from the examination.

Another solution of the problem is to compute correlation coefficients on the basis of all points, but to use a smaller quantity of measurement points, (a smaller number of degrees of freedom) than there had been in reality when evaluating significance (using tables). It would be sensible to choose measuring points for computation of correlation coefficients at temporal intervals equal to the time of significant attenuation of the autocorrelation functions of the EP's under analysis. Analogously, when we use the second technique the number of degrees of freedom should be made equal to the ratio of the measuring time to the attenuation interval of the autocorrelation functions. For practical purposes the number of degrees of freedom would be assumed close to the number of EP components in this case. In the case where the autocorrelation function does not attenuate or it attenuates so slowly that the number of degrees of freedom is low, standard methods for evaluating the significance of correlation coefficients are unusable. Then significance may be determined experimentally by inspecting the scatter exhibited by the correlation coefficient in relation to several pairs of curves obtained in similar conditions. If it is impossible to perform repeated experiments as well, a method for discriminating between processes generating the curves on the basis of a correlation coefficient cannot be used. However, a correlation coefficient can also be used as a formal measure of similarity between experimental curves. If processes generating the curves are to be discriminated or identified on the basis of a correlation coefficient, we would have to have an assessment of the statistical scatter of this coefficient.

Another shortcoming of using the correlation coefficient of an EP as a whole is the impossibility of determining the range of differences. It would be more beneficial to determine the correlation coefficient not for an EP as a whole but for its individual segments.

And so, the correlation coefficient is utilized as an indicator of the degree of relationship exhibited between two EP's recorded simultaneously in different regions, as an indicator of the degree of relationship existing between different temporal segments of the same EP, and as an indicator of the degree of similarity-difference exhibited by different EP's (in the last case it may serve as an indicator of intra- and interindividual variability).

Various "difference factors" have been suggested for quantitative assessment of the degree of similarity between pairs of EP's. The difference factor Zeta (117) may serve as a typical example. Sets of EP pairs recorded in different situations had to be compared. The composite correlation moment was determined in relation to all EP's, and the obtained values were subjected to a Fisher Z-transformation to normalize the distribution. The difference factor (Zeta) was determined with the formula:

$$\text{Zeta} = \frac{1}{2}(z_{1.2} + z_{3.4}) - \frac{1}{4}(z_{1.3} + z_{1.4} + z_{2.3} + z_{2.4}),$$

where $z_{1,2}$ is a factor obtained following Fisher transformation of a pair of repeating EP's in one situation, and $z_{3,4}$ is the same factor for a pair of repeating EP's in another situation. Zeta is an indicator of whether or not the similarity between EP's recorded in different situations is less than the difference between repeating EP's in the same situation. The lower the similarity, the more positive Zeta is.

John et al. (287) used a conceptually similar indicator of the degree of difference between EP pairs. They determined the so-called lambda factor--λ:

$$\lambda = (d_{1.3} + d_{2.4})/(d_{1.2} + d_{3.4}),$$

where $d_{i,j}$ is the difference between the standard deviations of EP_i and EP_j, and where 1 and 2 are repeated EP's to the same stimulus and 3 and 4 are repeated EP's to another stimulus. If $\lambda > 1$, the difference between EP's to different stimuli is greater than between repeated EP's to the same stimulus; if $\lambda = 1$, no systematic differences exist. It is impossible to determine the significance of this factor, since the statistical properties of the distribution are unknown.

Frequency Anaysis. Narrow-Band Filtration

All of the techniques of EP analysis examined above pertained to changes in amplitude occurring after stimulus delivery as a function of time. We can approach analysis of an EP in a different way by viewing the complex curve obtained by averaging as the sum of elementary sinusoidal oscillations, applying for this purpose a Fourier analysis, which leads us to a formal description of an EP's frequency composition. Its use is facilitated by an algorithm (Tuckey, 1965) permitting swift performance of the needed computations with a computer.

Various techniques are employed for EP frequency analysis: the method of quick decomposition into Fourier series (159,450,524), and the method of component demodulation (Walter, 1969). For practical purposes Fourier analysis was used mainly in research on the relationship between EP's and intelligence (99,217,218,524), and it enjoyed its most widespread application in analysis of steady-state potentials (394).

We can study the frequency spectrum of an EP by "passing" the initial tape recording through a set of narrow-band filters, thus obtaining amplitude values corresponding to each frequency isolated by the filter. Application of Fourier analysis and frequency analysis has produced information on the frequency composition of EP's and noise, and it has provided the grounds for using frequency filters when recording EP's to reduce variability: Frequencies typical only of noise are eliminated before averaging occurs. Such filtration may be performed with material filters, or filtration may be simulated with a computer when processing the raw data. Of course this does result in "impoverished" data, but at least they are more stable. On the whole, in the opinion of Perry and Childers (368) frequency analysis has contributed little to our understanding of the nature of EP's, and to their description, but it has turned out to be extremely fruitful in describing and analyzing steady-state potentials.

The EP as a Multidimensional Indicator. Use of Multidimensional Analysis

All of the EP assessment techniques examined above, which require unidimensional statistical analysis, reveal changes in some one characteristic in the EP in connection with factors being studied by the experiment (we may of course study several characteristics as well, but in this case each of them is studied on its own, and changes in relationships among them are not considered). Meanwhile valuable information may be contained precisely within indicators of the relationship between changes in different characteristics, for which reason it would be suitable to study the association of an external influence (or a number of influences) not only with individual characteristics but also with the entire set of EP characteristics. The methods of multidimensional analysis afford such a possibility (8,28).

Multidimensional analysis is applicable in cases where the object being studied is typified by numerous parameters, and where a relationship is hypothesized between these parameters, or where an object is being assessed on the basis of a set of parameters. Were we to interpret each point in time following stimulus delivery used in assessment of amplitude as a separate variable that could be described by any amplitude value, the individual EP would represent a multidimensional observation or a multidimensional object. In this approach every instantaneous amplitude value may be designated as $X(n,p,m)$, where n stands for the presented stimulus, p indicates the particular stimulus delivery under examination (on the basis of any characteristic--a property of the stimulus, the subject's state, and so on), and m stands for the point in time at which amplitude is determined. An EP represented as a set of instantaneous amplitudes may be designated as a point in multidimensional space, the location of which is determined by numerical assessments of amplitudes at each point in time. The number of points in time at which amplitude is measured defines the number of dimensions in the space.

Thus any set of singular or averaged EP's would be represented by a set of points in multidimensional space, and similarity-difference questions pertaining to such sets of EP's could be answered with the help of the corresponding techniques for assessing mutual relationships existing between points (or between vectors) in multidimensional space; the scatter of the points may be used as an indicator of the degree of similarity or difference between two sets of EP's or single EP's, and so on.

Use of multidimensional analysis is based on a number of assumptions relative to the nature of an EP, assumptions which permit us to interpret the EP as a multidimensional observation having a multinormal distribution. All of these assumptions (particularly that each single EEG segment following a stimulus represents the sum of reactions to the stimulus and the current activity of the EEG, in which the latter does not change in response to stimulus delivery) are violated to one extent or another, judging from certain facts, but as in the case of averaging, these deviations are not so great as to make multidimensional analysis inapplicable to EP's (Donchin, 1969).

After a set of EP's is represented in the form of points in multidimensional space, we can try to reduce the number of dimensions of the space without losing significant information. When we perform visual analysis--when we measure the amplitude of components from peak to peak, we intuitively reduce the data, substituting a set of amplitude values for a given component by one value representing the greatest amplitude. Such reduction is based on the intuitive assumption that amplitude from peak to peak adequately reflects all or a significant part of the information contained within all measurements of the amplitude of the given component. However, it is obvious that various unique features of the components remain undocumented as a result: little "humps" or "troughs," the rate of amplitude rise or fall, component duration, and so on. Understandably these "minor" details may turn out to be associated somehow with the experimental situation, and be extremely informative. Therefore we naturally lean toward a technique of data reduction which would permit us to account for the "minor" details as well, if they are found to be associated with the experimental conditions.

Multidimensional analysis offers us a number of techniques for reducing the number of dimensions while selecting out informative characteristics. One of them is linear combination of measurements, which produces a data description without information loss (Donchin, 1969). Reduction of the number of dimensions due to linear combination of measurements is based on determination of regression lines. In the same way that we can determine a regression line for two variables in two-dimensional space, describe it by an appropriate equation if the line turns out to be straight or nearly straight, and represent it by a point in multidimensional space, thus reducing the number of dimensions to one, by performing this operation several times with corresponding pairs, we can substitute any n dimensions by m ($m < n$). The choice of technique for reducing the number of dimensions depends on the criterion used to define the regression line.

Prescott (386) cites one application of this approach (429; Salzerg, Lustick, 1971), feeling it to be a promising technique of quantitative assessment of individual differences in characteristics such as EP asymmetry, rate of attenuation, and so on. Another technique for reducing the number of dimensions is to adapt a selected set of orthogonal functions to an analysis of an existing set of EP's (Donchin, 1969).

The main components method was used in a number of works to reduce the number of dimensions and analyze EP's. The method involves a search for the main properties, independent of one another, which in sum total characterize the object under analysis. The main components are essentially the result of selecting, by the least square method, a set of orthonormal curves representing a set of initially observed curves S. The first main component defines the direction of the greatest scatter in the multivariate distribution, the second main component defines the direction orthogonal to the former and having the next largest scatter, and so on. Thus the first component is the best approximation to the full set of initial curves, the second is the best approximation to the difference between the initial oscillations and the first component, and so on. This procedure is continued until such time that we arrive at a set that fully describes the initial set. The number of main components is equal to the number of dimensions in the description matrix. When all of the main components are accounted for and all of the scatter of the initial measurements is represented, the researcher has not lost any information, but he still has not enjoyed any sort of economy in the data's presentation. This laborious procedure reduces the data because it permits selection of components with rather low scatter (it should be noted that some single technique for selecting the main component does not exist). As a result each EP of a certain initial set may be expressed by a certain number of main components and weight factors. After this we can study differences between the main components and their weight factors in the presence of different experimental influences, rather than the differences exhibited by the initial curves. Perry and Childers (368) report description of an EP consisting of responses from 12 subjects using two main components.

The effect of experimental influences may be revealed better by main components or weight factors than by the initial data, in the same way that it is sometimes easier to reveal changes by analyzing curves broken down into component frequencies than by analyzing the raw data.

Lehman and Fender (311) reduced the size of the EP description with a set of Gaussian curves. The authors based themselves on the assumption that EP's are generated by different populations of neurons, each of which has its own latent period, but that individual members of a population "work" independently of one another, and their intrinsic latent periods assume a probability distribution about the mean latent period of the given population. If we assume that the number of neurons in each population is very large, that the probability that a reaction would occur at a moment in time close to the mean latent period of the population is described by a Gaussian curve, and that the mathematical expectation and scatter of the Gaussian process are a monotonous function of the working conditions of the neurons (of the task performed by the population), then when an electrode located on the scalp records events occurring within such a population, the recorded potential would have the shape of a Gaussian distribution. Thus the cumulatively recorded EP is interpreted as a linear sum of a set of Gaussian processes arising with different latent periods and amplitudes depending on the stimulus, and on the location and shape of the electrode.

Adhering to these assumptions, Lehman and Fender transformed the initial EP recordings into a set of Gaussian curves, and then they studied changes in the latent periods and amplitudes of these curves in connection with experimental influences. The first Gaussian curve was selected in such a way that its mean would correspond to the greatest amplitude of the EP, from peak to peak, and the greatest variability of the EP, and so that each subsequent Gaussian curve would "fit" the variability remaining after the preceding curves.

This technique corresponds to the intuitive interpretations of individual EP components as reflections of the activity of different neuron populations. It permits us to automate the measurement of latent periods and amplitudes, thus insuring an EP description technique very similar to that used in visual isolation of components, but one free of subjective influences.

All authors using various techniques for reducing dimensionality were able to arrive at an adequate description of the EP with three to six measurements, which is very close to the number of measurements used to describe an EP following visual assessment. Thus use of the techniques of multidimensional analysis confirms (or at least it does not repudiate) the intuitive notion that we can reduce 100-400 EP measurements to several peak-to-peak amplitude measurements (295).

In addition to permitting reduction of dimensionality and subsequent analysis of changes exhibited by the reduced data, multidimensional analysis allows us to determine the degree of similarity (difference) of multidimensional observations not subjected to data reduction; in this case the indicators of similarity may serve as a basis for classifying the observations.

Discriminant analysis was used for this purpose in a number of studies involving EP applications (196). Discriminant analysis is a classification technique in which we use data obtained from members of different groups, the group membership of which is not doubted, to develop criteria of group membership. The resulting criteria are then used to determine group membership of new observations. For example assume we obtain two different EP's in different situations. We can determine the situation to which a newly obtained recording of a single reaction to a stimulus corresponds with greatest probability. For every single recording of a stimulus response, we can determine standard multidimensional indicators of difference of the given EP from an averaged EP.

"Step" discriminant analysis, which in a sense unites the advantages of the main components method and discriminant analysis, has been used successfully to analyze EP's. Step analysis reduces the number of variables used in the analysis until such time that the best discrimination technique is arrived at. In general form, step analysis is performed in the following way. A variable which best describes a difference between two groups is selected. After all information correlated with this variable is "extracted," we add a second variable, if its addition improves the capability for discrimination offered by the first variable. After this the discriminant functions are defined as the space of these two variables. New variables are added in similar fashion until their addition ceases to improve the discriminant functions. The result of this procedure is that discrimination function which utilizes the smallest quantity of variables necessary for the best of possible discriminations.

If analysis of main components and discriminant analysis are applied to the same set of data, the variables that are found to be necessary for arrival at a good classification are found to be the same as the components isolated by the main components method. As an illustration we can cite an example from the work by Donchin and Cohen (195). It was revealed by discriminant analysis that differences between groups of EP's connected with the experimental situations under analysis stem mainly from differences occurring mainly at around 300 msec, and then around 14, 48, 288, and 136 msec. Analysis of the same data by the main components method showed that the component responsible for the bulk of the differences was the one having its peak at about 300 msec. Thus discriminant analysis permits us to reveal which characteristics or which temporal segments within the EP are significant to the factors under analysis (they vary in parallel with these factors).

Every researcher who has tackled the problem of EP variability is sympathetic to the wish to isolate some sort of basic types of EP's. EP's may be classified by visual assessment, but in the first place such a classification would be subjective, and in the second place it would be very limited in volume. Multidimensional analysis, meanwhile, affords a possibility for classifying EP's with the help of, for example, the methods of numerical taxonomy (recognition of images without reward (8)). The taxonomic method was used by Rusalov and Yunusov (56). Their goal was to isolate, from a certain sufficiently large population of EP's, individual groups of "comparable" EP's--that is, ones falling within the same taxon--and see what sort of characteristic known to the experimenter is possessed by all or most of the EP's within that taxon. If such a "characteristic" is found, it can be called a significant factor defining the shape of the EP in the given taxon. Thus we first classify EP's by their "morphology," and then we check the usefulness of such classification by making a comparison with additional information on the object being classified. The usefulness criterion is the possibility for predicting the properties of objects that have not yet been classified. There cannot be an optimum classification without a goal, and before requiring a mathematician to classify EP's in a given sample, the goal of classification must be defined.

The applications of multidimensional analysis examined here serve three purposed in the end: data reduction (isolation, on the basis of an analysis of the entire set of EP's, of the most informative variable of all variables characterizing the individual EP), their comparison (quantitative determination of the degree and range of difference), and EP classification. These goals are achieved by the rather complex and laborious methods of multidimensional analysis in parallel with the simple, broadly accepted method of isolating components on the basis of visual analysis of graphical recordings or numerical EP's, and in a number of cases the suitability of using multidimensional analysis must be proven through the acquisition, with its help, of new results differing from those acquired by the traditional technique (see for example (431)).

At the same time there are areas in which multidimensional analysis doubtlessly does open up new possibilities. Thus multidimensional analysis permits us to use single reactions to a stimulus. Due to the variability of EP's, if we are to assess the degree of differences existing between EP's recorded in different experimental situations, traditional methods for solving the problem would require acquisition, for each situation, of an ensemble of EP's sufficient for statistical analysis, inasmuch as comparison of two EP's would not be enough to answer the question as to the significance of differences.

Discriminant analysis permits us to use single reactions to a stimulus with this goal, and to solve the problem in areas where traditional methods are inapplicable.

An example of such research can be found in the work of Callaway (126). The author had to quantitatively assess the degree of similarity between EP's to two different tones and between EP's to the same tone delivered at different times in constant conditions, and to compare these indicators for two different groups--patients and healthy individuals. Two pairs of averaged EP's were obtained for each of the two groups: one pair in response to two tones of 1,000 Hz each, and another pair in response to tones of 1,000 Hz and 600 Hz. Coefficients of correlation within each pair, which are usually used to determine the degree of similarity, were computed. They turned out to be somewhat lower for patients than for healthy individuals, with differences between different and identical tones being revealed only among patients. However, the differences were not impressive, they said nothing about the scope of the differences in the EP's and, finally, there was no ordered way to represent differences between EP's to the same tone and EP's to two different tones through the correlation coefficients. The author applied discriminant analysis to single EP recordings. To analyze the degree of similarity within each pair of EP's, he studied two ensembles of 140 singular recordings from each subject, these recordings being used to obtain averaged EP's in each pair. This approach was found to be fully productive, since it revealed significant differences in the similarity of EP's recorded in response to identical and different tones, and since it indicated the range of differences.

Discriminant analysis permits a researcher having averaged EP's for a certain population of singular reactions to determine the degree of similarity between a single EP and the averaged EP. In the first place this factor can serve as an indicator of variability, and in the second place it affords a possibility for discarding a single recording differing from the averaged EP by an amount greater than some criterion, to acquire a new averaged EP, to perform the same operation once again, and thus to arrive at a set exhibiting a certain given level of variability. This process (as is true with computing the correlation coefficient between the "template" EP and a singular EP) may lie at the basis of a "labeled" filter, which can be modeled with a computer (368). The same technique can be used to answer the question as to whether or not there even was a response to a stimulus at a certain moment in time (for example when studying thresholds, and so on). Of course it would be difficult to determine the criteria in this case, but without a doubt discriminant analysis affords a means for precluding the "contaminating" influence of various artefacts. The methods of multidimensional analysis were successfully applied in a number of works to the use of singular reactions to stimuli (121,161,417,418,520), and apparently their application will continue to expand (206). In this connection we would like to emphasize Donchin's thought (1969) that it would be more suitable to employ general-purpose rather than specialized computers. A general-purpose computer, together with tape-recorded EEG's and the possibility for feeding data into the computer directly, affords a possibility for all sorts of analyses with the use of singular recordings of stimulus responses, which widens the possibilities of research in comparison with specialized computers that produce averaged EP's in most cases.

* * *

All forms of EP analysis are attempts at isolating some sort of characteristics or elementary functions from the EP's. In some cases the authors base themselves on intuitive notions concerning the physiological nature of the characteristics they isolate, assuming for example that individual

EP components isolated in amplitude-time analysis, or individual frequencies isolated in frequency analysis reflect the activity of different physiological systems or structures, or different aspects of the activity of the same structures. In other cases the initial criteria of the isolated characteristics are strict mathematical rules, and after isolating characteristics describing EP differences, the researcher seeks possible correlations between them and physiological or psychological variables. Some methods of analysis may sometimes have results limited to representing the same information in different forms and with different emphasis. Selection of the analysis technique is done arbitrarily today. In Regan's opinion (394) no one can at present name elementary functions related to EP's that have provable physiological grounds. In this connection it would be suitable to emply the diversity of data reduction techniques. It would be good to see the use of different techniques in the same study. Different characteristics may be found to be valuable in relation to different tasks in the same way that some handwriting characteristics are important to the readability of text, while others are important to determining the writer's state from his handwriting.

CHAPTER V

THE NEUROPHYSIOLOGICAL NATURE OF EP'S RECORDED FROM THE SCALP

Using EP's to solve some particular problem, the researcher must naturally first of all consider current notions as to what cerebral neurophysiological "events" are reflected within them.

In doing so, he must first know whether potential oscillations on the scalp are associated with oscillations arising in cerebral structures, and how they are associated. To put it more simply, it would be good to know the generators of the oscillations recorded from the scalp. Next follows the question as to the relationship between oscillations recorded by a macroelectrode and the activity of single nerve elements. Precisely what sort of neuron activity is reflected in "macro-oscillations" such as the EP: gradual changes (stimulatory or inhibitory postsynaptic potentials, presynaptic changes, and so on) or action potentials transmitted along axons? Having obtained answers to these questions, it remains for the researcher to clarify the role played by gradual changes in the potential and (or) in the neuron action potentials in supporting interaction of the organism with the environment, which in the terminology of modern science is often referred to as information processing or transmission, and which is inseparable from the concept of the mind. In other words how are these neurophysiological phenomena associated (are they associated?) with behavior? May they be interpreted as a "code" (Uttal , 1969; Bekhtereva et al., 1978)?

Unfortunately all of these problems are to a greater or lesser extent debatable. The only thing we can do is present the ideas that dominate today, and present the most typical facts reinforcing them, also making mention of the possibilities for other interpretations, and concurrently indicating the facts which do not agree with the commonly accepted ideas; it is impossible today to "fit" the available data into a well-ordered theory which would allow us, in the end, to use EP characteristics in the same way that we use the readings of a thermometer to determine temperature--independently of the measuring conditions. Nevertherless the knowledge that has been accumulated in this area is sufficient to permit fruitful use of the EP not only as an empirical diagnostic indicator but also for analysis of brain mechanisms. Let us briefly examine current ideas on these key questions.

Correlation Between Potential Oscillations Recorded From the Human Scalp and Oscillations in the Cerebral Cortex; Extracerebral Artefacts

At first, the basic search for evidence that EP's recorded from the scalp reflect intracranial events followed the lines of demonstrating similarity between oscillations simultaneously recorded from the scalp and from a nearby point on the surface of the cerebral cortex (see figures 6 and 7). It was found that in addition to similarity, we observe extremely noticeable differences which may be associated not only with the amplitude but also with the shape of the oscillations (77,261). Amplitude differencs are associated mainly with the complex properties of tissues and fluids separating the electrodes on the scalp and the surface of the brain. It is presumed in particular that one of the main reasons that the amplitude of oscillations recorded from the scalp decreases is the low resistance of the cerebrospinal fluid bathing the brain (239). Data exist indicating that this decrease can vary. Thus Cooper et al. (160) suggest that differences in the amplitude of oscillations occurring immediately within the cortex and on the scalp may vary from 1:10 to 1:10,000. Domino et al. (191) believe that the amplitude of an EP recorded epidurally is about 20 times lower than the amplitude of an EP recorded from the surface of the brain. They base their figures on data obtained with simultaneous registration of EP's from the surface of the brain and from implanted epidural electrodes in 67 persons. The extent to which the amplitude declines depends on the magnitude of that portion of the cortex which is responsible for synchronous generation of potentials: The larger it is, the lower is the decrease of the EP on the head surface. This was demonstrated in particular in an investigation of the relationship between activity on the scalp and activity recorded by electrodes chronically implanted in different regions of the brain of 12 patients (160). The obtained results led Cooper et al. to the conclusion that the physical conductivity of brain tissue is insignificant, and that the existing models that treat activity on the scalp as a reflection of a dipole deep within the brain are unfounded. In the opinion of these authors the way cortical activity is reflected on the scalp depends significantly on the synchrony of changes in potential occurring over rather large areas. They concluded from modeling experiments that if cortical activity is to manifest itself on the scalp, synchronous activity would have to occur on an area of cortical surface not less than 6 cm^2. In the absence of synchrony, cortical activity beneath a superficial electrode undergoes averaging. These ideas were confirmed by subsequent research (372).

Research by Heath and Gallbraith (261) demonstrates another source of differences in the EP's recorded from the scalp and within the cerebral cortex. They registered an EP (they summed 100 responses) to a light flash directly within the cortex and from the scalp in the visual and parietal regions. The shapes of the EP's recorded from the visual and parietal cortex differed. EP's recorded within the cortex and from the scalp in the region of the primary visual zone exhibited similar shape in the first 65 msec and differing shapes in the 100-300 msec period. The authors explained these differences by

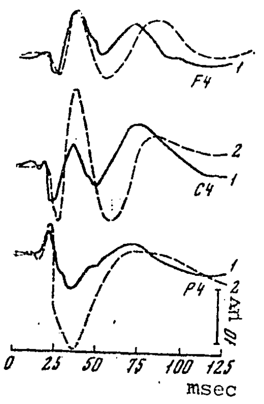

Figure 6

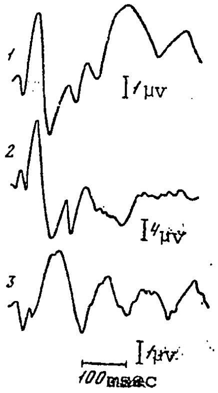

Figure 7

Figure 6. Comparison of Somatosensory EP's Recorded in the Cortex and from the Scalp of the Same Patient: Superficial recordings (*1*) and cortical electrode recordings exhibiting sufficient topographic correspondence (*2*) are compared. Positive deflection is downward (112)

Figure 7. Visual EP's Recorded Simultaneously From the Scalp and Within the Cerebral Cortex: *1*--from the scalp prior to removal of occipital lobe; *2*--from the scalp, simultaneously with the first recording; *3*--from the scalp following removal of occipital lobe. Bipolar registration. Electrode locations: 3 cm above the occipital protuberance, 3 cm to the side of it, and 7 cm to the side of the sagittal line in the parietal region. Cortical electrodes--at several points on the outer and inner surfaces of the occipital lobe and in posterier divisions of the parietal lobe. The pupils are paralyzed with homatropine, and the eyes are closed. Stimulation frequency--one flash every 1.5 sec. Average of 100 responses. Downward deflection--negative oscillation in the occipital region (163)

the fact that activity generated in the parietal cortex is recorded on the scalp and in the occipital region, but it is not transmitted into the visual cortex. They concluded on the basis of these data that in the case of scalp recordings, an electrode may reflect the activity of both nearby specific sensory divisions of the cortex and nonspecific regions farther away, no matter where the electrode is located. In this connection we observe, within the zone of specific sensory projections, comparable early EP components in the cortex and on its surface, while in the region of nonspecific cortical divisions we record late components of comparable shape (100-400 msec). Spatial summation of cortical potentials during the recording of EP's from the scalp is also demonstrated by Broughton (112) and other authors. It should be noted that concrete data on the degree of similarity exhibited by EP's recorded from the scalp and the adjacent cortex are often contradictory.

The reason for the discrepancies seen in the data of different authors may lie in the degree of correspondence exhibited by the locations of the superficial and cortical electrodes, in differences in the location of the indifferent electrode, in whether the cortical electrode is located subdurally or epidurally, and in electrode dimensions. If the oscillations are generated by small regions of the cortex, the similarity of the EP's would be greater when they are recorded from the scalp and epidurally than when they are recorded subdurally; the influence of the dura mater and cerebral fluid cited earlier is responsible for this (239). Moreover differences may also arise due to presence of multiple intracranial potential sources, both cortical and subcortical, and due to differences in the conditions of physical conduction on the scalp and within the cortex.

The intracranial origin of EP's is not doubted today on the whole, and their cerebral generators have been revealed quite persuasively in relation to some components. At the same time the existence of "extracerebral artefacts" in EP's--potential oscillations of extracerebral origin associated with a stimulus--has also been distinctly demonstrated. Muscle reactions and changes in the individual's corneoretinal potential and scalp potential are the sources of these "artefacts" (83,101,102,131,162,207,373,375; Ruhm et al., 1971).

Muscular "artefacts" are extremely hazardous in relation to EP components falling within the 10-80 msec period, especially after loud sounds. They are usually a manifestation of a startle reflex, which entails contraction of postaural, temporal, frontal, and occipital (neck) muscles. The crown is the least susceptible to the influence of contraction of these muscles. To avoid the startle reflex, it is recommended that loud sounds not be used (375). Muscle reflexes are absent in sleep, which is why audiometry having the purpose of recording mental components is performed with the subject asleep. A detailed analysis of myogenic reactions accompanying electrostimulation of the median nerve or the fingers (131) showed that they arise early among calm, relaxed subjects; they are observed most often in the occipital region, and they go away when the subject is given instructions promoting relaxation of the muscles, or when he changes his posture in such a way as to relax these muscles. The authors concluded that myogenic potentials offer practically no hazard of "contamination" in relation to calm subjects able to maintain a relaxed state.

At the same time, points at which EP's entirely free of myogenic artefacts could be recorded in response to electrocutaneous stimulation could not be found in some persons distinguished by pronounced myogenic reactions to electrosimulation of the median nerve or a finger, with registration occurring along the sagittal or coronary line of the head, within the zone of maximum EP amplitude.

Special research showed that oscillations associated with eye movements and blinking offer a "contamination" hazard in relation to components arising 150 msec and more after the stimulus (207,375,466). Blinking offers a special hazard in attention research, since it increases in frequency when attention is directed toward the stimulus (430), and it can thus be the cause of false regularly occurring changes in the EP in connection with attention. Attempts are made, though not very frequently, to eliminate or prevent noncephalic "artefacts": Single responses coinciding with blinking, as recorded with eye electrodes, can be dropped automatically or visually by hand from the samples to be averaged; electro-oculograms can be recorded simultaneously with the EP, and the potential oscillation representing a particular percentage of the oscillations recorded in the electro-oculogram can be subtracted from the EP (162,258,364, etc.).

In general, although "contamination" of an EP by artefacts representing potentials of noncephalic origin can occur, it does not make use of the method impossible; it only requires that the researcher be heedful of recording conditions influencing the expressiveness of noncephalic oscillations, and that he take special steps to eliminate them or to reduce their proportion within the EP. He should first of all take care to see that the subject's posture is comfortable, and that his muscles are relaxed. The greater the interelectrode distance, the greater are the possiblilites of "contamination" by muscle potentials, such that bipolar recording is better in this regard. Inasmuch as myogenic "artefacts" in an EP are distinguished by greater variability than the EP itself (245), instability of an EP should serve as a warning in relation to noncephalic artefacts. Another clue of an oscillation's myogenic origin is a very rapid decline in its amplitude as the electrode is moved from the zone of maximum amplitude.

Judging from an analysis made by Goff et al. (1976) and by Allison et al. (83), it is impossible to fully avoid myogenic oscillations when recording EP's. Using presence of a comparable oscillation when the response is recorded directly in the cortex as a significant criterion of a component's cerebral origin, they isolated a number of myogenic oscillations in the first 80 msec following stimulus delivery; these oscillations differed following stimuli of different modalities. Moreover they isolated a high amplitude positive isolation in the 90-130 msec period, dominating in the frontal divisions and having, according to their data, an identical origin following stimuli of all modalities--reflex contraction of the orbicularis oculi (see chapters VII-IX). Inasmuch as a neurogenic positive oscillation also arises concurrently with it, and because the real positive component of this period is an alloy of a neurogenic and a myogenic potential, it would be important to note that the myogenic oscillation is expressed to a greater extent among novice than among experienced subjects, and that it is expressed more strongly after unexpected stimuli than after expected ones, the latter dependence being expressed better among novices.

Thus regularly occurring changes of this component associated with the degree of uncertainty may reflect changes of myogenic origin, and not cerebral events. Naturally, we cannot call the interpretation of components in the works cited above conclusive. A neurogenic origin for components said to be myogenic and the reverse case are not excluded, inasmuch as none of the signs of their "discrimination" are sufficient. In particular, absence of a comparable component when a response is recorded from the surface of the cortex might simply mean that this oscillation reflects a potential within deep divisions of the brain. Equally, presence of similar oscillations on the scalp and within the cortex does not preclude the agreement of the spatial and temporal characteristics of a myogenic oscillation recorded from the scalp and an intracerebral oscillation recorded within the cortex.

These universally known circumstances are emphasized here to preclude rendering any existing ideas about the neurogenesis of EP's absolute from the start.

Development of Ideas on the Correlation Between Different EP Components and Individual Brain Systems and Structures

That individual components making up an EP may change relatively independently of one another was discovered in early studies on human EP's. As a result components gained significance as the structural units relative to which researchers sought generating structures and functional correlations, though it was not at all obvious *a priori* that a given negative (positive) component reflected development of negativeness (positiveness) in some particular brain structures, rather than, for example, a "pause" between two peaks of positiveness (negativeness), or the algebraic sum of simultaneous oscillations of differing genesis. We should note that this does not hinder revelation of functional correlations between a component, or a "pause", and particular structures.

Ideas, present at that time, about the neurogenesis of components of EP's recorded directly within the animal brain had a significant influence upon the early stages of this search (57). In a number of cases experimental studies on animals made it possible to reveal, rather distinctly, a correlation between individual EP components and the activity of particular nerve elements. The first hypotheses on the origin and functional significance of EP components in man arose on the basis of these data. As we know, the EP's of animals were commonly subdivided into so-called primary and secondary, or specific and nonspecific responses (321,408). Early electric reactions arising in the projection zones of the cortex and responses to impulses arriving along specific afferent thalamocortical fibers are referred to as primary or specific responses. Bioelectric reactions reflecting the activity of the brain's so-called nonspecific system are called secondary or nonspecific responses. It was demonstrated in animal experiments that secondary responses depend to a significant extent on the reticular and thalamic nonspecific systems (2,185, 409; Lindsley, 1967).

Early components (occurring in the first 60-100 msec) of EP's recorded from the human scalp were expressed predominantly within the region of cortical zones corresponding to the stimulus modality, while late components were recorded over a significantly broader area of the scalp, and they exhibited highly similar shape in response to stimuli of different modalities. Morever it was discovered that early and late components behaved differently when the subject is under anesthesia and when he is asleep, and in the presence of very short interstimulus intervals, in which case the nature of the differences is similar to differences found in similar changes occurring in the primary and secondary components of animals (144; Goff et al., 1962, 1966; etc.).

As a result some researchers began interpreting the early components of the human EP as primary (specific), and late components as secondary (nonspecific) (321). In correspondence with this, early and late EP components began to be used as indicators of the activity (or state) of different systems--specific and nonspecific. Although division of human EP components into primary and secondary (specific-nonspecific) proceeded without adequate grounds and not one of the criteria employed was necessary or sufficient (44,57,245), this division was universally accepted for a rather long period of time, and much of the 1960's literature contains references to early components as primary or specific, and to components occurring after 100 msec (the vertex potential in particular) as secondary or nonspecific. It was often presumed in this case that secondary responses are generated in nonspecific structures of the brain stem, and that they are recorded from the entire scalp due to physical conduction.

Williamson et al. (534) conducted research specifically to test the hypothesis that correlation exists between late EP components and nonspecific brain stem systems. The logic behind the research was as follows. It is known (from animal experiments) that the specific and nonspecific systems are relatively independent: When one is destroyed or switched off and the other is stimulated, an EP may be observed in the cortex in response to stimulation of the surviving system. Hence it follows that if the late components do in fact reflect impulses arriving in the cortex along nonspecific projection pathways, they would have to persist in patients with specific pathways cut above those regions in which collaterals to nonspecific formations branch off from specific pathways. A decline in the intensity of early components or their absence, and persistence of late components would be expected in such patients. However, research on a group of patients with lesions in the parietal region of one of the hemispheres and with corresponding sensory disorders showed that when early EP components were absent or of reduced intensity, late components were also absent or reduced in both hemispheres in response to stimulation of the damaged side. When stimulation occurred on the healthy side, relatively normal EP's were recorded in both hemispheres.

The authors concluded that the entire EP in the hemisphere contralateral to that stimulated stems from activity of the primary somatosensory cortex, which is aroused only through a specific bundle of nerve fibers, and that late reactions of the ipsilateral hemisphere reflect the latter's subsequent activation through interhemispheric pathways, possibly through the corpus callosum.

It would make sense to emphasize here that from a logical standpoint, the absence itself of late EP components following disturbance of the integrity of primary projections zones is not proof that these oscillations are generated precisely by these zones in the intact brain. They are possibly generated in subcortical formations, but only under the influence of corticofugal impulsation from the primary projection zone, or with its participation. At the same time were we to admit generation of components in the 100-250 msec period in the cortical projection zones, we would not be precluding the possibility that impulsation from nonspecific structures has a modulating influence. In addition to the reticular formation, limbicodiencephalic structures have been implicated as a possible source of the latter (31,66).

Davis et al. (177) studied interaction of EP's to stimuli of the same and different modalities delivered at an interval of 500 msec. The stimuli were equated in relation to their subjective intensity. Under the influence of a preceding stimulus, the amplitude of oscillation P200 in response to the testing stimulus--the second in the pair--always declined, but this decline was twice greater with the stimuli of the same mode than with the stimuli of different modes. Thus the authors demonstrated both the undoubtable mode-specific nature of component P200 and presence of a mode-nonspecific component among the factors governing the amplitude of oscillation P200.

And so we cannot completely exclude the presence of subcortical EP generators in the period following 100 msec; the only thing that is certain is that EP components occurring after 100 msec are mode-specific in the sense that their characteristics depend on stimulus modality, and that persistence of the appropriate cortical projection zones is necessary for their development.

The hypothesis that early components are primary or specific responses, in the meaning that these terms have in relation to EP's recorded directly within the cortex, has also not been confirmed yet. In general, the neurogenesis of components in the 10-100 msec period following stimulus delivery is far from clear. The existing data and hypotheses will be examined in the appropriate sections of this book. For the moment we will simply note that on one hand there are no early components which are unanimously identified as primary components (83), and on the other hand hypotheses have been suggested concerning components occurring in the 40-50 msec period following stimulus delivery--that they are generated in secondary projection zones or in the associative cortex (see chapters VII-IX).

In addition to demonstrating the modal specificity of EP components falling within the 100-250 msec period following stimulus delivery, EP research has also revealed components that are in fact modally nonspecific. According to current ideas they include the so-called late positive oscillation (LPO), or component P300. This oscillation arises either in response to unexpected stimuli or unexpected missing of a stimulus (375), or in the presence of some sort of activity associated with the stimulus (obviously this is why it was not recorded in early studies in which stimuli not requiring a reaction were presented rhythmically). One of the first studies in which component P300 was registered is that of Sutton et al. (487), who described an increase in the amplitude of P300 accompanying a decrease in stimulus probability. It was later demonstrated (488) that an oscillation with a latent period of about 300 msec also arises in the absence of a stimulus, at the moment at which the stimulus was expected but not delivered. Research by Ruchkin et al. (420)

showed P300 oscillations occurring after a meaningful stimulus and upon omission of an expected stimulus to be the same. Ritter and Vaughan (404) demonstrated arisal of component P300 following unexpected changes in sounds presented to the subject while he was reading a book, and registration of component P300 in conditions of difficult discrimination following all stimuli, even though they were not unexpected. Subsequent detailed research on the morphofunctional nature of these oscillations (Ritter, Vaughan, 1972) led them to the conclusion that oscillation P300 is generated in the associcative cortex, and that its characteristics do not depend on stimulus modality, in distinction from a sensory EP generated basically in the projection zone of a corresponding modality and culminating as oscillation P200.

Klinke et al. (301) describe an EP to an absent stimulus starting with an initial positiveness, which is not always evident, followed by a small negative oscillation, and then invariably a pronounced large positive oscillation. The authors feel on this basis that oscillation P300 is just one (the most pronounced) of several oscillations of "associative potential" (that is, potential in the associative cortex).

In recent years information has appeared indicating that the "monogenic" P300 component is actually two different independent oscillations arising in different regions of the brain a short time apart. It is hypothesized that one of them, which has a somewhat shorter latent period, is associated with an orientational reaction, and that the other is associated with voluntary attention (475). It is also hypothesized that oscillation P300 is not an integral process but the result of numerous oscillations of different origins, one which may be influenced by novelty and complexity of recognition and relevency of stimuli in different ways (164,283,284). Besides component P300, less positive oscillations have been described occurring in a period 300-600 msec after stimulus delivery (475,537; Linda et aL, 1972; etc.), and the isolation and description of new EP components will probably continue. None of the works cited above contain indications of the modal specificity of late positive oscillations.

Thus we can assume today that division of components of EP's recorded from the scalp into primary and secondary (specific-nonspecific) is only of historical interest. According to data available today, it would be suitable to distinguish four groups of components, as is done for example in the work by Picton et al. (375). The first contains the initial components (Picton et al. refer to them as super-early) recorded in the first 10-15 msec following stimulus delivery and reflecting the activity of specific afferent pathways and nuclei in the spinal cord and (or) brain stem and in subcortical structures. For the moment they have only been registered in response to clicks and electrocutaneous stimulation. The second includes early components (falling within the 15-100 msec period), which reflect activity mainly of the cortex' projection zones, not only primary but also, perhaps, associative. The details of their neurogenesis are not always known. Components falling within this period contain many extracerebral artefacts. The third group contains middle, or intermediate components falling within the 100-250 msec period after stimulus delivery. This group contains components N115-145 and P180-200 components, often referred to in the literature as the vertex potential, inasmuch as they were discovered and described for the first time in response to sound in the region of the vertex (178). The first positive component of this period, P90-115, is an alloy of cerebral and myogenic potentials, while all subsequent ones are purely cerebral potentials (83).

Comparison of the components in this period within an EP to indifferent light flashes, clicks, and electrocutaneous stimulation of subjectively identical intensity made it possible to hypothesize (83) that beginning with the vertex potential, they may be interpreted as functionally analogous--that is, reflecting analogous neuron operations, though in different divisions of the cortex (corresponding to the modality of the stimuli). N140, P190, and O260 in somatosensory EP's, N115, P180, and 230 in auditory EP's, and N145, P190, and O240 in visual EP's are distinguished as analogous oscillations falling within this period. Perhaps the neurogenic contribution to components P100, P90, and P130 is also analogous in relation to the modalities named above.

Components of precisely this period and of the next (after 250 msec), which make up the fourth group of so-called late components, are the usual object and implement of study in psychological and psychophysiological research. If we discount recent work (83; Goff et al., 1976), in which a group of late components is distinguished following indifferent stimuli (though they are of course interpreted as a reflection of a postdischarge), late components are usually recorded only after stimuli and are either unexpected or require some sort of activity--so-called signaling, or meaningful stimuli. They include primarily the LPO described above, and subsequent slow oscillations.

Still unanswered is the question as to whether the positiveness observed at about 300 msec after rhythmically repeating indifferent stimuli is a reflection of that same LPO that occurs in the presence of signaling stimuli, or whether it is associated with oscillations of different nature, for example with a part of a postdischarge (83). It may be said to be universally recognized that an LPO following meaningful stimuli is a mode-nonspecific oscillation connected with activity of the associative cortex.

Ritter and Vaughan (1972) suggest distinguishing sensory EP's to indifferent, rhythmically repeating stimuli that end with a negative oscillation following the vertex potential, from the cortical associative potential (CAP), the best expressed part of which is the LPO. A CAP may also arise in the absence of a real sensory stimulus--at the moment when the stimulus was expected with sufficiently high probability, but not delivered. The negative oscillation occurring 200 msec following delivery of the meaningful stimulus is the sum of the negativeness of the sensory EP and a negative CAP oscillation (458).

It should be noted, however, that any "group" designation of components in a description of results would be impossible due to substantial independence of individual components within any group. It is no accident that such descriptions of EP's in analyses of results have been encountered with increasingly greater rarity in recent years, and the indication of separate components is becoming common; correspondingly, potential generators are also being sought in relation to each component taken individually.

Attempts at determining the location of a generator producing oscillations recorded from the scalp have boiled down in recent years to theoretical development of a model of the brain as an isotropic three-dimensional conductor, and to determination of a dipole or several possible dipoles that should produce the same potential distribution on the scalp as the one actually observed (or one close to it). After this the theoretically calculated locations of the dipoles are compared with the neuroanatomical information on the brain, and then the locations that coincide with a physiologically adequate source are assumed to be proven--that is, it is presumed that the model has "interpretive value."

An example of this approach can be found in research by Smith et al. (463). These authors recorded EP's to clicks, light flashes, and electrocutaneous stimulation in 15 persons. The indifferent electrode was extracranial. EP's were recorded from the scalp at points C_2, C_3, and T_3 and, in additon, with a nasopharyngeal electrode. EP's to stimuli of all modalities produced within the first 80-100 msec following stimulus delivery had similar shape in relation to all electrodes; later components (occurring after 120 msec) were recorded in the vicinity of the nasopharyngeal electrode with polarity opposite to that of the rest of the electrodes. Using a mathematical model in which the brain was viewed as a homogeneous conducting medium, the authors studied the possible locations of a dipole serving as the source of oscillations recorded simultaneously by the employed electrodes in successive moments 20 msec apart. According to this model the source for the early components of the visual EP's (up to 120-140 msec) is located close to the surface of the cortex; 160 msec after stimulus delivery the source shifts deep into the brain and closer to the midline, moving after 240 msec somewhat upward, vertically along the midline. Similar results were obtained with the other modalities.

In the opinion of the authors, according to this model mesial structures of the mesencephalon, the mesial temporal cortex, the hippocampus, and the lingual gyrus can make an equal "claim" upon the role of the source of late oscillations. The results of this work are not at all absolute proof that a dipole located in the deeper structures of the brain is the source of the late components. The very hypothesis that the source is a localized dipole rather than many individual sources or dipole layers may be incorrect; viewing the brain as a homogeneous medium also remains debatable. However, if the initial assumptions are valid, then the results indicate the possibility that oscillations arising in the brain's deeper divisions may be reflected on the scalp due to physical conduction, a possibility which has been repudiated by some data (160).

The validity of such a possibility is demonstrated by Jewett et al. (285,286), who registered, on the scalp, potential oscillations arising in the center of the cochlea. Incidentally these authors suggested potentials of the "near" and "far" fields (near and far relative to the recording points) as difference criteria to be applied to scalp recordings. Near field potentials are typified by significant differences in shape (that is, amplitude and polarity) associated with insignificant changes in the position of the recording electrodes. Absence of significant differences in response to small changes in recording points is typical of far field potentials. Thus by recording EP's with a set of electrodes located close together, we can localize the source of a near field, while far field potentials would be the same beneath all electrodes. At the same time a single electrode may record the activity of different far field sources.

It is clear from this how complex and undefined the mutual relationships are between potential oscillations on the scalp, in adjacent and remote divisions of the cortex, and in profound brain structures. The situation becomes even more complex when we consider that construction of simple models of dipoles in a homogeneous medium--an analytical approach that is widespread today and presents the appearance of being successful--is, in Regan's opinion (394), stupefying and dangerous. The initial success enjoyed with simple models of single dipoles does not provide the grounds for presuming, Regan emphasizes, that any other model might not fit the data just as well. Such another model, one that is mathematically more complex, may contain a different equivalent source, the neurophysiological interpretation of which would differ significantly from the neurophysiological interpretation of a simple dipole model. If an attempt is not made to test out more than just one model, the mathematically simplest one, we will never be sure that the obtained data do not also correspond to some other hypotheses. Moreover, although components are usually interpreted in the analysis and study of EP neurogenesis as certain structual units relative to which generating structures and functional associations are sought, it is not at all obvious *a priori* that a given component reflects development of some particular bioelectric process in nerve elements adjacent to the electrode, rather than a pause between two successive processes in the same structures, or the algebraic sum of changes in potential occurring in a number of structures different distances away from the recording points. This possibility should be kept in mind, though for practical purposes the commonly accepted interpretation has turned out to be fully productive, and we are able to associate some components with specific generators rather clearly and unambiguously.

Specific current ideas about the generators of indivdual EP components are presented in our examination of the neurogenesis of EP's to stimuli of different modalities. It is impossible to categorically define the source of a number of components today. It would pay to emphasize here that even when the neurogenesis of a component is known, caution should be exercised when interpreting changes in this component as reflections of changes in its hypothesized generator. A change in a component may be a manifestation of changes in neighboring components.

The Relationship of EP Oscillations to the Activity of Single Nerve Elements

Animal research, which usually deals with EP's recorded directly from within the cortex and not from the scalp, is the main source of our ideas on this issue. As neurophysiology developed, the tendency to interpret slow oscillations as the integral result of spike (pulsed) activity of neurons was superceded by notions of the dominant role played in EP generation by sufficiently synchronous slow potential oscillations of the soma or dentrites, recorded with macroelectrodes on the surface of the cortex or in subcortical formations (2,211,212,388; Purpura, Cohen, 1962). (The idea that EP's reflect the nature of impulses traveling along afferent fibers into projection zones is still accepted today only in relation to the earliest EP components recorded from the scalp.) However, although the role of slow, gradual potential changes accompanying EP generation (and other slow activity in the cortex) has been recognized, concrete experimental data on the nature of the relationship between the examined phenomena are far from ambiguous.

As we know, gradual potential changes of two types may arise in nerve cells: stimulatory postsynaptic potentials (SPSP), manifested by depolarization or negativeness, and inhibitory postsynaptic potentials (IPSP)--hyperpolarization, positiveness. Experimental studies describe different relationships between potential changes in neurons on one hand and the polarity and nature of slow oscillations recorded with a macroelectrode from the structure under examination on the other. Among them, in addition to the frequently repeated and replicable results, we can also find contradictions. Perhaps the reason for this lies in differences in the experimental conditions, and a literature analysis does not always clarify the differences in these conditions fully.

A hypothesis that had once been rather popular (167) was that alternation of negative and positive EP phases on the scalp reflects alternation of SPSP's and IPSP's in cortical neurons; it now requires additional study, since significant diversity in simultaneous responses by different cortical neurons to the same stimulus, the possibility of simultaneous existence of SPSP's in some neurons and IPSP's in others, and the corresponding incorrectness of relating neuron events to EP components unambiguously have been discovered (168).

In general, we have not as yet been able to reveal a relationship between slow oscillations on the surface of the cortex on one hand and pulsed discharges or slow changes in the potentials of single neurons on the other, though in some conditions certain mutual relationships depending on what superficial slow oscillations were considered (for example the EEG or EP's), on the state of the animal (anesthesia, sleep, alertness), and so on have been revealed. Data are appearing indicating possible significant participation of neuroglia in the genesis of superficial slow oscillations (135,158,247).

Summarizing, we can say that for the moment, unfortunately, there is no "bridge" between EP's and the activity of single neurons. Existing points of view on the possibility of using EP's to analyze cerebral mechanisms vary from almost total skepticism to the opinion that EP's may serve as a "window" for research on the central nervous system just as successfully as recording the activity of single nerve elements. At the present level of knowledge, it is impossible to establish the advantages of one method over the other (394).

CHAPTER VI

VARIABILITY OF EP'S

Every experimenter beginning his research on EP's encounters both inspiringly comparable, stable EP's and discouragingly different EP's in successive trials under what appear to be identical conditions experienced by the same subject, and all the more so by different subjects (figures 4 and 8). Interindividual differences are especially great, but even interindividual differences can also be highly pronounced, despite stability of the general pattern and latent period of the responses.

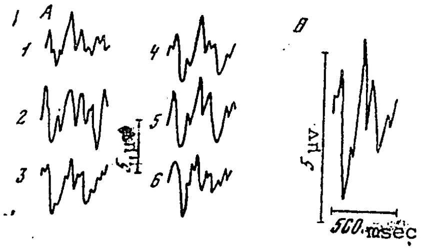

Figure 8. Example of the Variability of an EP to a Light Flash in Successive Recordings From the Same Individual (318): *A*--EP's summed from 25 responses: *1-6*--successive averagings; *B*--EP summed from 150 responses

The beginning researcher would naturally want to have some sort of reference points from which to conclude that the EP's he is recording, and their variability, do not differ too much from those encountered in most previous studies employing identical or similar recording conditions.

There has not been much systematic research on normative data in this aspect. The existing data on variability (that is, the scatter of latent periods and amplitudes) are presented in our examination of the typical morphology of EP's associated with each modality; in this section we will examine some general issues.

Sources of Intraindividual Variability. Variability of Noise and "Intrinsic" Variability of EP's. Variability Assessment Techniques

Inasmuch as the number of single reactions usually employed in averaging is such that a certain fraction of noise always remains in the EP, variability caused by noise is unavoidable. The question lies in whether or not noise artefacts are all that cause variability in EP's. The problem of dividing EP variability into reaction variability and noise variability (that is, background variability of an EEG recorded in the absence of reactions) is theoretically complex, and it is not fully resolvable in the same way that we cannot answer the question as to whether an EP is a reflection of reorganization (or sychronization) of neuron activity in response to a stimulus, or a reflection of the "addition" of new "events" to constantly present spontaneous activity. However, for practical purposes it is entirely possible to reveal the relationship existing between the role of noise and the "intrinsic" variability of an EP, for example by comparing the variability of the background EEG and the variability of the EP. The more they correlate with one another, the better are the grounds for assuming that the noise artefacts play a significant role in EP variability.

A large number of studies of this sort have been conducted (143,148,267,372,425; Halliday, 1972; etc.). Some authors concluded that the variability of noise has the dominant role, while others suggested variability of the responses themselves to be the main source of variability. Analyzing the appropriate data on sources of variability, Childers et al. (1972) noted that the role of the variability of noise is emphasized predominantly in the studies making use of rhythmical stimulation, while when aperiodic stimulation is involved, the variability of reactions is usually viewed as the main source of the variability. This is to be expected on the basis of data indicating that aperiodic stimulation eliminates some noise associated with the alpha-rhythm (265), and that a significant proportion of the variability of visual EP's may stem from insufficiently reduced alpha-activity at the time of averaging (500). On the whole, the larger proportion of the data available today show that although noise does make its "contribution" to the variability of EP's, the variability of the reactions themselves is a significant source.

What are the causes of intraindividual variability of EP's? First there are the variations in the subject's state: changes in sensitivity, changes in emotional state, fluctuations in attention, habituation, the action of the orientation reaction, and so on. Changes in sensory input which are caused by uncontrollable eye movements, changes in pupil size, and contractions of ear muscles, and which are unrecognized by the subject and the experimenter may be a source of variability (Tanaka et al., 1974). Stimulation of different divisions of the retina may be a source of variability associated with point stimulation and insufficient fixation of gaze (189,203,508; etc.).

The steps taken to "fight" variability become clear from the above discussion: keeping vigilance at the same level, keeping the sensory input constant, discarding responses to the first few stimuli (or at least to the first in a series) before averaging, excluding EEG segments with distinct artefacts from averaging, and so on. Mathematical assessment of the variability of signals and noise (EP's and background) would be desirable in all studies, but itis absolutely mandatory in cases where the causes of EP changes are unclear or contradicted by the bulk of existing data. Incidently there is a simple automatic technique assessing EP stability (327). It is based on comparing two halves of an EP, representing EP's averaged separately in relation to all odd and all even stimulus deliveries.

A rather simple technique can be used to obtain visual and numerical characteristics for variability of noise; this technique was suggested by Perry and Childers (368) as a mandatory control over each EP: A number of EEG segments recorded in the absence of a stimulus equal to the number of EP's are averaged in parallel. This method is being employed quite fruitfully, though summation of EEG segments recorded in the absence of a stimulus may give wrong information on noise artefacts in an EP, inasmuch as a stimulus not only elicits an electric reaction but also alters background activity. Noise variability may be assessed with the help of a ratio method consisting of successive addition and subtraction of EEG segments associated with the stimulus, followed by their division by the total number of additions and subtractions (422,433). The method of so-called cumulative averaging (121) may provide information on the variability of single EP's in the course of averaging, and on the validity of comparing averaged responses. Incidentally an analysis performed with the assistance of this method distinctly demonstrated significant periodic oscillations of EP amplitude not corresponding to the premise that the probability distribution of amplitudes at the basis of the averaging process is constant. The research results demonstrated the danger of mistaking EP differences revealed through different averagings and associated with "spontaneous" amplitude oscillations for differences directly caused by experimental manipulations.

A method has been developed for determinging the temporal intervals of an EP within which nonhomogeneity is observed. This method reveals only periodically arising segments of nonhomogeneity: Were we to "mix" single responses from two different EP's at random, the method would not reveal nonhomogeneity. A technique has also been developed for separate averaging of different groups of EP's, to be applied if the sequence of EP's to be averaged turns out to be nonhomogeneous (417).

We are interested in assessing variability not only because high variability must serve as a warning to the researcher (it may be the result of extracerebral noise, abrupt variations in the subject's state, artefacts, and so on), but also because the variability of the background governs the researcher's treatment of potential oscillations in the EP as components: If their amplitude is less than background variability (which is often the case in regard to early components), the number of responses added together would have to be increased. A comparative assessment of any two EP's would require a knowledge of their variability; otherwise such an assessment would usually be meaningless (394).

Finally, we must have an assessment of variability because, as numerous studies have shown, variability is a significant EP characteristic, and not just noise. The importance of considering variability as a special indicator of an EP was discovered for the first time in connection with the fact that small doses of LSD-25 dramatically reduce the variability of visual EP's while having little influence upon their amplitude (302).

Significant changes in variability were later demonstrated in connection with different effects upon and features of the nervous system and behavior. In particular, inasmuch as the variability of EP's recorded from children is obviously superior to that of adults, the association variability has with the degree of development or maturation of the nervous system has been studied (128,209,210; Callaway, 1973). Research has also been conducted on the relationship of variability to intelligence (129), pathology (275), general nervous system properties (54), and so on. The overwhelming majority of the studies revealed correlation between variability characteristics and the indicators under analysis. Analyzing the results of these works (and when performing one's own research), it is important to recognize that different indicators are used to measure variability. Callaway and Halliday (130) provide a detailed comparative analysis of different variability indicators. They demonstrated in particular a relationship, varying in degree and sign, between five variability indicators and EP amplitude. Moreover their analysis showed that different variability factors (variations in latent periods and amplitudes of responses, the proportion of noise present, and so on) should affect different indicators differently. A researcher desiring to use variability as an EP characteristic should acquaint himself rather attentively with this work, since it is one of the most meticulous studies in this area.

Interindividual Variability

An interesting study by Childers et al. (143) sought the causes of interindividual variability. The authors based themselves on the idea that interindividual variability has two sources: one in common with intraindividual variability, and the other governed specifically by interindividual differences in reactions to a stimulus. The former source is the presence of numerous factors examined above, identical for all subjects and manifesting themselves randomly in the recorded EP at each given moment. It may be assumed for example that differences in the physiologicalstate of different subjects at the time of EP registration are a significant cause of interindividual differences. However, if the same factor lies at the basis of inter- and intraindividual differences, then averaging of an identical quantity (sufficiently large) of single EP's for the same subject and the same quantity of single EP's recorded from different subjects should produce identical or very similar EP's. The results showed that this does not happen: EP's obtained by summing 50 singular successive responses by the same subject differed very significantly from EP's obtained by averaging singular reactions of 50 different subjects. The amplitude of individual EP's was as a rule 1.5 times greater than that of the group EP. This means that interindividual variability is greater than intraindividual variability, and that is has "its own" sources, apart from those generating intraindividual variability.

In order to eliminate nonfunctional interindividual differences and amplitudes caused by thickness of bones or soft tissues and other like factors, Childers et al. compared EP variability following normalization. Normalized intraindividual EP's were also found to be greater in magnitude than interindividual EP's. We are still unsure of what "specific" sources of interindividual variability there are. One of them might be individual features associated with the relationship between the surface of the brain and the surface of the head: What appears on the basis of external criteria to be the same point on the surface of the heads of different people may be associated differently with the same region of the brain.

Evidence of this possibility can be found in the fact that interindividual variability of visual EP's decreases with three-dimensional averaging (107), and in simultaneous recording, by Childers et al., with numerous scalp electrodes followed by three dimensional representation of spatial-temporal EP's, which reduced interindividual variability. Given the introduction of appropriate technical devices into practical research, this technique will apparently aid research in which interindividual variability is an interference. This includes to some extent all research requiring group comparison of changes in EP's occurring in response to some particular influences. Differences that are distinctly evident in each subject may be smoothed out in group analysis, inasmuch as they fall within barely different time intervals (similarly as with reduction of the amplitude of a component due to the variability of its latent periods).

An example of such a situation can be found on comparing EP's in response to monocular stimulation of healthy individuals and patients with one injured eye. Comparison of EP's in response to stimulation of the stricken and the healthy eye did not reveal a statistically significant difference in the group as an average, while comparison of sets of EP's recorded in response to stimulation of the healthy and stricken eye of the same subject revealed, in all cases, a lower amplitude for the stricken eye (368).

It would obviously be sensible to select subjects with sufficiently similar EP's for group studies (or, what would be the same thing, to exclude, from the analysis, EP's that differed dramatically from those of the main group), or to isolate basic "types"--subgroups of curves from the sample under analysis, to perform intergroup statistical analysis on the basis of these subgroups, and then to make an attempt to identify the components in the different subgroups, after which the results are analyzed for the group as a whole.

Inasmuch as some fraction of interindividual variability stems from differences in the background EEG, it would possibly make sense to select subjects with similar background activity, or to try to present stimuli on an identical background.

The sources of interindividual differences continue to be an object of research. Data showing the correlations between some EP parameters and intelligence (see Chapter XII) and the genotypic dependence of EP shape (40,119) encourage a search for correlates, within individual features of EP's, of functional-morphological features of brain systems important to behavior. When repeated recording is involved, significant interindividual variability accompanied simultaneously by EP stability serves to some authors as the groundsfor suggesting individual specificity of EP's (97). Analogies are even made in this case with the individual specificity of fingerprints. Nevertheless it should be noted in this connection that individual specificity (in the meaning in which this concept is applied to fingerprints) had never been demonstrated yet in the literature available to us. In order to confirm the existence of individual specificity of EP's, we would have to demonstrate the presence of a set of characteristics in a combination that never repeats itself in any other members of a population sample of sufficiently representative size.

On the whole, EP variability is concurrently the "scourge" of research, limiting the possibilities of the method's application, and a significant EP characteristic, associated in particular with the maturation level (or state) of the nervous system (25,127,128).

MORPHOLOGY AND NEUROGENESIS OF EP'S TO STIMULI OF DIFFERENT MODALITIES

Because of the absence of standardization in EP recording procedures (which is fully understandable and unavoidable in the given stage), EP "standards" for what is "normal" do not exist. At the same time an increasingly greater amount of research is being conducted in this direction, and typical EP characteristics may be isolated from the published data for a certain set of conditions today. It would appear suitable to create a set of standards for the types of stimuli most frequently encountered in laboratory practice as a beginning "guidebook" for work with EP's.

Unfortunately the results of a literature analysis reflect the evolved stereotypes of research (arbitrary on occasion) and fail to fall within a well-ordered system: There are more data pertaining to some conditions or modalities, and less pertaining to others, and the main sample of "representative" results that are to play the role of "standard" would have to be taken from the available set of results intuitively. In doing so, we would of course consider the strictness and "purity" of the selected studies (registration of eye movements, control of muscular artefacts, sample volume, number of summations, presence of averaged background segments as a control, and so on), as well as the number of different works offering similar results in relation to EP morphology. The results of such an analysis are presented in the following chapters, which describe EP's in relation to different modalities of stimulation. We emphasize the great complexity of selecting the "standards" so that the reader who uses them would not abandon further analysis of EP morphology, and believe the presented data to be absolute. Slight discrepancies between EP's obtained in a concrete study and their "standard" are fully possible, even in similar recording conditions, but significant differences should signal the researcher that something is wrong.

CHAPTER VII

AUDITORY EP'S

Morphology of EP's to Clicks and the Beginning of a Tone

It was namely in response to sound that the first EP's were recorded and described: the K-complex arising during sleep (322), and reactions arising in the EEG during wakefulness and in light drowsiness, in response to sound (178). The potential oscillations Davis described, which fall within a period 100-120 msec following an acoustic stimulus, were named the "vertex potential," since they exhibited their greatest amplitude when recorded in the vicinity of the crown. They represent that part of the EP to sound in which the amplitude is most pronounced. As the recording equipment developed, earlier auditory EP components were recorded as well: first components arising in the 20-80 msec period following stimulus delivery (237), and later the earliest component, arising in the first 10 msec (286).

A detailed work published in 1974 offers results that may be used as a "standard" for EP's to a short tone or click (375). The research was conducted on 12 healthy adults. An EP from which 15 components could be distinctly isolated were recorded from the vertex of each of them (the indifferent electrode was positioned on the mastoid process) in response to a click with a loudness of 60 db and a stimulus delivery rate of 1 per second; 1,024 responses were summated. To isolate the different components, the EEG tape recording, which bore stimulus marks, was processes several times with different periods of analysis. The recorded EP's are shown in Figure 9*A*, *B*. The letter designations of auditory EP components used in the subsequent discussion correspond to the designations of Picton et al. According to the data of different authors, the similarity exhibited by EP characteristics (Table 1) attests to the validity of using the data of Picton et al. as a standard for an EP to tones or clicks recorded in the vicinity of the crown.

Goff et al. (1976) studied the characteristics of EP's to a click recorded from 24 points on the scalp in the 10/20 system (Table 2, figures 11, 12).

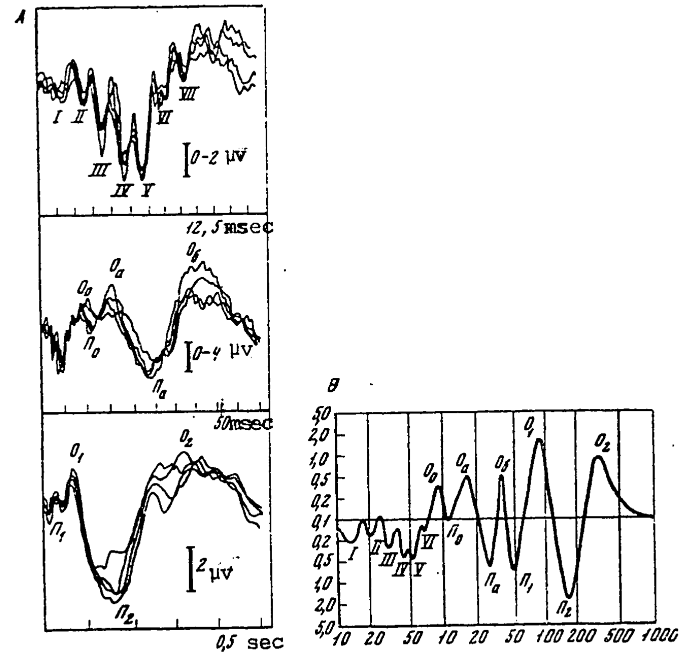

Figure 9. Typical Auditory EP Recorded in Response to a 60 db Click Delivered to One Ear With a Frequency of 1 per Second: *A*--Real EP of one subject, summated from 1,024 responses. Monopolar registration with electrodes in the vicinity of the crown and on the mastoid process; *B*--schematic EP to the same stimulus delivered to a group of eight persons, presented in logarithmic scale (375)

Figure 11 illustrates amplitude measurement and creation of isopotential maps for individual EP components presented in figures 12, 14, and 17, using an imaginary positive component with its amplitude maximum in the left parietal region. Examples of measuring amplitude from a base line to the peaks of components recorded with different points of contact are presented. At point C_z the component being measured is absent, it reveals itself at point T_6 but its amplitude, measured from the base line, is zero, its amplitude is negative at point C_4, and at point O_2 this component manifests itself as a small oscillation in another component. The amplitudes determined for all of these cases are shown. Fine stippling represents the area in which the component's amplitude attains not less than 75 percent of its maximum value, course stippling represents the region in which amplitudes are 50-75 percent of maximum, and the region of maximum amplitude is shaded. The same system of symbols is used in figures 12, 15, and 18. Diagonal lines drawn through points of contact in these figures represent all

Table 1. Latent Periods of the Components of EP's to a Click or a Short Tone, Frcm the Data of Different Authors, Msec (From Picton et al., 1973)

(1) Компоненты						(3) Автор, год
(2) Самые ранние						
I	II	III	IV	V	VI	
1,5	2,6	3,8	5,0	5,8	7,4	Picton et al., 1973
1,5	2,6	3,5	4,3	5,1	6,5	Jewett, Wilkinson, 1971
(W1) 1,5	(W2) 2,5	(W3) 3,5	(W4) 5,0		(W5) 6,0	Lev, Sohmer, 1972
(4) Средние						
О_0	П_0	$\text{О}_а$	$\text{П}_а$	$\text{О}_в$		
8,9	12	16	25	36		Picton et al., 1973
	(1) 13	(2) 23	(3) 28	(4) 39		Ruhm et al., 1967
	13	22	32	45		Mendel et Goldstein, 1969
	10	13	27	35		Goff et al., 1969
(5) Длиннолатентные						
(6) П_1	(7) О_1	П_2	О_2			
50	83	161	290			Picton et al., 1973
50	100	175	300			Davis, Zerlin, 1966
	90	175				Rapin et al., 1966
(П3а) 50	(03в) 81	(04в) 100	(П5а) 175			Goff et al., 1969

Key:

1. Components
2. Earliest
3. Author, year
4. Middle
5. Long latent period
6. P
7. N

points of contact at which the given component attains 90 percent of its maximum amplitude in at least one subject of a group.

Thus the number of diagonal lines in each region indicates the number of subjects for whom the amplitude of the given component attained 90 percent of maximum in this region. The maps were created for each subject and each component. Group maps were created in similar fashion. The number of subjects from whom EP's were recorded to compile the particular isopotential map is shown in parentheses.

Figure 12 shows the topography of an EP to a click. Components N75 and N95 are so variable among different individuals that the median amplitude did not exceed 50 percent of maximum at any of the points of contact; thus it was found to be impossible to create an isopotential map for these components

Table 2. Auditory EP Components (from (246))

(1) Компонент	(2) Латентный период, мсек	(3) Максимум амплитуды, мкВ			(6) Предполагаемое происхождение
		медиана (4)	(5) разброс		
(7) П10	9,8±1,7	+1,4	+0,5	+5,5	Н
(8) О15	15,8±2,2	—1,8	—0,8	—7,5	М
П25	24,8±2,6	+3,0	+0,9	+5,7	Н
О30	29,0±2,5	—1,0	+0,1	—2,5	М
П35	32,9±2,7	+4,8	+2,0	+16,2	М
О40	40,5±4,8	—3,5	—0,8	—8,5	М+Н
П50	51,2±4,7	+6,1	+1,0	+14,2	Н
О60	59,7±6,3	—3,2	—0,7	—7,7	М+Н
П70	69,5±5,3	+4,4	+0,2	+13,5	Н
О75	75,5±7,5	—2,2	—0,7	—8,4	М
П90	91,2±7,8	+10,7	+1,4	+52,0	М
О95	95,4±8,8	—1,2	+0,5	—4,8	Н
П110	112±22	+13,0	+0,7	+48,6	М
П115	114±7,7	+2,5	+0,5	+6,9	Н
О115	115±21	—7,1	—3,9	—9,8	Н
О145	146±16	—0,8	—0,1	—2,5	Н
П180	178±16	+16,7	+11,9	+24,4	Н
О230	230±18	—2,4	+1,5	—6,8	Н
П270	266±23	+3,8	+0,8	+11,0	Н
О300	296±34	—5,9	—3,6	—19,2	Н
П340	338±30	+2,9	—1,7	+5,2	Н
О400	394±26	—7,3	—3,6	—9,7	Н

Symbols: H--Neurogenic origin; M--myogenic origin.

Key:
1. Component
2. Latent period, msec
3. Maximum amplitude µv
4. Median
5. Scatter
6. Proposed origin
7. P
8. N

(Goff et al., 1976). The latent periods and variability of the components, shown in Table 2, were determined from the values of the given component at all recording points, while amplitude was determined only at the point where it exhibited its greatest value.

Mention should be made of the work by Wolfpaw and Penry (53), who believe that the difference they revealed between EP's to a click recorded at the vertex and in the temporal region is the result of addition of a group of "local" oscillations generated in the temporal cortex to the oscillations generated in broader regions of the cortex and reflected identically at the vertex and in the temporal region. Subtracting the EP recorded at the vertex from the EP recorded in the temporal region, they obtained a positive-negative complex with latent periods of 105-110 and 150-160 msec respectively, which they interpret as the temporal component of the auditory EP.

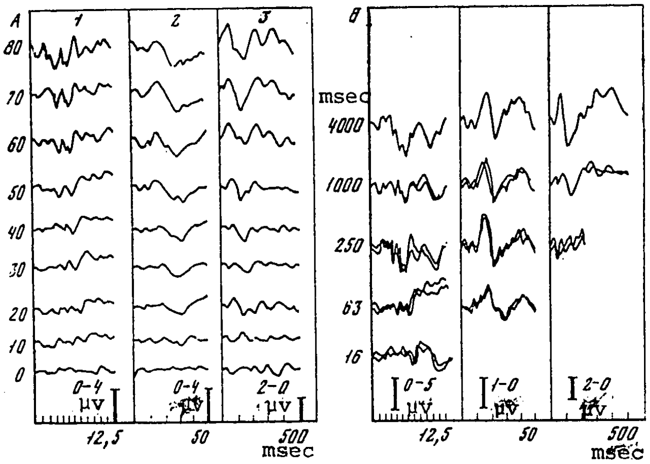

Figure 10. Effect of Some Stimulus Parameters on Auditory EP Components: *A*--Click Intensity: *1*--Averaged from 4,096 responses with an interstimulus interval of 50 msec; *2*--averaged from 2,048 responses with a 200 msec interval; *3*--averaged from 256 responses with an interstimulus interval of 2 seconds; *B*--Delivery rate: The number of summated responses is (from the top down) 1,024, 1,024, 2,048, 4,096, and 8,192 (375).

Data presented in (300) may be used to describe the approximate range of changes in the EP in response to change in the intensity and duration of stimuli, or the interstimulus intervals (Figure 10).

It should be noted that the analog filters used in most recording systems cause a shift in the latent periods, which may attain, in relation to early components for example, 13 msec and more (308).

Differences in the amplitude of EP's to tones of equal loudness may result, according to data from different studies, from differences in the rise times (484).

Presentation of a tone of sufficient duration causes arisal of an EP to stimulus cessation--the so-called off-reaction (157,296,358,434). EP's to stimulus cessation have a shape identical to EP's to stimulus onset, differing only by having a lower amplitude (by a factor of 2-3), and they are not pronounced in all people. As an example EP's to stimulus cessation were observed among 20 percent of subjects exposed to a 1,000 Hz, 50 db tone with a 1 second duration, and among 50 percent of subjects exposed to a tone of the same frequency with a loudness of 75 db and a duration of 1.5 seconds (157).

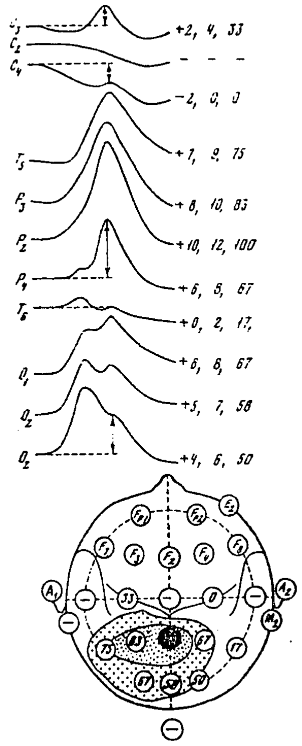

Figure 11. Analysis of the Topography of EP Component Amplitudes: The initial amplitudes (μv), amplitudes after transformation (μv), and amplitudes expressed as percentages in relation to maximum amplitude, adopted as 100 percent, are shown in that order to the right of the curves. See text for further explanation.

A somewhat shorter latent period for component N1 in the EP to stimulus cessation than that observed for the EP to stimulus onset was noted in a number of works. The amplitude of N1-P2 in the EP to stimulus sensation increases linearly with an increase in intensity, and the latent period of N1 decreases (434). It is interesting that the amplitude of the EP to tone onset is not always greater than that to tone cessation. Thus when tones of 500 msec dureation were presented with a 2,500 msec interval, the EP's to tone onset were about three times greater than EP's to tone cessation but when tones of a duration of 2,500 msec were presented with a 500 msec interval, the responses to the start of the tone and its end were identical (371).

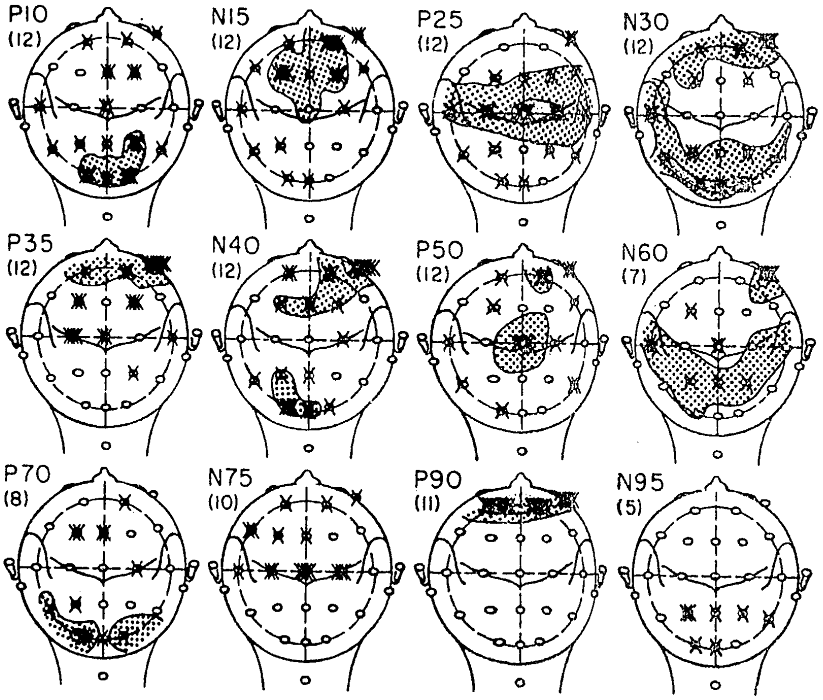

Figure 12. Topography of the Components of an EP to a Click: Explanation in text (see pages 62-64)

An increase in the preparatory interval, a decrease in the mean tone delivery rate, or uncertainty of delivery would increase the EP to both stimulus onset and cessation. This leads to the notion that amplitude is associated not only with the type of response (on or off) but also with the uncertainty of the moment of delivery.

Dependence of EP on Sound Frequency

The amplitude of N1-P2 has been shown to decline in response to an increase in tone frequency (86,221). It was hypothesized in this connection that one of the determinants of the amplitude of N1-P2 is the number of nerve elements in the cochlea activated by the stimuli (221). Because tone frequency is inversely proportional to the surface area of the basilar membrane activated, low tones elicit EP's of greater amplitude than do high tones. This explanation is in full agreement with the fact that the thresholds for stimulation by high tones (4,000-5,000 Hz) are higher than those

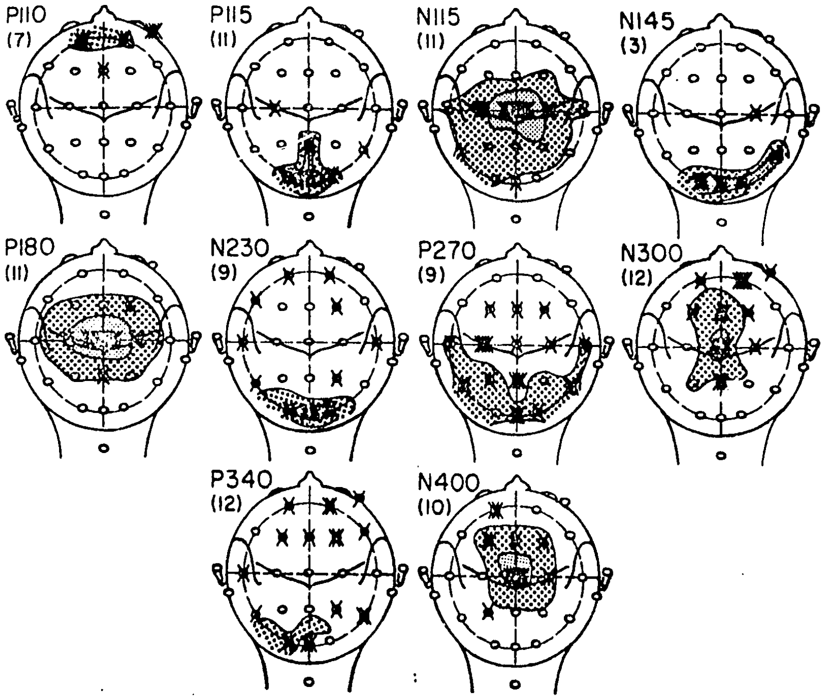

Figure 12. (Conclusion)

for low tones (250 Hz) (252), determined both from components N1-P2-N2 and from subjective reports, and with the fact that sound pitch influences the dependence of EP amplitude on intensity. It is interesting that the curve describing the dependence of amplitude on intensity for frequencies typical of speech lies somewhat higher than curves describing all other frequencies (503). It was concluded from an investigation of EP's to 375, 1,000, and 8,000 Hz tones, delivered either simultaneously with a 250 Hz tone or successively, that the amplitude of EP components N100-P180 reflects the activity of the auditory cortex and its tonotopic organization with every frequency broadly represented (Butler, 1972). The same is implied by the results obtained by Khechinashvili et al. (72).

EP's in Reponse to Change in Frequency of Constant-Intensity Sound

A special comparative study was performed on EP's in response to amplitude and frequency modulation of a tone in an effort to find the best type of stimuli to be used in audiometry (484). A 1,000 Hz tone 30 db above the subjective threshold was presented. The rise time was varied from 5 to

250 msec; the stimulus had a subsequent plateau of 800 msec, identical in the cases of amplitude and frequency modulation. The latent period of oscillation N1 and the amplitude of N1-P2 were determined. The amplitude and latent period were found to be greater with frequency modulation than with changes in amplitude (14 μv as compared to 8 μv), given an identical rise time. The greater the rate of growth in frequency changes, the greater was the amplitude and the shorter was the latent period. The latter varied from 114 msec (at a rise time of 5 msec, and with a frequency change of one octave) to 271 msec (at a rise time of 250 msec, with a frequency change of a tenth of an octave). With amplitude modulation, an increase in the rise time from 5 to 250 msec changed the amplitude and latent period from 8 μv and 112 msec to 4 μv and 198 msec. The amplitude and latent period of EP's to frequency modulation are more a function of the rate of frequency change than the magnitude of the change or the rise time. A rise time of 10 msec is, in the opinion of the authors, the most appropriate to audiometry. Inasmuch as one of the main functions of the human auditory system--discriminating speech sounds--is associated more with discrimination in the frequency spectrum than in intensity, use of frequency modulation as the stimulus in EP recording may turn out to be more adequate than tones and clicks in regard to research on functions of the auditory system and, in particular, speech perception.

Mention should also be made of research describing rhythmical oscillations with a period corresponding to the frequency of the delivered tone (348). Responses were recorded from the vertex, and 999 responses were summated. Tones in the 250-2,000 Hz range were presented. These frequency-specific reactions were distinguishable at an intensity of 10-20 db above the subjective threshold, but an intensity of more than 40 db was required for registration of distinct reactions. These reactions were also studied by Sohmer and Pratt (465).

EP's to Verbal Stimuli

When we record EP's to verbal stimuli, we encounter the problem of "physical" similarity of words in relation to the rise time of the leading edge of the sound, amplitude-frequency modulation, and so on. A longer rise time than with clicks and commonly employed tones is possibly the reason why EP's to verbal stimuli are often of lower amplitude than EP's to tone bursts of the same intensity (Figure 13).

Usually when we record EP's to verbal stimuli, the latter are recorded on tape, which is then played back to the subject in such a way that the moment a word begins is synchronized with the beginning of the averaging interval. For some reason studies involving the use of EP's have still not made use of artificial formants which could be subjected to speech analysis, and which could at the same time yield more readily to smooth physical modulations than do pronounced words.

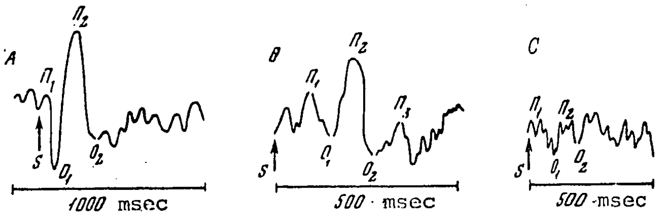

Figure 13. EP's in Response to Tones and Verbal Communication: *A*--to 500 Hz, 90 db tones; *B*--to the beginning of a verbal communication containing an instruction; *C*--to the beginning of the same communication played backwards--that is, a meaningless speech fragment (Sharrard, 1972)

Published data concerning the shape of EP's to verbal stimuli and the degree of their similarity to EP's to nonverbal stimuli having comparable physical characteristics are rather contradictory, which may be the product of different experimental conditions. Comparing EP's to verbal stimuli with EP's to tones or clicks, some authors fail to note any significant differences (222,356,414,446), while others describe entirely different EP's to monosyllabic words and to noise of similar configuration and intensity: N40, P80, N123, P213, N262, P322, N363, and P411 after words, and P23, N47, P93, N185, P244, N374, P415, and N456 after noise (92). The following EP's were recorded monopolarly in the temporal region in response to spoken numbers and clicks presented at the same loudness (85 db): P42 (20-50), N101 (85-130), P205 (185-230), N266 (240-280), P317 (290-350) (356). In a number of works (249,346,540) only two components are clearly isolated in EP's to verbal stimuli: N69-153 and P160-306. Wood and Goff (1971) describe a triphasal complex: P100, N200, and P250-800. We can see from the available studies that it is fully possible to record EP's to verbal signals, and that they can be used productively to solve the corresponding problems.

It would be important to note the following. By evolved tradition, differences between EP's to verbal and nonverbal stimuli are usually interpreted as changes in the amplitudes or the latent periods of individual components. Implicit to this tradition is the supposition that the component remains constant in the examined cases. We should expect, however, that EP's to verbal stimuli would to have a somewhat different origin from that of EP's to clicks or tones (in the same way that the origins of early components of EP's to illumination changes and to changes in the structure of the visual field are different), though experimental proof of this does not exist as yet, if we discount data on interhemispheric asymmetry (see Chapter XIII). This hypothesis is based mainly on the fact that the integrity of the auditory cortex is not significant to discrimination of the intensity and frequency of long tones, but it is necessary to discrimination of the temporal characteristics of a stimulus, to perception of short stimuli, and to analysis of verbal stimuli. Detailed study of EP's to verbal stimuli, their description in relation to the most widespread situations, and the study of their neurogenesis will probably occur in the near future. Without a doubt their use will broaden in the near future, both in research on the mechanisms responsible for analysis of verbal stimuli, development of speech, and dominance of the hemispheres, and in the study of memory, attention, and so on.

Neurogenesis of the Components of EP's to Clicks or Short Tones

The hypothesis that oscillations arising on the scalp in the first 10 msec following a stimulus reflect activation of the cochlea, transmission of impulses along the auditory nerve, and activation of the brain stem's auditory nuclei (286) was confirmed by an analysis of the distribution of the amplitudes of these oscillations over the scalp (375). The neurogenesis of components falling within the 10-60 msec period following the stimulus remains extremely unclear. The authors of the first description of auditory EP components falling within the 10-60 msec period following the stimulus (238) interpreted them as a reflection of intracerebral potentials. Following Bickford's work (101,102), which demonstrated the doubtless presence of myogenic artefacts in this period, many studies were performed to reveal the origin of the components within this period. These efforts confirm the significant hazard of "contamination" by myogenic artefacts, but they simultaneously present numerous data on the intracerebral origin of components in this period (137,245,246,325,376,422,460).

Goff et al. (1976) conclude from their own data and from an analysis of Picton et al. (376) that components in the 10-60 msec period are basically neurogenic, but they may be "contaminated" by myogenic artefacts, thus in the end representing an alloy of neurogenic and myogenic activity. One of the sources of "contamination" is muscular activity in the course of the startle reflex following loud sounds, in connection with which Picton et al. recommend avoiding loud sounds and recording EP's in the vertex area (where there are no muscles) or during sleep (when muscles are relaxed).

What is the origin of cerebral EP's falling within this period? Their latent periods imply a relationship with the activity of the medial geniculate body, thalamic nuclei, and the auditory and associative cortex. Inasmuch as very low correlation was discovered between the latent periods of EP's recorded from the primary auditory cortex and EP's recorded from the scalp (137), Picton et al. suggest that the activity of the primary auditory cortex is reflected to a very small extent in EP's recorded from the scalp. They believe that components N_o, P_o, and N_a (see Figure 9) reflect the activity of the medial geniculate body or polysensory thalamic nuclei, and that oscillation P_a represents activation of neurons in the associative cortex. The latter hypothesis is grounded in the fact that a pronounced positive oscillation with a latent period of 25-30 msec has been recorded intracranially from the associative cortex of the frontal, occipital, and parietal regions (136,141,422). Thus in their opinion nonspecific oscillations arise in the first 50 msec after the auditory stimulus.

According to Goff et al. (1976) the 60-110 msec period is filled mainly with myogenic oscillations; we were unable to find persuasive data in the literature indicating the neurogenesis of components falling within this period. All components following component P115 have a "pure" neurogenic origin. The largest number of neurogenesis studies is devoted to components N1 and P2--the so-called vertex potential, the part of the EP that has the most pronounced amplitude. As was noted earlier, for a rather long period of time these oscillations were thought to be a reflection of the activity of the brain's nonspecific activating system (321).

Investigation of the distribution of the amplitudes of all components of tonal EP's recorded from the scalp led to the conclusion that components N1-P2 arise in the auditory cortex (508,510). It was discovered that the amplitude of N100-P200 had its maximum at the vertex, that it decreased as the electrode was moved away from the latter in a frontal direction, attaining its zero value approximately at the level of the line passing above the fissure of Sylvius, and then that it once again increased with opposite sign. Earlier oscillations also changed in similar fashion. The authors computed the theoretical distribution of potentials over the scalp for all hypothetically possible sources of these oscillations, basing themselves on data concerning the morphofunctional structure and temporal characteristics of the auditory system, and current ideas about the distribution of potentials over the surface of a three-dimensional conductor. After this they selected, from the set of hypothetically possible sources, that for which the theoretical amplitude distribution agreed best of all with the empirically obtained distribution. A dipole layer perpendicular to the surface of the cortex and parallel to the orientation of the primary auditory cortex (Heschl's gyrus) was found to be such a source. The authors concluded that the examined EP components are generated in the primary auditory cortex. This was also in agreement with the dominance they noted of EP amplitude on the side opposite the stimulated ear for the case of monaural stimulation. Other authors came to similar conclusions as well (245,534), discovering that integrity of the primary auditory cortex is necessary if EP components falling within the 100-200 msec period following a stimulus are to be recorded in response to sound from patients with cerebral afflictions.

It should be noted that Kooi et al. (303) were unable to detect a shift in EP polarity above the fissure of Sylvius when EP's to sound were recorded with the indifferent electrode located in the vicinity of the rib cage, and they explained the shift in polarity observed by Vaughan and Ritter by the fact that the indifferent ear electrode was in fact active, with its activity exceeding that beneath electrodes below the fissure of Sylvius, which is what causes change in polarity. Polarity shift in the vicinity of the fissure of Sylvius was later shown to occur with an extracranial electrode (314,463).

Picton et al. believe that polarity shift is caused more likely by the activity of the lower margin of the hemisphere than by a deeply located dipole (one in the auditory cortex), and that components N1-P2 reflect mainly the activity of the frontal and not the auditory associative cortex. Their opinion is based on two groups of facts. On one hand they observed these components to have their highest amplitude in the frontal and central regions, and other authors (517,527) recorded oscillations with comparable latent periods directly within the frontal cortex, while on the other hand their research did not reveal a shift in the polarity of N1-P2 when the recordings were made with a thoracic electrode, and that there was no interhemispheric difference in EP's in response to monaural stimulation. Moreover, recording directly from within the auditory cortex, they noted absence of oscillations with latent periods close to those of EP's recorded from the scalp (137). The fact that these components are absent or reduced among patients with damage to the primary auditory cortex is interpreted by these authors as evidence of an influence played by the primary auditory cortex upon the activity of the frontal associative cortex via cortical-subcortical-cortical or cortical-cortical pathways. Picton et al. concurrently presumed that the auditory cortex also participates to some extent in the generation of these components, in addition to the "main" source in the frontal associative cortex, and they agree fully with the idea (510) that these components are mode-specific.

Significant evidence indicating participation of the primary auditory cortex in the generation of N1-P2 is contained in the work of Peronnet et al. (366), who concluded that components N1-P2 reflect the activity of the auditory cortex and the parietotemporal associative cortex, the degree of participation of these regions depending on the experimental conditions and individual features of the subject. Butler's data (122) on the frequency specificity of these components and on their reflection of the tonotopic organization of the auditory cortex also imply participation of the auditory cortex in generation of N1-P2. The complex polygenic nature of components N1-P2 is confirmed by Khechinashvili et al. (1973), who suggested, on the basis of the presence of two "saturation" points accompanying an increase in the amplitude of N1-P2 connected with growth in stimulus intensity, existence of two independent systems generating these components.

And so, most of the data today indicate that the auditory and associative (frontal and parietotemporal) cortex perticipates in the generation of N1-P2. These components are doubtlessly polygenic, and our ideas about their generators will obviously become more refined, and they will undergo change. Much less research has been conducted on the origin of the rest of the components falling within this period, ones which may vary independently of one another. In sleep, for example, only the amplitude of oscillation N2, which is interpreted as a reflection of difuse activation of the cortex (375) in sleep, rises. However, why the rest of the components do not increase concurrently remains unclear. Ritter and Vaughan (1972) believe oscillation N250 to be part of an associative potential of the cortex, inasmuch as it is also observed in the presence of an expected stimulus (301,375). However, it is unclear as to how much the nature of the negative oscillation of this period in response to an indifferent stimulus is similar to that of an oscillation arising in response to omission of an expected stimulus or the action of signaling stimuli (458).

Goff et al. (246) suggest that oscillations following components N115-P180 in an EP to an indifferent stimulus are possibly a manifestation of the so-called postdischarge. The idea that oscillations P270 and P340 reflect a so-called late positive oscillation is believed by Goff et al. to be less probable, inasmuch as these oscillations exhibit different amplitude distributions over the scalp.

Kevanishvili et al. (299) published an article analyzing the origin of a number of components of tonal EP's. Relying on their own and published data, the authors concluded that components P51, N100, and P192 and the following negative-positive complex have varying origin. This is implied by facts such as the difference in the nature of the association expressed by the first three components and two subsequent ones with stimulus intensity, the differences exhibited in their ontogenetic changes, the decline of the former in response to an increase in the latter during sleep, the shorter recovery period of the latter, and so on. It is hypothesized that oscillations P51, N100, and P192 reflect activity of the associative cortex arising in response to impulsation from nonspecific thalamic synchronizing nuclei.

Considering the certain contradiction existing between this hypothesis and information on modal specificity of components within the first 200 msec following a stimulus, the authors note that the existing notions, based on animal experiments, that a relationship is necessarily present between specificity and projection zones cannot be applied with full certainty to man. They emphasize the known fact of inter- and intramodal specificity of reactions within the thalamic nonspecific system, and they suggest the hypothesis that reactions of the associative cortex may be more specific in man than in animals.

CHAPTER VIII

SOMATOSENSORY EP'S

Somatosensory EP's are reactions to stimulation of skin receptors and proprioceptors. Electrocutaneous stimulation continues to be the most frequently employed stimulation technique when recording somatosensory EP's, though natural stimulation techniques are also being utilized with increasing frequency--pricking the skin lightly with a pin, touching the skin, applying pressure, blowing streams of air, or striking a tendon with a hammer. The shortcoming of electrocutaneous stimulation is that it is "not physiological," while its advantages include synchrony of stimulation, which produces EP's of greater amplitude than those acquired by other stimulation techniques, and the ease of "dosing" the stimulus. Incidentally, the possibility is not excluded that the "nonspecific" action of electrocutaneous stimulation--alarm caused by an unusual stimulus--plays some sort of role in the high amplitude of responses to electric stimulation: Recording EP's directly from the cortex during an operation, Jasper et al. (277) noted that the amplitude of the response to moderate "physiological" tactile stimulation is greater than a response to a strong electric stimulus.

It should be remembered that the nature of outwardly similar components recorded with the use of different stimulus techniques may turn out to be entirely different, inasmuch as different forms of stimulation may address themselves, in part or in their entirety, to different peripheral receptors, and as a result they may activate entirely different cortical neuron elements, in the same way as has been demonstrated for different types of visual stimulation.

Morphology of EP's to Electrocutaneous Stimulation

Electrocutaneous stimulation is performed most frequently in the wrist region, where the median nerve is located closest to the surface, or (more rarely) in the region of the distal phalanx of the hand, usually of the index finger. Short (0.1 msec and less) square pulses of minimum intensity sufficient to cause muscle contraction in response to stimulation, or of near-threshold intensity (on the basis of a subjective report) are used (for greater detail see (76)).

A tremendous number of papers describe EP's to electrocutaneous stimulation, beginning with the work of Dawson (179), who used averaging for the first time (81,131,186,243,245,246,353,442,489; Goff et al., 1962; Shagass, Schwartz, 1963; etc). We can apparently adopt, as our normative data, the descriptions of somatosensory EP's to electrocutaneous stimulation presented in a number of works (245,246,489) (figures 14 and 15, Table 3).

Differences in the characteristics of early components cited in different works can be seen in Table 4. One of the possible reasons for the discrepancies in amplitudes and latent periods of the early components of EP's to electrostimulation may be differences in the system of filters used to record the EP's (187).

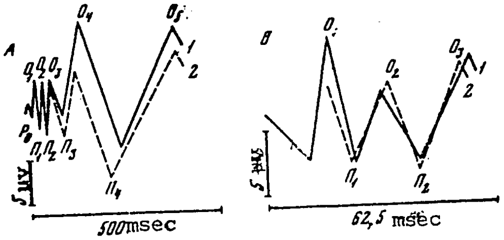

Figure 14. Schematic Somatosensory EP's at Age 9-18 (*1*) and 19-29 (*2*) (For Groups of 20 and 40 Persons Respectively): *A*--EP as a whole; *B*--early components (489)

An investigation that isolated two groups of subjects on the basis of different characteristics exhibited by the early components of EP's to electrocutaneous stimulation (243) indicates a possible cause of the discrepancy in descriptions of early components of somatosensory EP's to electrostimulation. Components N19, P27, N36, and P45 were recorded in one of the subgroups (18 persons), and components N18, P22, N26, P30, and P49 were recorded in the other (seven persons)--that is, another two components were recorded between components P22 and P49 (common with the first subgroup)--N26 and P30. Giblin suggests that all subjects have all of the components, but that in the first subgroup they are summed during the averaging process in such a way that they are indistinguishable as individual components. In general, positive oscillations with latent periods of 21-31 msec and 33-50 msec are the early components most frequently isolated. Oscillation P2 (33-50 msec) is followed by two negative-positive complexes: N3 (65 ± 14 msec), P3 (85 ± 20 msec), and N4 (135 ± 25 msec), P4 (220 ± 45 msec) (245). According to Tamura et al. (489) a group of 40

Table 3. Somatosensory EP Components (From (246))

(1) Компонент	(2) Латентный период, мсек	(3) Максимум амплитуды, мкВ			(6) Предполагаемое происхождение
		медиана (4)	разброс (5)		
(7) О14	14,2±0,9	−2,3	−1,1	−11,5	Н
(8) П15	14,9±1,4	+1,9	+1,6	+4,4	Н
О20	21,3±2,1	−2,0	−0,9	−3,3	Н
П20	20,9±1,8	+2,2	+0,7	+3,8	Н
О25	24,4±1,9	+1,2	+0,5	+4,3	Н
П30	28,6±3,4	+2,7	+1,2	+6,0	Н
О35	34,5±4,5	−4,2	−2,5	−7,3	Н
П45	44,9±4,8	+4,2	+1,8	+9,1	Н
О55	55,3±6,6	−3,8	−1,7	−9,2	Н
П65	65,5±5,2	+6,1	+1,3	+11,3	М
О70	71,8±6,8	−2,3	−0,4	−8,3	М
П80	79,5±6,3	+6,3	+2,0	+17,4	Н
О90	89,3±6,5	−1,1	+7,4	−5,5	Н
П100	102±12	+13,0	+6,5	+42,7	М+Н
О140	140±13	−8,9	−3,0	−18,2	Н
П190	192±16	+18,1	+10,6	+29,2	Н
О260	256±24	−4,7	−0,1	−12,5	Н
П300	295±30	+7,6	+3,5	+18,1	Н
О360	362±38	−9,5	−3,9	−17,3	Н
П420	418±48	+2,7	+1,4	+4,8	Н
О460	461±52	−5,1	−2,9	−8,[illegible]	Н

Symbols: H--neurogenic origin; M--myogenic origin

Key:

1. Component	5. Scatter
2. Latent period, msec	6. Hypothesized origin
3. Amplitude maximum, μv	7. N
4. Median	8. P

persons had the following components: N3-50 (8 ± 1.39 msec), P3 (85.4 ± 2.3), and N4 (135.9 ± 4.0), P4 (242.3 ± 8.8). In this work the authors also isolated negative oscillation N5 with a latent period of 391.8 ± 13.5 msec. A particular oscillation may be absent from any real EP with a lesser or greater probability. Data on the frequency with which individual components are recorded may be found in the work of Goff et al. (1976) (see Figure 15), and in tables 3 and 4.

Registration of oscillations from the scalp and above the cervicothoracic division of the spine reflecting activity in the afferent pathways and nuclei of the spinal cord, the brain stem, and subcortical nuclei in response to electrocutaneous stimulation has been reported several times in recent years. Jones (290) distinguishes four negative oscillations with latent periods of 9, 11, 13, and 14 msec; he believes that they reflect activity arising in response to stimulation of the median nerve in the

Table 4. Polarity and Latent Periods of the Components of EP's to Electrostimulation of the Median Nerve or Finger, According to the Data of Different Authors

Характеристики ВП (1)	Автор, год (2)
(3) П16 (4) O20 П25 П31 П48 O65	Goff et al., 1962
O20 П27 O38 П46	Larson, Prevec, 1969*
O18 П25 O34 П44	Nakanishi et al., 1973
O18 П25 O32 П43 O55 П85 O136 П242 O392	Tamura et al., 1972
П17 O24 П37 O62 П82 O118 П160	Lee et al., 1974
П16 O19 П24 O32 П37 O59 П88 O125 П161	Cracco, 1972
O20 П44 O76 П110 O168	Ikuta, 1972
O20 П29 O33 П39 O73 П96	Shagass, 1972
П26 П32 П42 П95 O110 П217	Velasco, Velasco, 1975**

* The named components were isolated on the basis of their own data and seven works by other authors.

** Recorded from the exposed cortex of 10 persons.

Note: The authors underscored the most stable components.

Key:

1.	EP characteristics	3.	P
2.	Author, year	4.	N

brachial plexus, the posterior roots or posterior columns of the spinal cord, the brain stem, and possibly the thalamus.

Morphology of EP's to Tactile Stimuli

Mechanical stimulation was used much more rarely in research on somatosensory EP's than electrocutaneous stimulation. This is connected with the methodological difficulties of the former. Nevertheless the possibility for recording, from the scalp, EP's in response to light touching of the skin or short-term touching and pressure with a hammer (226,251,309,340, 353,354; Erenberger et al., 1966; etc.), and to striking a tendon with a hammer (268,269) has been undisputably proven as of today (Figure 16). Distinct EP's can be recorded in response to mechanical stimuli whose intensity is insufficient for acquisition of reproducible cumulative nerve action potentials (309).

An electric vibrator is used most frequently for stimulation; the amount the head moves depends on the voltage applied, which makes it possible to fix the moment of stimulation and dose the stimulus with precision to allow study of the dependence between the EP and the intensity (226). The head of the vibrator is situated next to the pad of the finger (or some other object of stimulation) such that movements of the head are perpendicular to the surface to be stimulated. The nature of stimulation depends on what is attached to the head of the vibrator: a soft- or hard-bristled brush,

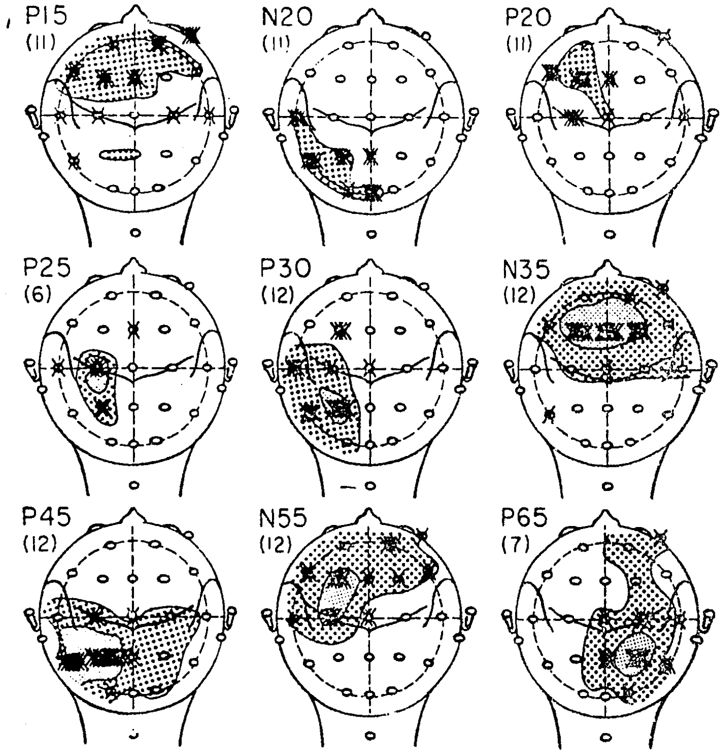

Figure 15. Topography of A Somatosensory EP (Goff et al., 1976)

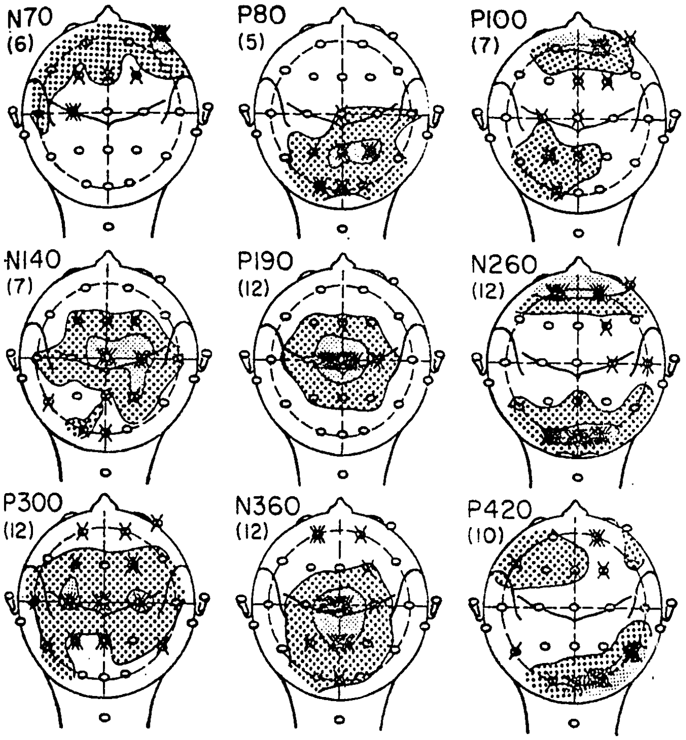

Figure 15. (Continued)

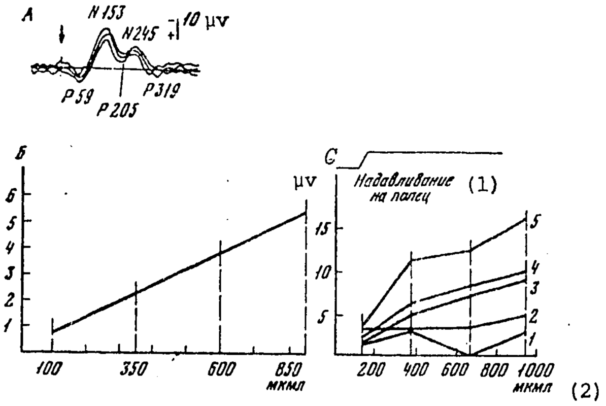

Figure 16. EP in Response to Pressure Applied to the Skin of the Right Index Finger: *A*--Typical EP averaged from 128 responses. Monopolar recording, with the active electrode in the primary projection zone; negativeness upward. The latent periods are indicated in msec; *B*--psychophysical curve. Subjective assessment of stimulus intensity in response to different forces (averaged normalized data for a group of nine persons); *C*--Dependence of peak-to-peak amplitudes of different components of the somatosensory EP of the same subject on pressure applied to the skin. *1*--N25-P59; *2*--P206-N245; *3*--N245-P318; *4*--N158-P206; *5*--N59-P158. Vertical lines indicate standard error of amplitude determined from 128 responses (Jonson et al., 1972)

Key:
1. Pressure upon finger   2. µml

a hammer, or a pin. The action of such stimulators is usually accompanied by a short burst of sound, which by itself may elicit auditory EP's (483), which should be accounted for when analyzing the results. In order to preclude "contamination" of the tactile EP's by reactions to sound, the EP's are usually recorded on a noise background that masks the clicks generated when delivering the tactile stimuli.

Early reactions to tactile mechanical stimuli are similar in shape to reactions to electrostimulation, differing only in having a lower amplitude and greater latent periods. EP's to different types of somatosensory stimulation were compared in a group of 33 persons (354). EP's were recorded in this study bipolarly with silver needles. Good agreement was revealed between the results of these authors and those of other works in which electrostimulation was employed; latent periods were longer and amplitudes were lower for the components of EP's in response to mechanical stimulation than those in response to electric stimulation; moreover the expressiveness of the responses was lower for the former (measured in terms of the number of subjects from whom this EP component was recorded): Responses to stimulation by touching with a soft-bristled brush were recorded from 69 percent of the subjects while responses to electrostimulation were recorded from 100 percent of the subjects. Differences in the latent periods of EP's to stimulation of fingers and toes corresponded to the difference in the distance from the cortex and in the rate of conduction of nerve impulses. The latent period and shape of EP's recorded at symmetrical points on different hemispheres were the same, while the amplitude could differ significantly. The EP characteristics cited by these authors are close to reactions described in response to similar stimulation in a number of other works (309,340; Offenloch, 1968; etc.).

Note that similarity in EP's to electric and tactile stimulation does not mean that the structures generating them are completely identical. Precisely what fibers are stimulated with electrostimulation is not entirely clear; it may be that some part of them are not fibers activated by tactile stimuli. Proprioceptors, particularly receptors providing information on tendon position, or "articulation sense," play a significant role in electrostimulation (243).

EP's were recorded in response to blowing a stream of air at the cornea or the nasal mucosa (338). Two oscillations with peak latent periods of 100 and 200 msec were isolated. The authors believe the first oscillation to be a manifestation of the blinking reflex, and the second they interpret as a vertex potential--that is, as an analog of the positive oscillation with a latent period of about 200 msec observed in EP's in response to all stimuli, particularly in EP's in response to electrostimulation of the median nerve and to vibrotactile stimulation. This oscillation was best expressed at point N3, where its amplitude attained 2-5 μv. The authors believe absence of earlier oscillations to be a consequence of low stimulus intensity, the increase of which is hindered by blinking.

Registration of scalp EP's in response to electrostimulation of tooth pulp has been reported (140). The authors interpret the oscillations they recorded as the first objective correlate of acute experimental pain. EP's have been recorded in response to change in skin temperature (142), and stimulation of taste receptors (232).

EP's Arising in Response to Passive Movement of a Finger

EP's in response to passive movement of the index finger 45° were recorded in seven patients in the procentral, postcentral, and prefrontal cortex with subdural electrodes, and with superficial electrodes in the precentral and postcentral regions and vertex of the same patients and five healthy individuals (362).

All electrodes were positioned in the right hemisphere. All subjects exhibited stable reactions in response to passive movement of the finger. An initial positive oscillation was observed after 36 ± 6 msec in the contralateral pre- and postcentral regions of the cortex, attaining a peak after 42 ± 4 msec. Its amplitude varied from 5 to 25 μv in different people, and it was greater in the postcentral region. It was followed in the precentral region by a negative oscillation with a peak latent period of 68 ± 15 msec, and an oscillation in the postcentral region with a peak latent period of 97 ± 20 msec; its amplitude varied from 30 to 50 μv. Subsequent oscillations observed over a period of 400 msec were stable in the same individual but varied significantly among different people. Reactions began to occur in the prefrontal region after 100 msec, and they were identical for ipsilateral and contralateral movements. The EP to ipsilateral movement, recorded in the pre- and postcentral regions, began with a positive oscillation with a latent period of 60 msec and more. High cross correlation (0.85) was noted for EP's recorded from the same points of contact, and low cross correlation (0.25) was observed for EP's recorded with different points of contact. Flexing and extending the hand did not change the EP, nor was activity noted in the finger EMG in response to passive movement, which is interpreted as evidence of reflection, within the EP, of the activity of afferent elements in the ligaments, and not in the muscles. Additional investigation of EP's recorded during short-term ischemic anesthesia permitted the authors to conclude that the EP's they recorded basically reflect activation of afferent fibers in the ligamental apparatus. Other characteristics of EP's recorded during passive movements are presented in (46).

Neurogenesis of the Components of EP's Arising in Response to Electrocutaneous Stimulation

The earliest oscillation recorded from the back surface of the neck, N14, reflects passage of afferent impulses along the cervical division of the spinal cord (Goff et al., 1976). The first EP component recorded on the scalp--P15--is viewed by most researchers to be a reflection of activation of subcortical structures--the thalamocortical radiation or the ventrobasal thalamic nuclei (81,112,246; etc.). Opinions concerning subsequent components are less unanimous.

Allison et al. (1973) evaluated the negative oscillation following the first positive one as a reflection of the transmission of impulses through the thalamocortical radiation; the next positive oscillation is interpreted as a reflection of primary positiveness--that is, activation of the bodies of neurons in the primary projection zone of the cortex by an afferent volley. The next positive oscillation, falling within the 35-50 msec period, which in distinction to previous ones was suppressed by anesthesia, was evaluated to be a reflection of the activity of neurons and the associated cortex, as a manifestation of activating influences by the ascending reticular formation.

Detailed analysis of the origin of early components reveals (112) that the negative and positive oscillations following P15-16 are recorded both from the scalp and the exposed cortex; in both cases they had opposite polarity depending on whether they were recorded in the precentral region or the postcentral region. It was concluded on the basis of this fact and other data that the two oscillations are generated by a horizontally oriented cortical dipole located in the rear wall of the central fissure. The opposite polarity resulting from the recording of these components in the precentral and postcentral regions stems from the fact that in these regions, the electrodes are correspondingly closer to different poles of the dipole. According to other data (455) oscillation P30 is generated in the posterior division of the central gyrus.

Thus there is no unanimity in opinions on the neurogenesis of early oscillations besides P15-16, but most researchers agree that these oscillations are a reflection of the activity of the somatosensory cortex (112, 226,511; etc.), and without a doubt they have an intracerebral origin, inasmuch as they are registered from the surface of the brain (246).

The search for the sources of these oscillations usually begins with the premise that they are monogenic in nature. It has been suggested, meanwhile, that their origin is polygenic (166). The latent period of component P13-17 was discovered to be independent of the scalp recording point; the latent periods of subsequent negative and positive oscillations resulting from movement of the electrodes sagittally were found to change regularly as well. Latent periods of subsequent oscillations varied differently for different subjects. The nature of changes occurring during sleep was different from that of changes occurring during alertness. Examining the possible explanations of the observed changes, the author believes algebraic summation of different cerebral generators that are activated nonsimultaneously to be the most probable. (The rate of change of the latent period--several milliseconds from point P1 to O1--is a little too great for transcortical propagation of an excitation.) The author suggests that the generators of these oscillations are in subcortical regions.

Distinct correspondence of components N45, P45, and N55 with simultaneous intracerebral potentials was not found. Nevertheless Goff et al. (246) hypothetically view them as neurogenic, in distinction from the subsequent oscillations, P65 and N70, which are evaluated as myogenic. Oscillation P100 represents, according to the same authors, an alloy of a myogenic potential dominating in the anterior regions and a neurogenic potential dominating in the posterior parietal region, and hypothetically reflecting, as is the case with component P80, neuron activity in the somatosensory cortex, which is recorded from the surface of the pia mater in the postrolandic region in the form of oscillations P100-N200.

Ideas concerning the origin of oscillations N140 and P190 (the vertex potential) have undergone a certain amount of evolution (see chapters VII-IX), and their connection with the activity of the somatosensory cortex may be said to be proven (246). Ideas on the later activity exhibited in the EP to an indifferent stimulus are very hypothetical, as is the case with analogous components in responses to stimuli of other modalities.

Goff et al. (1976) suggest that these oscillations are neurogenic, and that they reflect a postdischarge potential. Thus they hypothesize that component P300 following an indifferent stimulus is different in nature from a simultaneous EP component recorded in response to a significant stimulus.

CHAPTER IX

VISUAL EP'S

Morphology of Visual EP's

Using the data available in the literature, we can quite distinctly isolate the basic, sufficiently typical and reproducible components, beginning with 40 msec. In the occipital region, oscillation P150-200, which can serve as a "label" for identification of the rest of the components, is the most pronounced in amplitude and stability as a rule (88,209,272). (This oscillation is usually interpreted as component VI in Ciganek's designation system. It is preceded by negative oscillation N110-150, before which a rather variable positive oscillation, P100-110, is recorded (Figure 17). We can note from our own data and published information that while oscillation N110-150 is expressed quite distinctly in some subjects, having an amplitude close to that of P150-200, it is expressed weakly in others, appearing as a "hump" on a maximum positiveness consisting of two peaks--P100-110 and P150-200. Oscillation P100-110 can also be distinctly pronounced, while sometimes it is barely evident within the descending phase of P150-200, or it may be entirely undetectable; in this case, naturally, N110-150 is also not recorded, or it is barely evident, and that entire period is occupied by the "descending" side of oscillation P150-200. Oscillation N70-80, which precedes P100-110, is distinctly expressed as a rule. According to some data it is preceded only by oscillation P30-60 (70,245), while according to other data several earlier oscillations may be recorded (Table 5). A negative oscillation, N250-280, is recorded after oscillation P150-200. A postdischarge is often observed after a visual EP.

To describe the frequencies at which different components are recorded, in addition to Figure 18 we can use the data cited by Hull (272), who distinguishes components N50, P66, N85, P103, N126, and P174 in monopolar recordings of EP's to a light flash in the vicinity of the vertex. N85 oscillations are identified in 59 percent of the cases, P103 and N126 oscillations are identified in 54 percent, N50 and P66 are identified in half the cases and less, and only P174 is detectable every time. The characteristics of an EP to a light flash, based on the data of different authors, are presented in tables 5 and 6 and in figures 17 and 18.

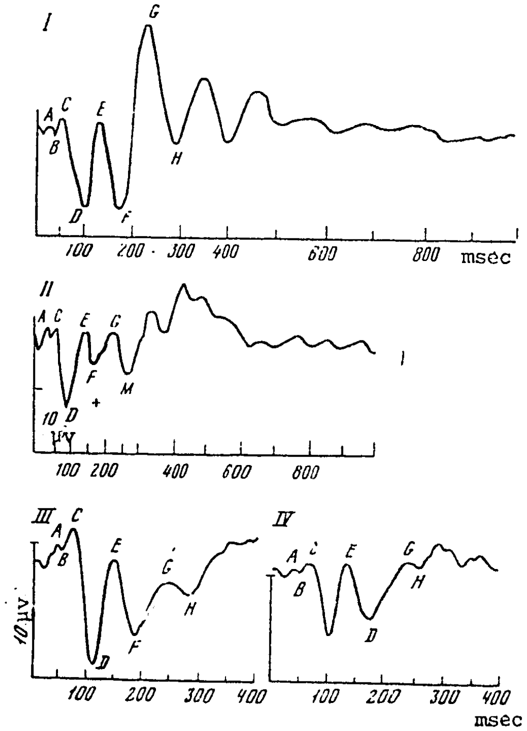

Figure 17.. Visual EP: *1*--typical visual EP to a light flash, in which eight oscillations can be isolated within the first 300 msec. after stimulus delivery; *2-4*--different variants of an EP illustrating presence of eight distinctly distinguishible components: *2*--an EP of one subject, summated from 24 responses; *3*--an EP summated from the responses of 10 persons (from 2,400 individual reactions); *4*--an EP summed from 1,000 singular reactions (from 100 responses recorded from each of 10 subjects) (97)

Goff et al. (246) provide the fullest description of potential changes on the scalp in response to monocular presentation of a light flash in the center of the visual field. Detailed acquaintance with this work is mandatory to investigation of visual EP's, and therefore the results of these authors are not illuminated in detail here.

An EP can also be recorded in response to switching off a light--the so-called off-reaction (12).

Table 5. Characteristics of the Components of an EP to a Light Flash, Recorded Monopolarly in the Occipital Region

(1) Параметр		П	O	П	O	П	O	П	O	(2) Число испытуемых	(3) Автор, год
ЛП	X			52,3	75,7	92,4	111,7	143,5		45	Nashitani, Kooi, 1968
	м			—	—	—	—	—			
A	X			3,9	6,5	5,8	7,0	7,8			
	м			—	—	—	—	—			
ЛП	X		42,4	56,6	74,8	103,9	147,2	194,0		13	Lehtonen, 1973
	м		2,0	2,2	3,8	3,8	5,1	6,5			
A	X		2,1	3,0	5,6	8,7	11,4	12,6			
	м		0,5	0,6	0,7	1,3	1,4	1,4			
ЛП	X			50,44	69,66	103,4	146,2	191,3	232,6	60	Bennet et al., 1971
	м			12,77	13,83	14,39	19,4	23,73	31,4		
A	X			1,89	—1,86	8,46	—4,31	6,43	—4,63		
	м			2,19	2,66	3,49	3,22	3,99	3,1		
ЛП	X	22,3	35,9	55,5	69,8	96,5	117,0	167,8	208,0	26	Зенков и др., 1974 (4)
	м	0,8	2,0	3,1	3,0	4,6	4,9	4,5	4,7		
A	X	1,3	3,9	4,7	4,6	7,3	5,3	13,9	9,2		
	м	0,3	0,6	0,67	0,6	1,01	1,01	1,01	0,99		
ЛП	X	35	50	66	85	103	126	174		15	Hull, 1973
	м	10	9	11	9	12	12	20			

Symbols: П--Positive oscillation; O--negative oscillation; ЛП--latent period, msec; A--amplitude, μv; X--mean; м--standard deviation.

Note: Amplitude was measured from the midline (Bennet et al., 1971) and from peak to peak (in the other works).

Key:
1. Parameter
2. Number of subjects
3. Author, year
4. Zenkov et al., 1974

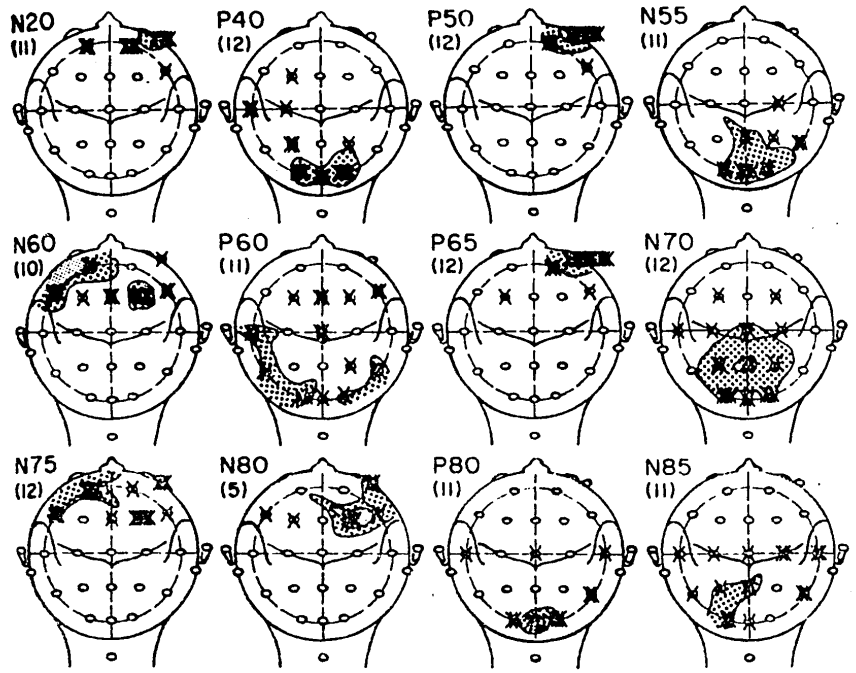

Figure 18. Topography of the Visual EP: The topography of component P95 is shown separately (from left to right) for all subjects, and for persons with a low- and a high-amplitude P130 component to illustrate differences in the topography of components occurring at the same time in persons with a low- and a high-amplitude P130 component (80)

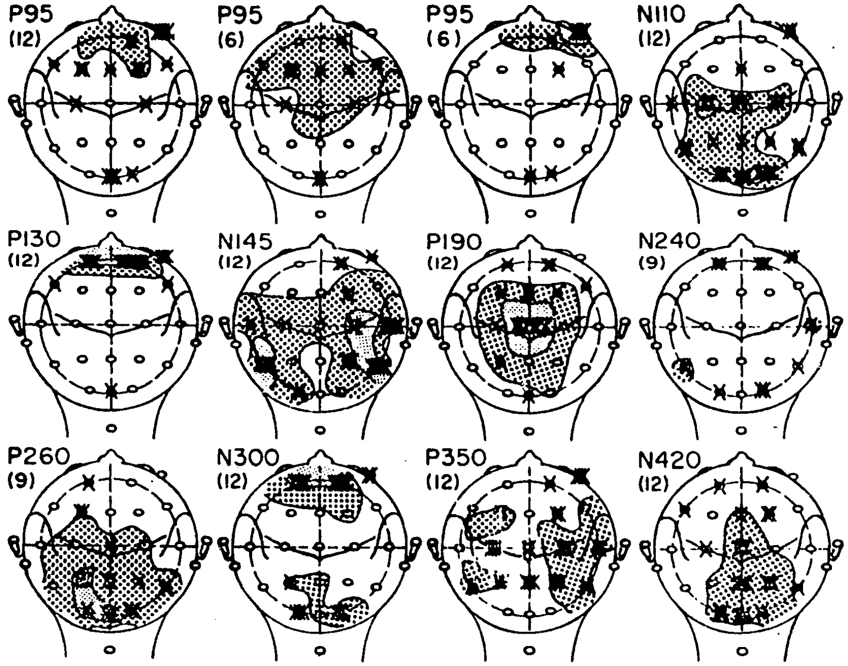

Figure 18 (conclusion)

Table 6. Visual EP Components (From (83))

(1) Компонент	(2) Латентный период, мсек	(3) Максимум амплитуды, мкВ			(6) Предполагаемое происхождение
		медиана (4)	разброс (5)		
(7) O20	21,2±3,1	−1,2	−0,6	−5,8	ЭРГ
(8) П40	38,8±4,7	+1,4	+0,4	+1,9	Н
П50	49,0±4,1	+4,4	+1,8	+16,5	ЭРГ
O55	53,7±6,0	−3,7	−2,3	−5,9	Н
O60	57,7±4,4	−1,4	+4,1	−2,6	ЭРГ
П60	62,1±6,1	+0,9	−1,6	+4,0	Н
П65	64,9±4,8	+7,1	+1,6	+20,8	ЭРГ
O70	70,5±5,7	−5,0	−1,8	−7,3	Н
O75	74,6±4,0	−2,2	+3,6	−4,6	ЭРГ
O80	82,9±3,9	−1,3	+8,7	−3,9	ЭРГ
П80	79,8±5,0	+2,2	0,0	+6,6	Н
O85	84,7±4,8	−2,0	+0,5	−2,9	Н
П95	96,9±8,0	+9,1	+5,5	+14,5	Н
O110	110±10	−2,4	+0,2	−4,7	Н
П130	128±17	+15,5	0,0	+40,2	М+Н
O145	146±13	−3,9	−0,5	−7,3	Н
П190	194±13	+11,8	+6,9	+20,0	Н
O240	236±18	−1,1	+1,3	−6,0	Н
П260	264±18	+5,7	+2,9	+12,6	Н
O300	304±31	−4,1	+1,0	−13,8	Н
П350	352±30	+3,7	+1,9	+22,1	Н
O420	415±20	−4,6	−2,0	−10,5	Н

Symbols: H--neurogenic origin; M--myogenic origin; ЗРГ--electroretinogram.

Key:

1. Component
2. Latent period, msec
3. Amplitude maximum, μv
4. Median
5. Scatter
6. Suggested origin
7. N
8. P

EP's Evoked by Presentation of Visual Structures

The characteristics examined above pertain only to EP's to change in illumination, which is often achieved by delivery of a short burst of light on a dark background (a flash produced by standard photophonostimulators is usually employed) or by diffuse illumination of a white screen or hemisphere. The latter method is better in that it eliminates or reduces the influence of gaze orientation upon the EP, thus insuring diffuse illumination of the retina. Structure visual stimuli--so-called visual "patterns" or visual structures--came into use in 1965, and recently they are being substituted increasingly more often for illumination changes. The morphology of these EP's should be viewed separately, since there are data indicating that the neurogenesis of an EP to a light flash is different from that of an EP to visual structures. One of the first comparisons of EP's to diffuse illumination and to visual structures (illumination of a black-

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24 JULY 1980 BY E. M. RUTMAN 2 OF 3

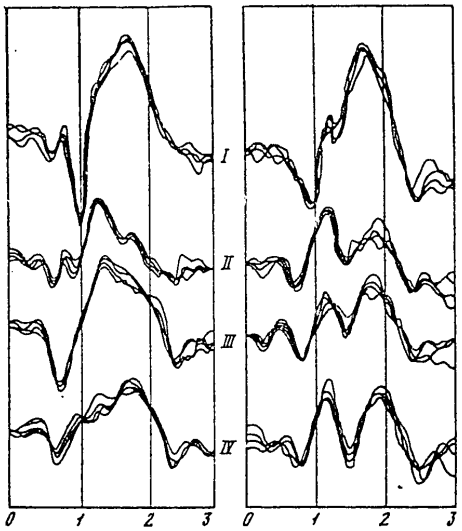

Figure 19. EP's of Two Subjects in Response to Presentation of Visual Structures: Summated from 100 responses; four EP's are shown for each structure. Binocular stimulation, negativeness downward (531); *I*--black-and-white checks (checkerboard); *II*--horizontal lines; *III*--rings; *IV*--radial lines

and-white pattern) was made by Spehlmann (467). The differences he discovered in the late components (enlargement of P260 following presentation of the pattern) served as the grounds for concluding that the latter are mode-specific, contrary to the interpretation of late components as nonspecific, which was accepted almost universally at that time. Changes in an EP in response to pattern illumination in comparison with illumination of a white background were also shown by other authors (151,152,287). Systematic research was later performed on EP's to visual structures (20, 48,70,254,255,281,282,331,401,530,531; Beteleva et al., 1974; Shagass et al., 1976; White, 1974; etc.) (Figure 19).

Despite significant interindividual variability in EP's to illumination of visual structures, two components typical of all subjects were distinguished in different works: N100 and P180 (White called them "A" and "B", Rietveld et al. referred to them as "gamma" and "zeta"; their characteristics were identical). These were precisely the components that exhibited the bulk of the change accompanying changes in contrast density. The greatest sensitivity was noted in relation to component P180. White emphasizes the limitations of the areas in which these components are recorded: It would be sufficient to shift the electrode from the occipital protuberance along the midline in the direction of the vertex a few inches to make these components decrease considerably and disappear.

Somewhat different EP characteristics were obtained in other investigations of EP's to illumination of a checkerboard pattern, and of their dependence upon stimulus characteristics in association with bipolar (315) and monopolar registration (70). Lesevre and Remond distinguished four components in an EP to illumination of a checkerboard pattern measuring 20° containing checks measuring 40′: 0, 1, 2, and 3 with peak latent periods of, correspondingly, 60, 90, 120, and 200 msec. The amplitude of oscillations 0, 1, and 2 was maximum in the vicinity of the occipital protuberance, while that of oscillation 3 was maximum in the parietal region. When a uniformly illuminated field of the same size that received double the illumination intensity was presented, the EP was distinguished by lower amplitude, oscillation 0 was absent, and oscillation 2 was absent or was of opposite polarity.

Fil'chikova (70) distinguished components N80-100, P110-140, N150-170, P180-230, and N220-260 in an EP to an "empty pattern"--diffuse illumination of a white field. When a checkerboard pattern was subjected to the same illumination, the author noted a significant increase in the amplitude of P180-230 and N230-260, and a decrease in the first two components. Moreover the latent periods of the first three components decreased so much that the fifth negative component of the checkerboard pattern situation corresponds to the fourth positive component (P110-140) associated with the "empty pattern." In other words a complete flip in polarity was observed in the 110-140 msec period; this was also noted by Rietveld et al. (401), and others.

Harter and White (255) made the fully valid hypothesis that an EP to a visual structure is the sum of a "nonspecific" reaction to change in illumination and a "specific" reaction associated with the nature of the visual structure. To isolate the latter in its "pure form" they subtracted, from the EP to the checkerboard pattern, a response to a light flash illuminating a white field not containing any sort of structure, or an EP in response to a pattern defocused by lenses. The latent period and shape of the components described above remained as before; only the amplitude changed: In particular, component N100 increased. This implies that an EP to a diffuse light flash is characterized in this temporal interval by opposite polarity, which was also demonstrated in other works (231,401). It should be noted, however, that the subtraction method used by Harter and White to obtain a "pure" EP to a pattern is valid only because they assume that summation of the components of an EP to illumination change and of an EP to an illuminated pattern would be linear. According to some data (331), meanwhile, the components of an EP to a light flash may undergo intensification when a visual structure is presented simultaneously.

The search for ways to acquire "pure" EP's to visual structures led to development of a large number of techniques for recording EP's arising in response to change in visual patterns occurring without simultaneous change in illumination. First among these techniques is registration of EP's in response to tachistoscopically delivered visual structures--EP's to "structure appearance" (Jeffreys et al., 1971, 1972). Subjects observe a white visual field, fixing their gaze on the center of the field of vision. Visual structures sporadically appear for a fixed interval of time in some region of the field (at the experimenter's choice). The moment of arisal of the structure serves as the reckoning point for summation of responses (20).

EP's are also recorded in response to "structure rotation" (for example rapid substitution of dark checks by light checks, and of light checks by dark checks) (133,154,252,396,468; Cobb, Morton, 1967), in response to movement of a structure within the visual field (315,332; Clarke, 1973a,b; etc.), or in connection with the beginning of eye movement while watching a motionless visual structure (315,439).

Tachistoscopic presentation of structures made it possible to study the dependence of EP's to visual structures on the area of the retina stimulated. Research showed (281,282) that the nature of EP's to visual structures presented tachistoscopically depends significantly on the zone of the retina stimulated. The authors isolated two of the earliest components, with latent periods of 65-80 and 90-110 msec, from responses to appearance of visual structures. Their polarity, amplitude, and distribution depended on the region of the retina stimulated and on change in the latter: For example change in the portion of the retina stimulated, from the upper half to the lower half or vice versa, resulted in opposite polarity. It is possible that the oscillation with the 65-80 msec latent period had not been distinguished in earlier works due to "mutual extinction" resulting from stimulation of the entire visual field, or due to greater interindividual variability associated with the experimenter's insufficient attention to the constancy of the area stimulated on the retina.

The distinguished components were designated only by their latent period, inasmuch as the latter is relatively stable, and polarity depends on the zone stimulated.

Broader study of EP's to visual structures revealed differences in morphology and nature of EP's in response to stimuli delivered by different techniques. In particular it was discovered that EP's in response to appearance of a visual structure within a visual field subjected to constant illumination differ from EP's in response to pattern rotation (262,282). There are data indicating that reactions to structure rotation are basically reactions to contrast reduction (in a sense a response to disappearance of the structure), which possibly might explain the difference observed between EP's to presentation and to rotation of a structure (220). The concrete characteristics cited by different authors for EP's to visual structures delivered by different techniques often differ, which may be the product of differences in experimental conditions, ones that often fail to be fully consistent.

Data from Shagass et al. (1976) are presented below. They recorded EP's in response to appearance and rotation of a checkerboard pattern in the right or left half of the visual field, mono- and bipolarly at 11 points on the scalp. Four components were isolated from monopolar recordings of EP's to pattern rotation: P95, recorded in the hemisphere contralateral to stimulation together with a simultaneous negativeness in the ipsilateral hemisphere, P125 and N165, dominating in amplitude in the ipsilateral hemisphere, and P225, with a maximum amplitude on the midline. These characteristics are close to EP descriptions given in a number of other works (154,252,469). An EP to pattern delivery recorded monopolarly consisted of three components: P125 and N175, recorded basically in the contralateral hemisphere, and P225, with maximum amplitude on the midline. Similar characteristics are noted in other studies, though the latent periods stated are somewhat shorter (204,316,347,469). Shagass et al. failed to confirm data cited by Vella et al. (512) indicating that an EP to arisal of a visual structure in either half of the visual field is greater in the right temporal region than in the left, which was interpreted as a reflection of a special role played by the right temporal region in analysis of spatial information.

EP characteristics associated with perception of visual structures and not accompanied by changes in illumination or other factors will probably be refined even more. Let us simply emphasize in connection with the above that demonstration of differences in the nature of EP's to light flashes or illumination of a white field and to presentation of visual structures makes it improper to describe, as is done on occasion, EP's to visual structures as slightly altered EP's recorded in response to change in illumination. Such a description implicitly contains a mistaken interpretation of the components of an EP to visual structures as being the same as within an EP to a light flash, with only the latent periods and (or) amplitude being different.

The future in psychological and psychophysiological research apparently belongs to the use of EP's to structures, and not to diffuse light flashes; expansion of their use is limited only by technical difficulties, but use of EP's to visual structures has already produced significant results today in research on and diagnosis of visual system functions.

It is also possible that EP's would permit us to study the mechanisms governing transmission of movement information in the visual system. Thus for example Clarke (149; Clarke, 1973) concluded on recording EP's to change in movement direction that such EP's are generated predominantly by mechanisms specifically sensitive to movement direction.

Significant practical results were obtained in the use of EP's to checkerboard patterns as a means for automatically diagnosing and subsequently correcting vision (see Chapter XI). When recording EP's to tachistoscopically shown patterns or to pattern rotation, and when analyzing the literature, we must consider data on the mutual relationship existing between reactions to an increase and a decrease in contrast applicable to foveal stimulation (220). We should also keep in mind the reported differences in EP's connected with the orientation of lines or with the angle between lines (347).

A report that EP's connected with saccadic eye movements were recorded deserves mention (504). The recorded oscillation (a triphasal oscillation with a latent period of about 100 msec) is interpreted by the author as an EP associated with natural visual perception. Worsening of the clarity of vision caused a decrease in the amplitude and increase in the latent periods of the responses, while in darkness and with the eyes closed, the EP's disappeared.

Neurogenesis of the Components of an EP to a Light Flash

A positive oscillation beginning 50 msec after stimulus delivery and lasting 40-50 msec was recorded directly from the outer surface of the visual cortex, in the presence of local anesthesia during a brain operation, in response to a light flash (Hirsch et al., 1961). This oscillation was followed by a lengthy negative wave. A positive-negative oscillation with a latent period of 70 msec arose in response to a flash in the anterodorsal part of the internal surface of the visual cortex. The response began in the region of the calcarine fissure as a negative oscillation with a latent period of 40-50 msec. Thus responses with a latent period of less than 40-50 msec were not recorded directly from the cortex. These data are consistent with results obtained from recording an EP in response to a light flash from the outer surface of the occipital lobe and from the scalp (163). In the opinion of the authors they are similar to EP's described by Ciganek (144) and beginning with a negative oscillation having a latent period of 40 msec. Because the EP was recorded after removal of the visual cortex, they concluded that the earliest oscillation--N40--has a subcortical origin, since it does not decrease following removal of the cortex. Subsequent oscillations--P70 and N110--are generated in the cortex in their opinion, inasmuch as they disappeared following its removal.

Another source of hypotheses on the origin of early components is research on the distribution of early components over the scalp resulting from stimulation of different regions of the retina. EP's to illumination of half or the entire field of vision by red light were recorded monopolarly from the entire scalp in one such study (352). Two hundred fifty-six reactions were summed. The EP's had a more complex shape in the parietal region than in the occipital region; moreover the earliest components were recorded in the parietal region, where the following components were recorded in response to stimulation of the center of the visual field: N54 (± 9.47) , P74 (± 9.73), N96 (± 8.07), P114 (± 3.41), and N146 (± 8.13).

When the lateral half of the visual field was stimulated, components N54, P74, and N96 had the greatest amplitude on the contralateral side, which corresponds to projection of the medial half of the retina mainly within the opposite hemisphere. Interhemispheric differences were not revealed in the amplitudes of the later components--P114 and N146--either. Oscillation P74 which, similarly as with its neighboring components, exhibited its greatest amplitude in the parietal region was the most pronounced among the early components. All early components decreased as the electrodes were brought closer to the occipital region, and in the vicinity of the occipital protuberance they changed their polarity. The shift in polarity of the components of the visual EP in the vicinity of the occipital protuberance was also observed in other studies employing both bipolar (Monje et al., 1962) and monopolar recording (Gastout et al., 1963). A shift in the polarity of a component with a latent period of about 70 msec was noted in response to movement of the electrode sagittally and transversely at a point 3-6 cm above the occipital protuberance (153).

Nakamura and Biersdorf examined possible dipole models (from (447)) of sources corresponding to maximum amplitude in the parietal region and to reduction of amplitude to zero in the occipital region. As a result they settled upon two equivalent models. According to one of them the source of early components is a dipole located in the primary visual cortex. According to the other, early components are generated by two dipoles located in secondary visual regions. It is hypothesized that they are oriented radially, and that the positive surface of one dipole is in the parietal region of the contralateral hemisphere, while the negative surface of the other is in the occipital region of the ipsilateral hemisphere. Thus the question remained open, but according to either of the models the early components (occurring after 50 msec) are interpreted as the result of the activity of neurons in either the primary or the secondary visual cortex.

Indications of the origin of component P115 are contained in a work by Arnal et al. (87). In the first place the difference they established in the nature of recovery of components P115 and P200 (P100-200 and P200-240 in their work) in the presence of small intervals between flashes implies a difference in the origin of these components. They also demonstrated that in distinction from P200-240, P100-200 depends on visual acuity, pupil size, and integrity of the optic nerve (amplitude decreases gradually in the presence of injuries to the optic nerve), which they interpret as evidence of the specificity of P100-200. Oscillation N160-180 is viewed in this work as the absence of activity in a period between two positive oscillations.

This notion differs significantly from the hypotheses of other authors. Thus Creutzfeldt and Kuhnt (167) view this oscillation as a manifestation of secondary synchronous activation of the cortex--that is, not at all as a pause. It should be considered of course that their conclusion is grounded on an analogy with data concerning the relationship between EP's and neuron activity of cortical elements in animals. Farber (1975) suggests the hypothesis that this oscillation is associated with arisal of impulses from the hippocampus which, receiving an inquiry from the cortex, sends an ascending response into the cortical projection zone. The absence of correlation between arisal of this component and maturation of nonspecific thalamocortical associations in ontogenesis, noted by Farber, is significant, arguing against an interpretation of this component as a reflection of thalamic activation.

And so, ideas about the nature of the negativeness preceding component P200 are highly diverse: we encounter the idea that it represents absence of a component (a pause between neighboring peaks), that it is thalamic activity, and that the visual cortex and the hippocampus are hypothetical generators or "triggers."

We examined the neurogenesis of component P200 above. We will simply note here that component P200 in the visual EP differs from the highly similar component P200 (occurring at the same time and exhibiting the same polarity) in auditory and somatosensory EP's in that in the latter P200 has one zone of maximum amplitude--the vertex, while P200 in the visual EP exhibits two peaks--in the occipital and central regions. Vaughan (508), who discovered this fact first, suggests that the P200 component in the visual EP created by the simultaneous action of two different generators, one of which is in the occipital region and the other is in the central region. Lehtonen (312) came to the conclusion that two generators were present after analyzing the nature of recovery following presentation of paired flashes with short intervals between them. It was found that the interstimulus interval influenced the amplitude of P200 recorded from the vertex more than from the occipital region, and that enlargement of the outline of a visual structure presented influenced the EP recorded from the occipital region without altering the vertex EP. Lehtonen hypothesizes that these oscillations differ in their neurophysiological nature, though both are generated in the modally specific visual cortex.

Mention should be made of a detailed study of the distribution of potentials on the scalp within a circle with a radius of 4 cm and with its center located at a point 4 cm above the occipital protuberance on the sagittal line following a light flash (107). EP's were recorded with 17 electrodes: One was located at the central point, and two groups of eight electrodes were located on the circumferences of circles with radii of 2 and 4 cm, at the points of intersection of these circles with horizontal, vertical, and 45° lines. The authors summed and averaged 10,000 responses to 100 flashes at a stimulation rate of two pulses per second. The EP's were recorded bipolarly--between all points on the circles and the central point, and at the eight points of contact between points located on the same line crossing the external and internal rings. Monocular (sometimes binocular), foveal, and parafoveal stimulation were employed. Different frequency filters were used: 0.3-5.0, 0.3-15.0, and 0.3-50 oscillations per second. EP's were not distinguished between the second and third filters, and some small oscillations were "lost" at the first.

The authors believe that visual EP's possess their main spatial-temporal characteristics within a narrow frequency band--0.3-15.0. Spatial-temporal maps showing the potential distribution in the zone under investigation every 10 msec were plotted for each point on the basis of the EP's. As a result, slow growth in positiveness in the first 120 msec forward of the occipital protuberance was discovered with monocular stimulation of the fovea of the right eye; a fast change (called by the authors a "potential rotation) occurred after 120 msec, together with arisal of a positive peak in the region of the occipital protuberance 190-310 msec following stimulus delivery. The authors suggest that the source (or sources) of the initial positiveness is located forward of the foremost electrode, and that the source of the positiveness falling within the 120-310 msec period is in the vicinity of the occipital protuberance.

The work examines the possibilities offered by several models: pulsating sources, dipole models, and so on. The observed shifting rotation and stabilization of potential could not be explained, in the opinion of the authors, by just passive conduction alone. It is thus hypothesized that the entire EP to a light flash is the product of activity of neuron populations in two principal spatially separated sources. It would be interesting to note that the spatial-temporal maps were found to be less variable than singular EP's, and that interindividual variability was observed only in separate temporal periods. This leads to the notion that there may exist small generators, in addition to the principal ones, responsible for variability exhibited by specific temporal periods. These generators might also be the cause of slight differences in the dependence upon stimulation type: foveal and extrafoveal, different colors, and so on.

The hypothesized generators revealed in this source for the two relatively long periods of positiveness located in different divisions of the head do not contradict the existing hypothesis concerning the neurogenesis of individual components.

Neurogenesis of the Components of EP's to Visual Structures

The independence of the components of EP's associated with visual structures and of EP's elicited by change in illumination is indicated mainly by numerous data on differences in the morphology of EP's to visual structures and to illumination changes (280,530,531; Mac Key, Jeffreys, 1972; etc.). This, incidentally, is also consistent with data indicating that nerve elements in the visual cortex exhibit high sensitivity to the structure of the visual field, and that they do not react to changes in diffuse illumination (270,271).

A number of studies by different authors are devoted to detailed investigation of the neurogenesis of pattern-specific EP components (281,282,343). In the first of these works, EP's were recorded along the sagittal line of the subject's head in response to presentation of oblique lines in the lower or upper half of the visual field. In some of the experiments lenses were used to reduce the visual acuity of the subjects so much that they were unable to distinguish the patterns presented to them, and the EP's consequently recorded could be interpreted as EP's to change in illumination occurring apart from presentation of a visual pattern. The amplitude and nature of the distribution of EP components over the scalp varied significantly between these cases.

In another work (282) the electrodes were located along the midsagittal and transverse lines on the head, and EP's were recorded (the first 150 msec following stimulus delivery) in response to visual structures presented in different portions of the retina. When the stimulus was delivered in the lower half of the visual field, the EP recorded at a point 5 cm above the occipital protuberance on the midsagittal line was represented by a positive-negative-positive complex with the first two components having latent periods of 65-80 msec (component Cl) and 90-110 msec (component C2). Subsequent positive oscillations were not analyzed in detail. When the same stimulus was presented within the upper half of the visual field, the polarity of Cl and C2 reversed itself. Any comparison of EP's recorded by electrodes located on the transverse line in response to stimuli delivered in the right and left halves of the visual field revealed a change in polarity of Cl at the level of the midsagittal line, and constant polarity of C2. Moreover the authors revealed stable differences in the distribution of components Cl and C2 depending on the region stimulated. A detailed analysis of the obtained data led the authors to the conclusion that Cl and C2 are generated by spatially different structures: Cl is generated in the striate cortex and reflects its retinotopic organization, while C2 is generated outside the striate cortex. It has been hypothesized (281) that C2 arises outside the striate cortex, on the upper or lower surface of the occipital lobe depending on the retinal zone stimulated (that is, in divisions having retinotopic organization, though less pronounced). C2 is interpreted by the authors as a reflection of the development of negativeness on the cortical surface. The independence of components CI and C2 was also confirmed by the fact that when paired stimuli were presented at small time intervals and the duration of stimulus delivery was varied, these components changed in entirely different ways.

Mischel and Halliday (343) arrived at a different dipole model of early components of EP's to visual structures on the basis of their data. The principal component they studied was a positive oscillation with a latent period of about 100 msec. Later, a special investigation of EP's to delivery, disappearance and rotation of a visual structure (220) demonstrated that the positive oscillation with a latent period of 107-134 msec and the positive oscillation with a latent period of 120 msec varied in different ways depending on arisal or disappearance of the visual structure. Interaction between reactions to an increase and a decrease in contrast was revealed for the case of foveal stimulation. Comparing their results with data in the works cited above (282,343), the authors concluded that their results, which are contradictory at first glance, reflect different cortical representation of reactions to intensification and reduction of contrast. Jeffreys and Axford predominantly recorded reactions to an increase in contrast (they employed a highly contrasted checkerboard pattern with elements of relatively small size--14°, presented for a short period of time), while Mischel and Halliday recorded reactions to disappearance of contrast (they recorded EP's to rotation of a high-contrast checkerboard pattern with a check size of 50′).

The difference in cortical representation of reactions to intensification and decrease of contrast is confirmed by the described difference in most components of EP's recorded in response to appearance and rotation of a visual structure (Shagass et al., 1976).

It is perhaps too early to assume these ideas to be conclusive. All they doubtlessly say is that there are differences in responses depending on the most varied characteristics of the stimuli delivered and the delivery techniques, which are often difficult to account for, and that possible sources of discrepancies in the results must be accounted for when analyzing literature and planning research.

It is of course difficult to make use of these ideas on the neurogenesis of C1 and C2, since the characteristics of EP's recorded by Jeffreys and Axford differ from those recorded in other studies, and for the moment there are no dependable techniques for identifying the EP components.

CHAPTER X

SOME MODALLY NONSPECIFIC CHANGES IN EP'S ASSOCIATED WITH STIMULUS CHARACTERISTICS

Reduction of EP's With Repeated Stimuli. Dependence of the Magnitude of EP Reduction on the Interval Between Stimuli. Refractory Phenomenon or Habituation?

A decrease in EP amplitude in response to repeated stimulus deliveries has been demonstrated for visual, auditory, and somatosensory stimuli (146,174, 177,367,368; Allison et al., 1962; Bogach et al., 1962; etc.). In some proportion of the cases the reduction of EP's due to repetition, especially visual EP's, is possibly the product of peripheral factors (Bergamini et al., 1965), but as a whole, it is commonly accepted that the amplitude decrease is of central origin (368,394,444).

The magnitude and rate of decrease depend on stimulus characteristics (frequency, duration, and intensity) and the subject's state. A number of factors may cause a decline in responses due to repetition: adaptation, tiring, the refractory phenomenon, habituation.

When small intervals are involved (up to 500 msec), the refractory period is the principal cause of response decline in neuron systems generating EP components. Inasmuch as the recovery rate of responses occurring within short intervals reflects the functional state of the corresponding neuron system, it is used as a diagnostic indicator of deviations from the normal, and it is also viewed as a potential correlate of individual features (76,128). If some specific goals of the research do not require very short intervals, stimuli are usually presented with intervals of not less than 1 second. In this case we also observe, in response to repeated stimuli, a decline in EP amplitude depending on interval magnitude. This decline pertains first of all to the amplitude of the vertex potential (that is, a positive oscillation with a latent period of about 200 msec), usually measured from the peak of the preceding negative deflection. This decrease is also observed in other components (except for early ones falling within the first 50 msec), but most studies have involved namely the vertex potential, which is what will be implied in the following discussion by the term "EP reduction due to repetition."

Two types of reduction are distinguished: fast and slow. The former includes an EP reduction arising after the very first stimulus deliveries and quickly attaining a magnitude beyond which the amplitude changes little in the future. It is observed with interstimulus intervals of up to 10 seconds, and the smaller the interstimulus interval (within the 0-10 second range), the more the reduction is expressed and the faster it develops. The second type of EP reduction does not depend on the interstimulus interval; it develops slowly and gradually in response to prolonged stimulation.

Inasmuch as an EP is the result of averaging, special procedures would have to be used to reveal a fast decline in amplitude (one occurring after the first stimulus delivery). One is to present stimuli in blocks, with a short interval between stimuli in a block, and long intervals between blocks. Then subsequent averaging of all of the first responses of all of the blocks, of all second responses, all third responses, and so on would produce an impression of the reduction experienced by the EP due to repetition of a stimulus with a particular interstimulus interval.

Such research (230,403) showed that in the 1-3 second interval, a decline in amplitude was observed in response to the second stimulus (as a rule the response is maximum mainly after the second stimulus) (143), by the third or fourth stimulus the decline attained 50 percent of the amplitude of the response to the first stimulus in the block, and from then on the amplitude hardly changed at all. The shorter the intervals between the stimuli and the greater the intensity and duration of the stimuli, the more quickly and obviously the reduction occurred. Amplitude recovered after stimulus cessation. Such an amplitude decline was not observed at intervals of more than 10 seconds. In addition to the fast amplitude decline described above, there was a gradual, slow decline that did not depend on the interval between stimuli, and which according to Ritter et al. (403) attained 10 percent of the magnitude of the EP in the first block of stimuli following 1.5-2 hours of recording.

Kavanishvili et al. (27) studied the dependence of the amplitude of an EP to tones on interstimulus interval. They studied components P1, N1, P2, N2 with latent periods of 54, 100, 195, and 322 msec respectively (the interstimulus interval was 5 seconds). A decrease in the interstimulus interval from 10 to 3 seconds caused a 20 percent decline in the amplitude of N1-P2, a 1 second interval caused a 60 percent decline, and a 0.5 second interval caused an 80-85 percent decline--that is, the dependence was found to be close to logarithmic. The extent of decline increased as stimulus intensity grew. Thus as the interstimulus interval was varied from 10 to 1 second, the amplitude of N1-P2 declined by 78, 53, and 45 percent in response to sound intensities of 90, 60, and 30 db respectively. In similar conditions the amplitude of P2-N2 declined by 53, 34, and 14 percent--that is, significantly less. Another extremely interesting fact described in this work is the shortening of the latent period of all examined components, except P1, in response to a decrease in interstimulus intervals. The latent period values presented above are for an interstimulus interval of 5 seconds. At an interval of 1 or 2 seconds the latent periods were 56, 90, 160, and 268 msec. The amplitude decreased insignificantly (20 percent) in response to shortening of interstimulus intervals from 10 to 3 seconds, and a significant decline occurred in response to further shortening of the intervals. This means that intervals longer than 3 seconds would best be used.

Research was conducted on the characteristics of fast reduction of EP's to repeated light flashes, averaged by a "sliding" procedure: Sixteen responses were averaged, "shifting" by 4 responses with each averaging procedure (310). Sixty-four responses were averaged to study slow EP reduction. Light flashes were presented regularly with an interval of 1 second, or with randomly varied intervals having a mean of 2.1 seconds. Amplitude was determined from the peak of component N110-135 to the peak of component P160-210 msec, and the "average reaction size" in the 70-220 msec period following the stimulus was computed. With rhythmical stimulation, the decrease in amplitude was observed within the first 3 minutes, and the greatest decline was noted in the first 15 seconds. With random intervals, a fast decline in amplitude was not observed.

What is the nature of "fast" decline (decline after the first few stimulus deliveries) in response amplitude? Two mechanisms--the refractory phenomenon and habituation--were suggested from the very beginning as the basis of this phenomenon. Habituation (extinction) is defined as a decrease in magnitude or a drop in the probability of a reaction accompanying repetition of the stimulus evoking it. Habituation differs from other forms of reaction decline, caused by the refractory period of reacting systems, tiring, or adaption, in that it affords a possibility for complete or partial, fast recovery of reactions when the conditions are changed suddenly (as an example when an unexpected stimulus is delivered). This recovery is called "disinhibition" (dishabituation).

Interesting research by Butler et al. (123) offers clear evidence that an EP reduction occurring in the 1-10 second interval is a consequence of habituation. The experimental method was quite brilliant. A 1000 Hz testing tone was delivered rhythmically to the left ear with an interval of 5 seconds. The EP to this tone was recorded. In different, additional series, an additional 1,000 Hz tone was delivered at a 1 second interval between the testing tones, either just to the right ear, or simultaneously to the right and left ears, or just to the left ear. Delivery of the additional tone caused a decline in the amplitude of the EP to the testing stimulus. The greatest decline was observed in this case when the additional tone was delivered only to the left ear (in this case the procedure was such that a 1,000 Hz tone was delivered to the left ear every second). Thus a paradoxical situation arose: Cessation of the right ear's stimulation caused a more-pronounced decline in the amplitude of the EP to the testing stimulus. It is impossible to explain these results by the refractory phenomenon, and the authors interpret them as a manifestation of habituation, the degree of which depends on the degree of similarity exhibited by the structure of the repeating stimuli.

These data allowed them to assert that habituation develops within the central primary projection zone, inasmuch as the physical conditions of the experiment are identical for the left ear (and consequently for transmission of impulses to the primary projection zone) no matter whether the additional tone was delivered only to the left ear or simultaneously to both ears: A 1,000 Hz tone was delivered every second. Only the general structure of stimulation changes: Either the same stimulus is delivered rhythmically every second to the left ear, or, in addition, the same stimulus is periodically delivered to the right ear simultaneously with the former, thus producing a different stimulation structure--that is, the nature of the repeating activity periodically changes.

The authors interpret the observed EP reduction as a manifestation of habituation to a particular structure of neuron activity, and they conclude that habituation is intensified when the stimulation structure repeats itself absolutely, in comparison with a situation in which some differences occur in the activity's repetition. These results agree with data indicating that the amplitude of an EP to a 96 db tone was greater when it was delivered mixed with louder and quieter tones than when just the one 96 db tone was delivered (176).

The rate of amplitude decline in response to stimulus repetition is much greater in the case of rhythmical stimulation than arhythmical stimulation. Different habituation characteristics were obtained in a study of the relationship between changes in EP amplitude on one hand and the size of interstimulus intervals and attention on the other hand during nonrhythmical stimulus delivery (357). Ohman and Lader exposed their subjects to 24 blocks of acoustic stimuli (1,000 Hz tones) with 10 stimuli in each block. The interval between the stimuli within each block was varied randomly within 2.4-3.6 seconds in one series and within 8-12 seconds in another. The interval between blocks was also varied randomly within 24-36 seconds, irrespective of the interstimulus interval within each block.

EP's were recorded in two situations: In the first, the subjects had to react as quickly as possible to each tone (attention to sounds), and in the second they had to perform a similar motor reaction to visual stimuli that were presented in both situations but which did not coincide with the acoustic stimuli (a situation of inattention to sounds). Reaction time and the GSR were recorded. Peak-to-peak amplitude for components P45-60, N80-110, P160-220, and N230-280 of the EP's to the tone were determined. Amplitude changes were analyzed by comparing all of the first, second, and subsequent stimuli within each block, and by comparing the averaged EP's of successive blocks.

The authors discovered an increase in peak-to-peak amplitude for the first three components in the attention situation as compared to the inattention situation, and in response to an increase in the interstimulus intervals. A decline in amplitude in response to repeated stimuli was revealed both by a comparison of responses within blocks and by comparison of responses to successive blocks, in which case in contrast to previous data attainment of an asymptotic level after the first three stimuli was not observed; instead, the amplitude continued to decline smoothly in response to repeated stimulation all the way to the last, the tenth stimulus in a block. Ohman and Lader note that the more abrupt decline in amplitude they discovered in response to repeated stimuli "within" a block in the "attention to sounds" situation was a surprise. They had hypothesized the reverse, that attention would "weaken" habituation. The explanation they gave for their result was that in the case of attention, the amplitude of responses to the first stimulus deliveries was greater, and therefore the transition to the "minimum" level was associated with a more expressive change. Perhaps when the subject is attentive he assimilates the stimulus delivery structure more quickly and is able to "second-guess" the moment of delivery better, which would be accompanied by a more expressive decline in amplitude.

While noting two possible mechanisms for the decline in amplitude in response to repetition--physiological (the refractory period) and (or) psychological (habituation), the authors do not commit themselves specifically in favor of one of them in their discussion. However, the fact that the decline in amplitude resulting from stimulus repetition was no less pronounced with long interstimulus intervals than with short ones, argues against a significant role for the refractory phenomenon.

The same is implied by Boddy's data (104). He studied the dependence of the amplitude of components N134, P192, and N284 in an EP to sound on the interval between this sound and a preceding acoustic or light signal. The intervals were varied within 500-1,250 msec. EP amplitude did not depend on these intervals in either a resting situation or one requiring a motor reaction to the testing sound.

Ohman and Lader demonstrated that an amplitude decline due to repetition may be observed independently of changes in activation level, as determined from reaction time and the GSR. Development of habituation independenly of activation level was also demonstrated in research by Orr and Stern (360). Their data are significant because they repudiate an explanation of the amplitude decline by only a decrease in activation level associated with extinction of the orientation reaction to a new stimulus accompanying the latter's repetition. Absence of habituation in EP's to acoustic stimuli (a tone or noise) in children 12-18 weeks old is an indirect confirmation of a "psychological" nature of the EP reduction accompanying repetition (Weber, 1972). It would be difficult to explain this fact by saying that EP's recover better at this age. At the same time we do know that the capability for organizing the outside world does not arise immediately after birth. It would perhaps be interesting to determine the moment at which EP habituation arises in ontogenesis, and compare it with other developmental characteristics.

It is generally accepted today that a decline in EP amplitude occurring in response to stimulus intervals of 1-10 seconds is mainly the result of habituation (230,231,310,377, etc.). Two neurophysiological mechanisms are hypothesized as the basis for habituation. The first mechanism is a direct reduction of the capability collaterals from specific projection pathways have for activating the reticular formation, caused by synaptic "tiring", or synaptic depression accompanying stimulus repetition. The second mechanism is inhibition of the reticular formation via a corticoreticular (predominantly frontal-reticular) pathway, arising when the delivered stimulus coincides with an expected stimulus, or (and) when it becomes insignificant--that is, when it no longer requires a reaction from the body (54). The second mechanism obviously plays the decisive role in fast habituation (377).

There is greater conflict in opinions concerning slow decline of EP amplitude accompanying prolonged repeated stimulation. Research on this phenomenon is made difficult by unavoidable fluctuations in the subject's alertness, the influence of which cannot always be distinguished from habituation and disinhibition (310). However, there are data indicating that slow amplitude reduction is also a consequence of habituation (Salamy, MacKin, 1978). The authors recorded components N85-100, P120-150, and N180-225 in response to prolonged delivery of clicks at a frequency of one per second. They arrived at averaged

EP's in their continuous stimulation experiments on the basis of 50 responses occurring every 5 minutes. An amplitude decline occurred in the first 5-10 minutes of stimulation, but only in those experiments in which the subjects were reading a book. When the clicks were presented without any sort of instructions, an EP reduction was not observed. Change in stimulation frequency or loudness restored the depressed amplitude of the responses, but it did not change it if a decline in amplitude had not been observed prior to this. Swift recovery of EP amplitude in response to changing conditions implies that habituation is the cause of the decline. Early brain stem responses (following within the first 10 msec) did not decline in this case (50,000 stimuli were delivered).

Thus a decrease in EP amplitude has been demonstrated in relation to stimulus repetition associated with the refractory phenomenon (for small interstimulus intervals--less than 500 msec) and with fast and slow habituation. These factors should be accounted for when planning experiments and analyzing results, so as not to ascribe an effect of habituation or the refractory phenomenon to some other action that coincides in time but which is independent of the variable under analysis. Excluding the first two to four responses from the averaging process and repeating comparable series of stimuli several times in succession are some recommendations given.

It was already pointed out above that for auditory EP's, it would be wise to use intervals beginning with 3 seconds. Some authors (205) feel an interval of not less than 1 second to be good for recording visual EP, while others (368) suggest that 0.5 seconds is enough. According to Lehtonen (313) early components (up to 120 msec) recover fully with an interstimulus interval of 1 second, while later components attain their maximun amplitude only with a 3 second interval. The 3 second interval is also probably necessary for registration of somatosensory EP's.

Studies on habituation should account for stimulus intensity, since in the event of high intensity, difficulties arise in distinguishing orientation reactions from avoidance reactions (424).

It should be noted in conclusion that the phenomenon of habituation itself has not been studied well enough yet. It would pay to emphasize in this connection that discussions of EP habituation are usually based on changes in the peak-to-peak amplitude of the vertex potential, and the contribution made by each of the two components remains unclear.

Dependence Of EP On Stimulus Probability

When different stimuli are presented, the probability of their arisal influences most of all the amplitude of an EP's late positive oscillation (LPO) having a latent period of about 300 msec. This was discovered for the first time with EP's to sound and light (487). The stimuli were presented in pairs:

The first was a preparatory stimulus, and the second was the testing stimulus, the interval between the pairs being 3-5 seconds. Two series of experiments were conducted: In one, either light or sound always followed the preparatory signal, while in the other the preparatory signal was followed, at a particular probability, by either light or sound. The amplitude of the LPO was greater in the second series, typified by uncertainty, and it was greater following stimuli having a low probability of delivery. Subsequent research (488,502, etc.) showed that the relationship between the LPO and the probability of external events is mediated by a subjective "field", or "alphabet", possessed by the subject, by his subjective expectations, which are formed under the influence of objective probability, but which are not at all defined by it uniquely.

This was revealed first of all in a "guessing game." In different series of experiments two stimuli were alternated randomly with different probabilities. The subject had to state his opinion beforehand as to which stimulus would be delivered. The EP's were averaged separately for correctly predicted (guessed) stimuli and wrongly predicted (unguessed) stimuli. The amplitude of LPO's to guessed stimuli was generally lower than that of LPO's to unguessed stimuli. It was found that the lower the probability of guessing in the given series, the higher was the amplitude of LPO's following guessed stimuli, and the lower the probability of errors in the given series, the greater was the amplitude of LPO's following unguessed stimuli. In other words if we assume that a subject expects to guess correctly and make a wrong guess with a certain probability proportional to the frequency of right and wrong guesses in the given trial, the LPO amplitude is indirectly proportional to the expectation of the given event, irrespective of whether the event is a right or wrong guess. At the same time the relationship between LPO amplitude and stimulus probability persists within guessed stimuli: the greater the probability, the lower is the LPO amplitude (apparently the greater the probability of the predicted stimulus, the greater is the anticipation of it). However, if the subject was told which stimulus would be delivered before each one was presented, the relationship between LPO amplitude and stimulus probability (frequency) declined or disappeared.

And so, these data show that LPO amplitude is governed not so much by an objectively prescribed probability of stimuli (or events) as by the degree to which the subject's expectations match the real events. The better the match, the lower the LPO.

The relationship between an LPO and probability apparently arises mainly because objective probability is what creates the subject's expectation (a stimulus that occurs more frequently is anticipated more strongly, while a rarer stimulus is anticipated more weakly). The mechanism of this relationship is examined in greater detail in Chapter XIV; it would be pertinent to emphasize here only that the described dependence should be considered when designing experiments and analyzing results.

USE OF EP'S IN PSYCHOLOGY AND PSYCHOPHYSIOLOGY

CHAPTER XI

USE OF EP'S TO ASSESS SENSORY FUNCTIONS

The scope of all studies of sensory functions using EP's is vast, and their detailed review would necessitate a separate book. Various directions in the use of EP's to study perception are examined in a number of monographs and articles (23,30,58, 394; Puchinskaya, 1975,1976; Regan, 1974; etc.). We will dwell only on some areas in which EP's have enjoyed practical application.

Use of EP's for Objective Audiometry

Because it was demonstrated in relatively early works (326,337) that thresholds (for an equal number of summed responses) are somewhat higher for early components than for late components, researchers concentrated their attention on using the components with the highest amplitudes--N1-P2. According to Cody et al. (156) when responses are recorded monopolarly from the vertex, to determine threshold it would be sufficient to sum 50 responses to stimuli delivered at a frequency of not less than one every 2 seconds. Use of tones 300-500 msec long is recommended in audiometry, so as to avoid interaction of on- and off- effects (470); the possibility of audiometry in deep sleep is also noted. Subjective thresholds determined by classical methods and thresholds based on late EP components were compared (96). The research was conducted on 40 persons with normal hearing and 36 with hearing disorders of various nature; thresholds were determined for three frequencies--500, 1,000, and 2,000 Hz. The threshold determined on the basis of late components exceeded the subjective threshold by an average of 3-5 db.

Davis obtained similar results in research on children 4-10 years old (175). EP's were also used to determine the auditory thresholds of newborn infants and young children. EP's in response to pure tones from 250 to 800 Hz were found to be identical for infants and adults. Thresholds were determined for children from the amplitude of P2-N2, since the EP's were recorded during sleep, at a time when this amplitude is the greatest. Distraction of attention from sound does not influence the threshold determined on the basis of an EP, or the difference between objective and subjective thresholds (157).

A dependence was demonstrated between thresholds and sound frequency (262). Four frequencies were presented--250, 500, 4,000, and 5,000 Hz. Subjective thresholds determined by classical methods were lower in all cases than thresholds determined from EP's; the average difference was 10 db for low frequencies and 20-22 db for high frequencies. The dependence of the difference between subjective and objective thresholds on frequency must be accounted for when assessing audiometric data and when choosing the stimulus to be used in psychophysical research.

Use of objective audiometry based on late components has been introduced into clinical practice, and it has permitted us to determine thresholds associated with functional hearing disorders (hysterical deafness) and simulation (157).

Parallel with introduction of audiometry based on late components into clinical and experimental practice, research continued on the possibilities for using earlier, so-called middle components for audiometry (342). Because their amplitude is lower than that of late components, the number of responses to be summed must be increased, but their lower dependence upon the interstimulus interval makes it possible to significantly increase the stimulation frequency, and thus to determine thresholds without increasing the research time. The advantage of middle components is their greater stability in experimental conditions than that of late components, and the possibility for recording them from a sleeping subject.

A series of studies by Mendel et al. (341,342) showed middle components to be stable under various recording conditions--in a light and a dark room, with eyes open and closed, while at rest and while simultaneously reading, with repeated recordings following at an interval of 3 hours or 1 day, and in different phases of sleep. Special research (Goldstein, 1972) showed that middle reactions (P13, N22, P34, N49) are registered sufficiently well and dependably when we average 5-12 responses to stimuli delivered at a frequency of 10-15 stimuli per second; these experimental conditions are recommended as a means for revealing reactions to near-threshold stimuli. N22-P34 has the greatest amplitude, attaining 0.73 μv. When the number of summations is increased sufficiently, thresholds determined from middle components are found to be lower than those determined from late components (342).

Back in 1958 it was demonstrated for the first time that in relation to middle EP components, the threshold intensity of a click differs from the subjective threshold by 5 db (238). Mendel et al. (342) published a report in 1975 comparing the thresholds based on late and middle components of the same people under identical conditions. The lowest thresholds and the greatest frequency of thresholds appearing below 30 db were observed in the group of 28 persons when middle components were used and when thresholds were determined in light sleep (stages 1 and 2 and the fast sleep stage). Thresholds were revealed on the basis of middle components for 23 out of 28 persons while in light sleep. As a result the authors recommend using middle components for clinical audiometry. The thresholds determined in this study are significantly higher than those of others. This may be the result of the particular amplitude criterion and positive reaction criterion adopted (Mendel et al. (342) used 75 percent, Rupin et al. (1970) used 50 percent).

Component P300 of an auditory EP has not been used to determine thresholds, but there are indications (Hillyard et al., 1971) that it may be a more sensitive indicator than other components. Hillyard et al. recorded EP's in situations where in each trial, the subject had to state whether or not a signal had been presented on a noise background. EP's were recorded separately for correct detections, false alarms, signal misses, and correct nondetections. Oscillation P300 was recorded only in the event of correct detections. The extrapolated threshold determined from oscillation P300 agreed with the threshold determined by classical psychophysical methods. When precisely the same physical stimuli were presented to the same subjects, but the latter did not have to determine presence or absence of a signal within the noise, component P300 did not arise. In this case other EP components began to be recorded at intensities 6-8 db higher than the minimum intensity at which oscillation P300 was recorded in the signal detection situation. Thus when active signal detection is involved, P300 may turn out to be a more sensitive indicator than other EP components. Temporally random signal delivery is a mandatory condition for the use of component P300, inasmuch as oscillation P300 may also arise in the absence of a stimulus, at the moment when the probability of its presentation is sufficiently high.

Objective audiometry is gaining firm foothold in clinical practice. Portable audiometers making it possible to record EP's quickly have appeared. They can also be used in psychophysiological studies. The arsenal of audiometric methods is constantly expanding, and ways for automatically assessing indicators are being developed (132,529).

Use of EP's in Response to Structured Visual Stimuli to Assess Vision

There are many situations (early childhood, mental underdevelopment, some forms of pathology, and so on) in which an objective (nonverbal) analysis technique is the sole possible one, and in which EP's become irreplaceable.

According to White (531; White, 1974), EP's in response to checkerboard patterns are successfully used in mass diagnostic studies, particularly to determine refraction in children up to 12 months old. A plan for automating visual testing using EP's has been proposed (200).

Fil'chikova (70) conducted a detailed study of the relationship between EP's and the check size and contrast of a checkerboard pattern. In contrast to Harter and White's data (254,255) that the maximum EP amplitude (that of the component with a latent period of 200 msec) was observed with a check angular dimension of 10', Fil'chikova noted maximum amplitude for different subjects at dimensions of 20', 40', and 60'. The reason for the discrepancies may lie in the use of different components as maximum reaction indicators, or in differences in pattern dimension. When the contrast of the pattern was reduced by lenses from ±1 to ±6 diopters, Fil'chikova observed a decrease in the amplitudes of components P180-230 and N220-260, an increase in the amplitude of component N80-100, and an increase in the latent period of component N150-170. In addition to changes in amplitude, Fil'chikova describes change in EP shape in response to change in the dimensions of the pattern's checks, in which case she notes that the EP shape typical of this pattern even persists with a low degree of defocusing. Her work demonstrated correspondece between the nature of the EP's and subjective perception of the clarity of the images, and it revealed a consistency between the maximum amplitude of late components and the best optical correction for persons with disturbed vision. The author concludes that the EP is a precise indicator of contrast perception, making it possible to determine optimum optical correction in the presence of refraction abnormalities.

When comparing published data and conducting experiments involving the recording of EP's to visual structures, the researcher must consider the available data on the influence of the stimulation zone and the component used as the indicator upon the dependence of EP amplitude on angular dimensions, and on the influence the size of the checks in the checkerboard pattern has upon the dependence of EP amplitude on the degree of defocusing. Thus it was demonstrated that when a checkerboard pattern presented in the upper half of the visual field is illuminated by a flash, the maximum amplitude of the component with a latent period of 90-100 msec was noted at an angular dimension of 10', while stimulation of the lower half of the visual field resulted in maximum amplitude in response to checks with an angular dimension of 40' (204). The authors suggested that this was associated with differences in the organization of the receptor fields in the upper and lower halves of the retina in connection with a differing biological need for identifying remote objects in the sky and close to the ground.

Harter (253) demonstrated that increasing the dimensions of the checks in a checkerboard pattern elicits the greatest amplitude when the stimulus is moved away from the center of the visual field. The author also noted that the check size which elicits the greatest response depends on which component is being used to measure the response (a component with a latent period of 95-100 msec or a component with a latent period of 170-220 msec). Differences in check size also influence EP changes in response to defocusing. The latter significantly reduces the amplitude of an EP to a checkerboard pattern with a check size of 10-20 ", while when checks of larger size are used, defocusing has little influence, or it is even accompanied by amplification of the EP (530).

Campbell and Maffei (134) studied the dependence of EP amplitude on the contrast of a grid consisting of light and dark stripes, presented on the screen of an oscillograph. The dependence of EP amplitude on contrast, expressed in logarithmic units, was found to be linear. Extrapolation of the function to zero amplitude produced a contrast value close to the threshold determined by conventional methods. There are other indications of a correlation between EP's and contrast thresholds as well (307).

It is not clear yet what it is in structured stimuli that influences EP characteristics--outlines, intersections (corners), the length of straight lines in the outline, changes in contrast along the margin, and so on. These questions are presently being investigated (257,330,331,401).

CHAPTER XII

EP'S AND INTELLIGENCE RESEARCH*

The hopes of electrophysiologists to find EEG correlates of intelligence free of the influences of language, culture, and other factors have not been supported. While distinct, meaningful differences have been observed in comparisons between normal people and the mentally retarded, comparison of the EEG characteristics of persons with different IQ's within a normal sample has produced contradictory results and prevented arrival at definite conclusions (451,513,514; Ellingson, 1966).

New possibilities have arisen with the appearance of the EP registration method, which promised more than the EEG on an *a priori* basis in view of the relationship of EP's to external stimuli and information processing, absent from the resting EEG. Distinct individual differences in EP's and EP changes occurring at early age in parallel with maturation of the nervous system also inspired a search for dependable indicators of mental development within EP characteristics. As a rule this search has involved comparison of EP's either of people of different intelligence levels ("extreme" groups were selected from a normal population) within the so-called "norm", or of "normal" individuals and the "mentally retarded." Both comparisons were made on adults and children, but comparisons of the latter type were usually performed on children in connection with the hope of finding some sort of indicators of the cause of retardation in mental development. Various EP characteristics were studied: latent periods, amplitude, variability, degree of interhemispheric asymmetry, extinction rate (rate of amplitude decline in response to repeated stimulus deliveries), frequency characteristics, and so on.

The first works (215,219; Ertl, 1965) revealed an inverse relationship between the latent periods of EP's (especially components falling within the 100-500 msec period) and intelligence. The amount of correlation between EP latent periods and intelligence varied in different works from -0.10 to -0.88.

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*We will not examine the question as to what so-called intelligence tests do in fact reflect. They have been subjected to critical analysis in a number of papers (see for example: 4,17; Cronbach, Drenth, 1972).

Ertl (216) conducted his research on a rather large sample consisting of 317 boys and 256 girls selected at random from among 8,000 children in grades two through eight. Intelligence was measured by Wechsler's scale and by two other tests; EP's to 400 light flashes delivered at random at intervals varying within 0.8-1.5 seconds were summed and averaged as well. A special procedure isolated statistically significant potential oscillations that did not always coincide precisely with visually distinguishable components. Intercorrelation of intelligence indicators with the latent periods of four initial EP oscillations isolated in this fashion revealed a highly significant inverse relationship between them, more pronounced in relation to late components than to early ones. Visual comparisons of EP's in the extreme groups revealed presence of EP's with greater shape complexity and with earlier components among subjects with high intelligence quotients than in the group with low intelligence quotients.

It should be noted that the work of Ertl et al. was subjected to valid criticism in connection with the absence of sufficient grounds for identifying the EP components of different subjects for subsequent comparison of latent periods (127) (see Chapter III). The intelligence-associated differences they revealed can more likely be interpreted as a manifestation of a difference in the EP component composition of persons with low and high intelligence. If this is so, then data acquired from research on the relationship between intelligence and the frequency characteristics of EP's that do not offer difficulties in identification of individual components would essentially be in very close agreement with the results of Ertl et al. A larger EP oscillation frequency corresponds to higher intelligence quotients (223,524). Weinberg (524) discovered the most significant correlation between the expressiveness of EP frequencies of 12-14 Hz and intelligence. This relationship also revealed itself distinctly in comparative visual analysis of EP's recorded from 6 subjects with the highest IQ's (146) and 6 with the lowest (77): Dominance of slower EP components was typical of the latter. The author examined the obtained results in light of the hypothesis that a scanning mechanism that recodes perceived stimuli exists within the cerebral cortex, and he suggested that frequencies correlating with intelligence reflect the optimum frequency of the scanning mechanism.

Information on the relationship between EP latent periods and intelligence was obtained in later works free of the methodological shortcomings in the early works of Ertl et al.

Thus an inverse relationship between the latent periods of EP components and intelligence was demonstrated in research conducted on a group of 109 adult subjects (451). EP's were recorded in a situation of "high external activity" (the subject had to press a button in response to each flash), "moderate external activity" (the subject had to count the flashes), and "internal activity" (the instructions prescribed lying calmly and watching the flashes). An inverse relationship was discovered between EP latent periods (especially of late components having latent periods of 200 msec and more) in the experiment as a whole and capabilities. The magnitude and number of meaningful correlations increased when the internal activity situation, which was viewed as the lowest degree of activity, was analyzed separately. The authors concluded that it would be best to study the mutual relationships existing between EP indicators and capabilities in conditions least promoting activation. It should be noted, however, that the correlations found in this study turned out to be much lower than in Ertl's work (215) (from 0.15 to 0.32, in comparison with 0.10-0.88).

An inverse relationship between latent periods and intelligence was also demonstrated in other works (103,233,335; etc.). According to Callaway high intelligence quotients occurred with shorter visual EP latent periods, the correlations being expressed to the greatest extent with bipolar registration in the frontal-parietal region and with the use of Ertl's method to determine latent periods (128). This relationship became stronger with tiring. However, such correlations were not discovered for auditory EP's, and in some cases opposite relationships were observed between latent periods and intelligence.

At the same time a significant number of studies have been performed in which no correlation was discovered between EP latent periods and intelligence. Significant correlations were not discovered between the EP latent periods of newborn infants, their speech behavior at an age of 3 years, and the IQ's of the same children at age 4 (213). Significant correlations were not discovered in a comparison of the latent periods of component P193 of an EP to a light flash in sleeping infants with IQ's and other tests (sensomotor, perceptual, and so on) of the same children at age 7; the group consisted of 851 children (only 1 out of 48 correlations was found to be significant) (263). EP's were recorded from sleeping children.

Differences were not observed in latent periods between developed and mentally retarded children 10-11 years old (Rhodes et al., 1969). A number of studies (97,172,263; Shagass, 1968; Rhodes et al., 1969; etc.) failed to reveal an inverse relationship between EP latent periods and intelligence, and in some cases they revealed opposite relationships. Rust (423) published the results of research on the mutual relationships existing between intelligence and personality traits on one hand and the amplitude and latent period of components P50, N112, P215, and N399 in a tonal EP recorded in a state of rest: No mutual relationships were discovered. Having analyzed the published data, the author concluded that there are no data today that would permit derivation of a theory of personality or intelligence in the terms of biological variables.

It should be noted that the presence of correlations between any particular EP characteristics and intelligence quotients does not by itself prove biological predetermination of intelligence or indicate the existence of some sort of nervous substrate for intelligence. On the contrary, the correlations may be the product of an influence of intelligence level (and equally of personality traits associated with it) upon the subject's attitude toward the research, which would govern the subject's activation level during the experiment, attention, and other factors influencing EP characteristics. Callaway (128) for example believes that correlations between latent periods and intelligence doubtlessly depend to a certain extent on interaction between the subject's intelligence and his attitude toward stimulus delivery, on his attention, and so on. It would not be difficult to understand that the result of such interaction is governed by the subjective difficulty of the assignment, the subject's attitude toward the experimenter, and so on. All of this makes the existing discrepancies in the results of different studies understandable, and even inevitable.

On the whole it would be difficult to arrive at categorical conclusions concerning the significance of correlations existing between EP latent periods and intelligence, and on the nature of this correlation (for details, see (128)).

The results of research on the relationship between EP amplitude and intelligence are even more contradictory. Differences in amplitude connected with intelligence were discovered for the first time in a comparison of the EP's of healthy and mongoloid children who were behind the healthy children in mental development (94). Amplitude was found to be significantly higher among mentally retarded children. Later, Rhodes et al. (1969) obtained the opposite results. The authors compared the EP's of 20 highly developed and 20 retarded children selected from among 800 schoolchildren 10-11 years old on the basis of IQ's. The amplitude of late components of EP's recorded from the former was greater; interhemispheric asymmetry was also noted, which did not occur in the group of retarded children. The authors believe interhemispheric asymmetry and not EP amplitude to be the most promising indicator of intelligence.

Absence of differences in EP amplitudes accompanying significant differences in intelligence indicators was demonstrated in a number of studies. In particular, detailed research on the relationship between EP amplitude and intelligence in a group of normal adults basically produced negative results (451). Correlation was discovered only in relation to the degree of EP amplitude decline accompanying transition from high external activation to low external activation, and not in relation to absolute amplitude values.

Nor was a correlation revealed between intelligence and EP amplitude in a later work (454). This research was conducted on two groups of eight persons each having high and low intelligence quotients, selected from among 28 persons. The sole characteristic by which the groups of high- and low-intelligence individuals differed was EP variability. It increased more in response to an increase in amplitude and a change in the situation for persons with low intelligence.

Summarizing the results of the search for intelligence correlates in EP amplitude, Prescott (386) called them unpromising. Perhaps the research would be more successful if we move from measurement of the amplitude of an EP as a whole, typical of such studies, to measurement of the amplitude of individual components, especially late ones associated with cognitive processes. In this case we should obviously study the degree of change exhibited by component amplitudes in different situations. One reasonable direction of inquiry would be to seek intelligence correlates in the rate of extinction (that is, amplitude decline in response to stimulus repetition) of the EP (128). Research by Lewis (318), which demonstrated a correlation between the rate of extinction of reflex acceleration of heartbeat in response to repeated deliveries of a visual stimulus in children 9 months old and intelligence quotients recorded at an age of 4 years are encouraging in this direction. Faster extinction of auditory EP's was noted in normal children in comparison with mentally retarded children (94). Studying extinction in relation to the amplitudes of the second and first of a pair of EP's recorded in response to stimuli spaced 2 seconds apart, Callaway noted that in some situations people who are more capable exhibit more-pronounced extinction than those who are less capable.

In general, the influence of a preceding stimulus upon an EP evoked by a subsequent stimulus is governed by several mechanisms (see Chapter X). One of them, at least in relation to interstimulus intervals of less than 10 seconds, is the predictability of the stimulus, the degree of anticipation. This is possibly the cause of the relationship existing between the rate (or degree) of EP decline in response to stimulus repetition and intelligence. Confirmation of this hypothesis can be found in the direct relationship existing between the degree of amplitude decline in EP's recorded in response to self-stimulation and intelligence (128). This decline is interpreted as an effect of greater anticipation and greater preparedness for appearance of the stimulus than is the case with unexpected stimulus delivery. Inasmuch as it may be presumed that the decrease in EP amplitude occurring with self-stimulation reflects adaptation to the stimulus, which is expressed better in persons having a higher level of intelligence, it would be interesting to study the effects of self-stimulation in different conditions. We could expect that if intense stimuli (especially electrocutaneous stimuli) were to be delivered, amplitude would decline with self-stimulation, and if very weak stimuli requiring recognition were to be presented, on the contrary there would be an increase in amplitude.

It would probably make sense to study the relationship between extinction rate and intelligence in different conditions: during passive perception, in the presence of distracting stimuli, with attention focused on the stimulus, and so on. In this case it would be interesting to analyze the relationship exhibited by extinction rate in these conditions. It would also be suitable to study the connection the dependence of EP amplitude on stimulus probability characteristics has on indicators of intelligence.

A unique method for revealing differences between healthy and mentally retarded children on the basis of EP amplitude was proposed by Shipley (449). Recording EP's to simultaneously delivered sound and light, the author discovered that EP's were lower in amplitude in this case than the sum of EP's to the same stimuli delivered separately. He interpreted this effect as an indication of inhibition accompanying simultaneous delivery of two stimuli. Inasmuch as the amplitude of such "bimodal" EP's was lower for mentally retarded children than healthy children, Shipley concluded that inhibition was more highly pronounced among mentally retarded children.

Interhemispheric asymmetry is the most promising EP characteristic associated with amplitude for diagnosing mental retardation (386). Lower interhemispheric asymmetry of EP's was noted in mentally retarded children in comparison with normal children in a number of works (128; Rhodes et al., 1969; Bigum et al., 1970). Interhemispheric asymmetry in frontal divisions was 2.5 times greater among normal children than among mentally retarded children (233).

Detailed research was performed on differences between normal and mentally retarded children in the nature of interhemispheric asymmetry (399,400). The authors discovered not only a decline or absence of asymmetry in mentally retarded children, but also presence of "reverse" asymmetry within them: While tonal EP's were greater in the right hemisphere for normally developed children, EP amplitude was greater in the left hemisphere for retarded children. Separating the subjects into two groups based on handedness, they demonstrated that hemisphere dominance must be accounted for when making such comparisons. The authors believe asymmetry to be a fully promising indicator (even a quantitative correlate of intelligence), but they point out a number of problems that must be solved before the method can be introduced into pediatric practice. Choice of recording points is one particular problem; in the opinion of the authors it would be best to enlarge the number of these points. They also suggest that if we were to broaden research on asymmetry in children suffering retardation due to different causes, we might possibly find those forms of retardation for which asymmetry is a sufficient diagnostic sign.

We cannot fail to note that the obvious heterogeneity of components subjected to comparison in some works elicits bewilderment. For example to determine asymmetry, Richlin et al. (399,400) reckoned the amplitude from the peak of maximum positiveness to the peak of maximum negativeness, irrespective of the moment at which the peak arises. It is evident from the figures they present that the amplitudes of normal and mentally retarded children are measured between the peaks of clearly different components. When making a detailed comparison of works on this subject, we must obviously account for the technique used to assess interhemispheric asymmetry, and it would be wise to use several techniques in conjunction with one another in our research. Prescott (386) recommends a method devised by Saltzberg and Lustick to assess interhemispheric asymmetry, inasmuch as this method accounts for differences in amplitudes and latent periods simultaneously. Prescott suggests that its use would be more successful than the use of existing indicators, and that it would hasten our discovery of a "neurobiological" indicator of intelligence, similarly as what is happening with the psychometric index today.

It should be noted that for the moment the overwhelming majority of correlations between intelligence and asymmetry have been revealed only in research on children (128). It may be possible that we have not yet arrived at the best conditions for revealing correlations between interhemispheric asymmetry and intelligence, as well as other indicators. Callaway (128) suggests on the basis of his own research that it would be better to use short stimuli and a restful situation. In this case he proposes that "verbal" persons (those exhibiting higher intelligence) would "use" their left hemisphere, which is why EP's to indifferent signals would be lower in this hemisphere. On the other hand we would expect better revelation of differences associated with intelligence when structured or verbal stimuli and assignments are presented. What would possibly be a valuable indicator is not interhemispheric asymmetry of EP's to identical stimuli on its own, but differences in its degree in response to different stimuli (verbal-nonverbal, simple and structured, and so on; see Chapter XIII).

EP variability is another possible correlate of intelligence (as well as of nervous system maturity and development) being studied. A significant part of the research done in this area is credited to Callaway and his colleagues (1965, 1969, 1975). They have demonstrated a relationship between variability on one hand and intelligence, age, pathological mental alterations, and activity indicators on the other. Lower EP variability corresponds to higher intelligence and better performance of assignments requiring sensomotor integration. Callaway (128) interprets high variability as a sign of an immature or poorly integrated and biologically unadapted nervous system.

The nature of phenomena at the basis of EP variability continues to be an objective of research (differences in extinction rate, EEG variability--that is, "noise" artefacts in EP's, and so on), and the success of using variability to evaluate intelligence or maturity depends significantly on progress in this area.

Inasmuch as EP variability is known to be influenced by a number of circumstances (rate and degree of extinction, fluctuations in wakefulness and attention, and so on), we must, as Callaway notes (128), "capture" that set of conditions in which the relationship between variability and intelligence would reveal itself in the best way.

In general, as was noted above, different supplementary variables that are not always controllable play a significant role in research on the relationship between EP's and intelligence (128) (for example motivation, attention, the way the subject's feels at the time of the study, his attitude toward the experiment, and so on); this may be the cause of the inconsistency seen in the results of different studies. At the same time control of such variables, and especially of their purposeful changes, may open up to prospects in the search for intelligence correlates. The search in this direction is now underway, though for the moment the facts and their interpretation are rather contradictory and ambiguous.

The search for intelligence correlates in EP changes governed by attention began relatively recently. One of the approaches involves establishing differences in the amplitude of EP's to the same stimulus depending on whether the latter is irrelevant or relevant to the assignment, and depending on the difficulty of the latter. As an example research was conducted on changes in EP amplitude associated with attention exhibited by persons of high and low intelligence (190). EP's to light flashes were recorded in a situation where the subjects had to count flashes and where they had to solve a complex problem presented at the center of the visual field. The decrease in the EP occurring in the second case was greater among persons of high intelligence. The opposite result was obtained as well (454): The difference between EP amplitudes recorded in attention-inattention situations was greater among persons of low intelligence. However, the authors do not believe these results to be contradictory, suggesting that the differences lie in differing difficulty of the "distracting" assignment posed in the two studies. The distracting problem in the former study was so complex that subjects of low intelligence generally had difficulty solving it and they could not concentrate on it sufficiently well; hence follows the lower decline in amplitude in response to the testing stimulus. In the latter study the "distracting" assignment (reading magazines) was easy for both groups, but it was easier for persons of higher intelligence, such that they could both read a magazine and perceive the tones; therefore the amplitude of their EP's to the testing signal decreased less. And so, in one case subjects of low intelligence could not concentrate on the "distracting" problem due to its difficulty, while in the other case subjects of higher intelligence did not concentrate enough due to the ease of the "distracting" problem: Thus the result appears contradictory.

Another study analyzed changes in an EP to a light flash in a situation of passive perception (at the beginning of the experiment) and while performing a motor reaction in response to the flash (at the end of the experiment) (452). The difference in EP amplitudes was greater among persons of higher intelligence, which was tentatively explained by greater relaxation toward the end of the experiment. Thus the research begins with definition of independent and dependent variables in such a way that they could be substituted for one another in the most diverse ways in the course of their interpretation.

Incidentally, the situation is changing. Owing to recent achievements in research on the relationship between EP's and attention (377; Hillyard et al., 1971, 1974; etc.), we can expect significant successes in research on the mutual relationships between intelligence and attention. These achievements are now permitting us to substitute speculative notions of the "greater or lesser" distracting role of a proposed assignment by actual measurements of attention (in this case we would naturally have to record EP's in the presence of both the testing and the distracting stimulus). If we add to this independent measurement of assignment difficulty, we could expect that correlations with intelligence indicators would be revealed in the characteristics of attention (the nature of attention distribution as determined from an EP, the rate of changes occurring in an EP in connection with attention, and so on).

We have listed the most broadly employed indicators, and the search for them will doubtlessly broaden (and concurrently narrow down as we discard the unuseable indicators).

Several attempts are being made to find intelligence correlates in the so-called EP recovery function. When two stimuli are presented a small interval apart, the intensity of the first stimulus and the size of the interstimulus interval influence the size of the EP following the second stimulus. The dependence of the amplitude of the second EP on the interstimulus interval and on the intensity of the first stimulus is viewed as a characteristic of the recovery function. Theoretically, the recovery function may be analyzed in relation to any EP component, but it is usually determined in relation to early components, particularly components N20 and P27 of the somatosensory EP.

A method for determining the recovery function was proposed and developed in the works of Shagass et al. (1961, 1964, 1972, etc.). The somatosensory EP is typified by best recovery with an interstimulus interval of 10-20 msec, decreasing recovery in 25-100 msec intervals, and then improvement of recovery, which becomes complete at intervals of 300 msec and more. The physiological processes at the basis of recovery are unclear. Pribram (1967) suggests that recovery may reflect the action of a special filtering mechanism regulating the rate of information processes. Shagass (444) described recovery as a manifestation of a certain recovery mechanism that always goes into action following excitation of a cell.

Differences have been described between groups of persons with average (119.8) and low (71.9) IQ's in relation to the nature of somatosensory EP recovery during presentation of paired stimuli at different interstimulus intervals varying within 7.5 and 300 msec (519). The poorer recovery in response to short intervals exhibited by the group of persons of low intelligence was interpreted by the authors as a manifestation of disturbed cortical activation at the level of the thalamic system.

Callaway (128) reports that recovery of EP's at interstimulus intervals of about 100 msec correlates with a continuum having mental retardation at one end and normality at the other.

All research conducted to date on the relationship between EP characteristics and intelligence concerns itself only with the group differences; as a rule, however, it is noted that high interindividual variability precludes determination, on the basis of the revealed differences, of not only the individual IQ but also membership within a group. No study has ever produced quantitative correlates of intelligence.

Thus for the moment not a single indicator can be used for diagnostic purposes. Indicators such as interhemispheric asymmetry, variability, and perhaps EP changes connected with attention and extinction are the most promising today. The predominantly negative results of research in this area are the product, in Prescott's opinion (386), of the inadequacy of the stimuli employed or of imperfections in the analysis technique, and they should not diminish the enthusiasm of the researchers.

Research by Perry et al. (369) on a group of 98 children with an average age of 5 years 7 months and an average IQ of 119.5 (varying between 94 and 144) can be cited as an example of using multidimensional analysis successfully in the search for intelligence correlates. The methods of multidimensional analysis were used to determine the mutual relationship existing between general and verbal intelligence measured by Wechsler's tests and other behavioral characteristics on one hand and isolated special EP characteristics on the other. Significant multiple correlations were discovered between EP indicators and general intelligence, as well as intelligence based on the activity scale (but not verbal intelligence). The mutual relationship between EP's and activity indicators was also found to be significant with the use of canonical correlation.

CHAPTER XIII

USE OF EP'S IN RESEARCH ON FUNCTIONAL INTERHEMISPHERIC MUTUAL RELATIONSHIPS (FUNCTION LATERALIZATION, HEMISPHERIC DOMINANCE, AND SO ON)

EP's have been found to be an extremely valuable tool in research on the manifestations and mechanisms of functional asymmetry of the cerebral hemispheres, interest towards which has grown extremely high in recent times, and the possibilities of EP's have been far from exhausted. We will try to outline the basic directions of research employing EP's in this area, and present the basic facts accumulated as of today.

Simple comparisons of EP's recorded from symmetrical points on different hemispheres can be found in many works, and they have produced rather ambiguous results. A number of papers noted absence of asymmetry (228,229, 507, etc.), but perhaps the bulk of the data indicates that the amplitude of EP's to "simple" stimuli (tones or light flashes) recorded from right-handed persons is greater in the right hemisphere (303,366), while that of EP's in response to verbal stimuli (auditory or visual) is greater in the left hemisphere (117,118,346,etc.). Communications can be found of opposite nature, in which the conditions appear to be similar but in fact the interhemispheric differences of comparable directions noted in different works often pertain to different components.

The discrepancies in the results may have several causes. One of them is the success with which electrodes are positioned to reveal asymmetry. Thus interhemispheric asymmetry of auditory EP's was discovered at points T3 and T4, while at points C3 and C4 the EP amplitude was the same (Ruhm et al., 1970). Another cause is associated with the stimulation technique: Interhemispheric differences may reveal themselves differently in response to one- and two-sided stimulation. Two independent factors make themselves known in the interhemispheric asymmetry of an EP in response to one-sided stimulation: the distribution of conducting fibers and the dominance of one hemisphere over the other. In this connection interhemispheric EP differences recorded with one-sided stimulation reveal themselves predominantly upon stimulation of the side contralateral to the dominant hemisphere, since in this case both factors are added to each other, resulting in a clearly greater amplitude on the contralateral side. In the opposite case the opposite action of these factors may lead to an identical EP amplitude in both hemispheres in response to one-sided stimulation.

Because it has been demonstrated in a number of works that the nature of asymmetry depends on which hemisphere is dominant, interhemispheric comparison of EP characteristics averaged for a group of subjects, performed in earlier EP studies, would apparently be meaningless without determining the dominant hemisphere. The result obtained in this case may be affected by the particular ratio of right and left hemisphere dominance in the group of individuals.

The dependence of EP characteristics on the dominant hemisphere and the stimulation technique may be illustrated by a work analyzing the relationship between EP's arising in different hemispheres in response to change in illumination in half or all of the visual field, depending on whether the right or left hand is dominant, as determined from handwriting preference (Gott, Boyarsky, 1972). The group of subjects contained nine right-handed and six left-handed individuals. The authors employed monocular stimulation in one half of the visual field to compare EP's arising in different hemispheres in response to stimulation of just the direct visual tract: The visual stimulus was presented to the right or left of a fixation point (at a 38° angle), during which time the right or left eye was closed. Thus one hemisphere received only "direct" stimulation--via the direct visual tract, while the other was stimulated only through interhemispheric associations--via the corpus callosum or the anterior commissure. Four components were isolated from the recorded EP's, and the latent period and amplitude were determined for each of them in the right and left occipital regions, using monopolar registration. When illumination was changed in the entire field of vision, the differences between the EP's in the right and left hemispheres were detected in neither right-handed nor left-handed individuals. Comparison of the EP's arising in the right and left hemispheres in response to "direct" stimulation of each showed that the latent period is long in the left hemisphere for right-handed subjects, while the reverse held true for left-handed individuals, for whom the latent period was longer in the right hemisphere. Consequently responses to "direct" stimulation arise in the dominant hemisphere a little later than in the nondominant hemisphere. The authors assessed this to be evidence of a longer direct visual tract (in the cortex or in subcortical formation) in the dominant (as defined by handedness) hemisphere.

This hypothesis is also supported by comparisons of the EP's of the same hemispheres (right and left) of right-handed and left-handed subjects. EP's recorded in the left hemisphere of right-handed subjects had longer latent periods than those of left-handed subjects, while longer latent periods were observed in the right hemisphere for left-handed subjects--that is, longer latent periods were observed in the dominant hemisphere. Different relationships were revealed on comparing the amplitudes. Interhemispheric differences in amplitude were not observed at all for right-handed persons, while for left-handed persons the amplitude was greater in the right (dominant) hemisphere. We recall that we are dealing here with a comparison of EP's in response to "direct" stimulation of the given hemisphere. The real amplitudinal differences attest to "asymmetry" of the "right-handed" and "left-handed" brain.

We believe the fact that different results were obtained with different stimulation techniques to be significant in this work. The "asymmetry" of the relationship between the amplitudes of EP's recorded in the right and left hemispheres of right-handed and left-handed subjects may be the product of a difference in speech dominance of the hemispheres of left-handed persons. Research conducted in the last 10-15 years has shown that dominance of hemispheres determined from hand use preference does not at all necessarily correspond to hemispheric speech dominance. The sole absolutely strict technique available today for determining hemispheric speech dominance is to inject sodium amital into the the carotid artery. Using this technique, Branch et al. (108) discovered that the speech center of right-handed individuals is located in the left hemisphere, but it was in the right hemisphere of only a third of the left-handed individuals. For most of the left-handed individuals studied, dominance of the left hand combined with speech dominance of the left hemisphere. These data were confirmed in research using the method of dichotomous presentation of verbal material (428); it was established that the speech center was located in the right hemisphere of only 40 percent of the left-handed individuals studied. In the same study, the speech center of right-handed individuals was located in the left hemisphere in 87 percent of the cases.

And so, right-handedness and left-handedness do not reflect the "symmetrically opposite" organization of the brain: The speech center of right-handed individuals is usually located in the left hemisphere, while lateralization of the speech function is highly variable for left-handed individuals, and the speech center may be either in the right or in the left hemisphere, or both. Incidentally, this circumstance may serve as a cause for discrepancies in the results of different studies, especially those dealing with EP's recorded from left-handed individuals.

In other cases we do not usually account for the influence of the dominant eye; incidentally, the dominant eye influences EP amplitude identically in both hemispheres (Calver et al., 1970). Differences in EP's in response to a light flash were analyzed for a group of 24 women depending on hand and eye dominance and on the side of stimulus delivery (the flashes were presented in one half of the visual field). Independently of the factors listed above, the amplitude of the EP was always greatest in the right hemisphere when the flash was presented in the left half of the visual field. EP amplitude was greater for persons exhibiting left-eye dominance than for persons with right-eye dominance. An earlier study (203), in which only men participated, revealed the interesting fact that the amplitude of EP's to light flashes was greater in the right hemisphere only for left-handed individuals, being absent from right-handed individuals. This implied that lateralization of functions due to hand dominance is more-pronounced among men than among women. Similar conclusions were made from an analysis of interhemispheric asymmetry and EEG indicators (244).

Detection of interhemispheric EP differences also depends on the choice of indicator to be analyzed. In addition to comparison of latent periods and (or) amplitudes, which is what we encounter most frequently, indicators such as the coefficient of correlation between EP's recorded from the right and left hemispheres (356) and the degree of coherence (a frequency analog of the correlation coefficient) between EP's recorded from different regions in the right and left hemispheres (171) has been employed rather successfully. It should be noted that because the nature of the recorded indicators is unclear, any asymmetry observed is often interpreted in favor of the initial hypothesis. In the paper cited above for example (171), significantly high coherence was discovered for EP's to clicks in the occipital and temporal regions of the speech-dominant hemisphere, while on the other hand coherence was observed to be greater between the same regions of the nondominant hemisphere in relation to EP's recorded in response to light flashes. The authors view this result as evidence of asymmetry in the perception of auditory and visual stimuli at a level lower than verbal, and as a manifestation of right hemispheric dominance in visual perception. However, the notion that greater coherence of EP's in different regions is a sign of hemispheric dominance in analysis of the particular type of stimulus that elicited the EP is not undebatable. It might be, on the contrary, that the left occipital region is dominant, and that the "unique" EP changes associated with analysis of visual information, which are expressed to a greater extent in the former, might cause a decrease in the similarity of EP's recorded in the occipital and temporal regions. Of course the hypothesis suggested by Davis and Wada (171) would most likely be true, since dominance of the right hemisphere in analysis of simple visual stimuli is presupposed in the data of many authors, but it does not at all logically follow unambiguously from the facts they obtained.

Despite the listed difficulties, use of EP's has turned out to be extremely productive, and it is to an illustration of this that we will now turn our attention. Let us examine use of EP's to analyze dominance and interaction of hemispheres during perception of verbal stimuli. Because there are no simple methods for determining which hemisphere is dominant in speech, it would be extremely valuable to find a dependable correlate of dominance in EP characteristics. We cannot for the moment say that such a correlate has been found, but the existing results at least afford the grounds for continuing the search. One of the directions of this search is simple comparison of EP's to verbal stimuli recorded in different hemispheres. It was demonstrated in a number of studies that among right-handed individuals, the amplitude of EP's to verbal stimuli is larger in the left hemisphere than in the right (329,339,356,540, etc.), while asymmetry of EP's to nonverbal stimuli (clicks, tones,) is nonexistent (356), or it is opposite in nature (366).

There are data showing the reverse to be true as well. As an example Haaland (249) recorded, from the vertex and from the frontal and temporal regions of nine persons, EP's in response to verbal stimuli presented dichotomously, monauraly, and binauraly. He isolated a negative oscillation with a latent period of 69-153 msec (N1) and a positive oscillation with a latent period of 166-306 msec (P1). The amplitude of each of them was measured from a midline, as determined from the EEG in the 100 msec preceding the stimulus. Component P1 was larger in the right hemisphere while N1 was the same in both hemispheres. Absence of asymmetry in oscillation N1 was interpreted by the author as evidence against the hypothesis that acoustic and linguistic analysis proceeds separately, with the former dominating in the contralateral hemisphere. Other studies did not discover any interhemispheric differences in EP's to verbal stimuli ((392) in the case of acoustic stimuli, and (228,229) in the case of visual and auditory stimuli).

The amount of difference between EP's to verbal and nonverbal stimuli revealed "within" each hemisphere may also be an indicator of interhemispheric relationships. Presence of a difference in the left hemisphere coupled with absence of this difference in the right is viewed as an indication that the region of the left hemisphere next to the electrode contains verbal analysis mechanisms that are not present in the right hemisphere--that is, as a manifestation of dominance.

Brown et al. (113,114) demonstrated that differences in the semantic meaning of identical words (depending on context) influence the shape of an EP to a greater extent in the left than in the right hemisphere (the coefficient of correlation between repeated EP's in different hemispheres was determined in this work). Wood et al. (540) compared EP's recorded in response to the same verbal stimulus (a syllable consisting of two letters) depending on whether this syllable had to be subjected to verbal analysis (when its second consonant differed) or compared with the same syllable but delivered at a different pitch. A significant difference was observed only in the left hemisphere.

Adequate activation of the hypothesized "asymmetrical" mechanism, which depends on both the nature of the assignment and the stimulus, is apparently significant to revealing interhemispheric differences. For example research by Kostandov and Genkina (35) did not reveal differences in the nature of the interhemispheric asymmetry of EP's to verbal and nonverbal visual stimuli, recorded in response to direct stimulation, while other authors (for example (118)) (delivering the stimulus in the center of the visual field) demonstrated differences in the asymmetry exhibited in response to verbal and nonverbal stimuli.

In our opinion the wrong choice of stimulus and assignment may be the reason why Kostandov and Genkina failed to find differences in the asymmetry of EP's to verbal and nonverbal stimuli, even though the methodological advantages of their study would lead one to believe that they should have revealed the differences more clearly. The verbal stimuli they used were individual letters, and the nonverbal stimuli were complex patterns. The subject had to memorize the delivered stimuli, so that he could later report how many times they were delivered, or recognize them from a set of patterns presented after the experiments. Insmuch as letters are memorized more likely by their name and not their shape--that is, they do in fact require linguistic analysis, it may be thought that every pattern was also subjected to evaluation as a possible letter, and that it was only after the possibility of attaching a "convenient" verbal name to it was rejected that it was memorized as a pattern. Thus both types of stimuli could have "turned on" linguistic analysis, and therefore the differences between verbal and nonverbal stimuli were not detected.

The same can also be said of research conducted by Shalburne (448), who compared EP's to words and to nonsense syllables without detecting differences. Nonsense syllables alternating with words are initially perceived as words, and it is only after linguistic analysis--the same sort seen with word perception--that they become nonsense syllables. Data reported by Donchin and Herning (196) describe the influence of assignment nature on asymmetry. They observed a greater amplitude for component P300 in the left hemisphere when the subject had to guess which letter would be presented on a screen: A or B. If appearance of one of the letters required a fast motor reaction, the amplitude was greater on the right. It may be hypothesized that in the case of the fast motor reaction, linguistic analysis was substituted by recognition of letter traits "critical" to the reaction.

In their study cited above, Kostandov and Genkina discovered very interesting hemispheric differences in EP's to direct stimulation of the hemispheres: The amplitude of component P300 in response to direct stimulation of the left hemisphere was greater in the left hemisphere than in the right, while in the case of direct stimulation of the right hemisphere, differences were not observed in the EP's recorded from the different hemispheres. We find this fact interesting in light of some data indicating that performance of parallel assignments improves after the brain is "split" (236). The authors believe that the improvement stems from elimination of the inhibitory influences passing from the working hemisphere to the other hemisphere. The greater EP amplitude in the left hemisphere in response to direct stimulation of the latter may be explained by the fact that the left hemisphere, having been stimulated "directly," partially inhibits information processing in the right (the amplitude of oscillation P300 is lower), while the right does not have similar action (when the right hemisphere is stimulated "directly," oscillation P300 is the same in both hemispheres). Thus the data of Kostandov and Genkina may be interpreted as evidence of the dominance of the left hemisphere in analysis of semantic visual stimuli.

It would pay to mention one more result obtained in this work: The amplitude of component P300 was more pronounced in the left hemisphere in response to both verbal and nonverbal stimulation, while the amplitude of P200 was greater in the right hemisphere following nonverbal stimuli. The fact that differences exist in the interhemispheric relationships observed with the different components recalls the need for considering the component under discussion when analyzing and comparing published data.

Data presented by Zenkov and Panov (20) and their interpretation of them imply possibility for revealing asymmetry associated with speech dominance with the use of nonverbal stimuli as well. The authors presented checkerboard patterns differing in clarity--from near-threshold to distinctly suprathreshold. At near-threshold clarity of the stimulus, EP's were better expressed in the occipital region of the right hemisphere, the first increase in clarity was accompanied by a greater increase in EP amplitude and reduction of latent period in the left hemisphere, while with maximum clarity asymmetry was not observed. The authors interpret these data as a manifestation of initial dominance of the right hemisphere in perception of visual-spatial stimuli that do not yield to precise verbal assessment (at near-threshold stimulation), and gradual inclusion of the left hemisphere in the process as the clarity increases to a point sufficient to permit precise interpretation of the stimulus as a checkerboard pattern. The possibility that attention plays a role in the nature and degree of interhemispheric asymmetry is not excluded (Khomskaya et al., 1976).

As we can see from the sum total of these works with conflicting results, we cannot as yet use EP's as absolutely dependable correlates of dominance in perception of verbal stimuli, or as indicators of linguistic analysis. However, we cannot doubt that EP's can be used to obtain new valuable information on interhemispheric mutual relationships that is often inaccessible by any other means. Contradictory results in diagnosis of dominance do not provide the grounds for pessimism: They only imply a need for making improvements in the methods and finding new approaches to solving the problem.

Perhaps a more dependable indicator of speech dominance could be found in EP's arising following the beginning of speech or articulation. Using a reverse averaging method, Grozinger et al. (298) recorded EP's from 17 persons preceding the beginning of speech, phonation, or articulation for 3.5 seconds, and in the following 0.5 seconds. They summed and averaged 80-300 EEG segments free of artefacts. They recorded rather stable potentials following the beginning of speech or articulation, and extremely variable potentials preceding its beginning, as determined from the moment an EMG of mouth muscles showed a response. Distinct interhemispheric asymmetry of these potentials was established. Analysis and elimination of possible artefacts caused the authors to conclude that the recorded potentials were intracerebral in origin, and that the observed interhemispheric asymmetry reflected hemispheric dominance. Preparatory research by the authors, in which potentials were recorded simultaneously with intracerebral and superficial electrodes during stereotaxic operations, confirmed this point of view.

EP's were used to study development of hand dominance in ontogenesis (138,139). This question is still unclear today. One of the points of view is that hand dominance develops after birth, but that at the moment of birth no sort of dominance exists, and it is only in the course of the child's development that a transition occurs from "ambidexterity" to right- or left-handedness. According to another point of view development is broken down into stages of right-handedness, left-handedness, and equal use of both hands. A mutual association has been revealed in children between hand dominance and the frequency of arisal of somatosensory EP's ipsilateral to the stimulated side (139). Ipsilateral EP's were observed in right-handed subjects more often in response to stimulation of the right hand than stimulation of the left, which the authors believed to represent more-frequent interhemispheric transmission of stimuli from the dominant hemisphere to the nondominant, than vice versa. Later these same authors studied development of right-handedness, left-handedness, or ambidexterity in children up to 48 months old, parallel with changes in somatosensory EP's, namely in the early negative oscillation N18-21 (N1). Development of dominance was determined from the way the child grasped an object. EP's were recorded bipolarly above the postrolandic region, with the second electrode located on the vertex. Several phases were isolated in development of dominance.

Bimanual grasping (undeveloped dominance) dominates at ages up to 5-6 months. This correlates with presence, in the evoked responses, of wave N1 only above the hemisphere contralateral to the side stimulated. After 5-6 months undeveloped dominance is superseded by primitive one-sided manipulation. In this case contralateral and ipsilateral N1 waves with equal latent periods and amplitude were noted in the evoked responses. At 8-9 months of age the subjects begin to differentiate into right-handed, left-handed, and ambidextrous. An ipsilateral wave was observed among right-handed and left-handed subjects only with stimulation of the dominant hand. Both the contralateral and the ipsilateral N1 wave were recorded among ambidextrous subjects, irrespective of the side stimulated. In this period the ipsilateral N1 wave appeared 2-8 msec after the contralateral wave in all cases, which agrees with the latencies described in relation to transcallosal transmission. Thus interhemispheric transmission of somatosensory signals, as seen from the behavior of wave N1, was found to be proportional to the degree to which dominance is developed.

The obtained results confirmed the hypothesis that the right and left hemispheres differ in neuron organization. Without a doubt similar research should be conducted using verbal and nonverbal visual and auditory stimuli. This might provide new information on development of hemispheric dominance, on the relationship between handedness and the location of the speech center, and so on.

CHAPTER XIV

EP'S AND ATTENTION RESEARCH

The term "attention" is used to describe phenomena such as the orientation reaction to unexpected stimuli (involuntary attention), a state of maintained readiness to perceive stimuli and react to them, variations in activity indicators recorded during lengthy assignments, selectivity of perception, limited capacity of the information transmission channel, and so on. EP's are a promising means for studying all forms of attention, but we will deal mainly with the area in which use of EP's has produced the greatest results--research on selective attention. The role of nonspecific cerebral systems in producing and maintaining alertness (undirected attention) and changes in EP's connected with alertness levels are examined in books by Khomskaya (1972), Beteleva et al. (5), and others.

It was precisely owing to EP registration that a significant shift occurred in the last 5 years in our ideas about the physiological mechanism behind selective attention, and unprecedented possibilities for their study were opened. These successes were achieved not right away but only after significant methodological improvements in the experimental approaches to studying selective attention. The history of using EP's in this area clearly demonstrates the importance of making the initial conceptual premises clear, and combining sufficiently complete and deep knowledge on psychological and physiological approaches to the problem under examination for productive conduct of psychophysiological research on attention mechanisms. Let us briefly examine the history of attention research making use of EP's (a number of reviews may be recommended for a fuller acquaintance (57,60,75,350,351,377,492)).

General Characteristics of Early Research on the Relationship Between EP's and Selective Attention

The very first EP studies connected with attention orientation were probably initiated more due to the desire to observe whether or not attraction of attention would cause any changes in EP's, than due to the desire to substantially study the mechanisms of attention or find its neurophysiological correlates. But even later, after the investigations were clearly directed at finding the correlates of selective attention--of that process which participates in selection of a relevant stimulus from a certain set of stimuli, behavioral manifestations of attention were not subjected to meticulous examination as a rule. Attention was understood to be a process defining whether or not impulses evoked by a sensory stimulus would reach the required division of the nervous system. It was supposed that attention "edits" the sensory input (intensifies impulsation elicited by a relevant stimulus, and weakens or completely suppresses impulsation elicited by an irrelevant stimulus).

Our ideas about the physiological mechanisms of attention basically boiled down to the following at this time (in the early 1960's). A number of neurophysiological studies revealed that stimulation of nonspecific thalamic nuclei causes a local or phasal rise in cortical activation (279). It was hypothesized on this basis that the activity of these nuclei may be responsible for selective amplification of the flow of sensory impulses at the cortical level, and would thus be the physiological mechanism of selective attention. Although an association between local thalamic activity and selective attention was not strictly demonstrated anywhere, and although it is logically difficult to imagine how such activity could produce selective attention, even within a single modality, not to mention attention to a combination of polymodal characteristics, this hypothesis enjoyed very broad acceptance. (This is also true in relation to the idea that local inhibitory thalamocortical influences (461) are a mechanism of selective attention.) The decrease in EP's to testing stimuli in response to delivery of distracting stimuli, and suppression of sensory impulsation by various experimental influences upon cortical pathways leading from cochlear receptors served as the grounds for the hypothesis that selective inhibition of an irrelevant input is the result of descending inhibitory influences of the reticular formation (264). This hypothesis was also universally accepted for a rather long period of time, even though the idea that an irrelevant sensory input can be suppressed by a peripheral effect is incompatible with data on perception of irrelevant information obtained in the ingenious experiments of Broadbent (109) and others. Data on peripheral suppression of a sensory input were later placed under doubt due to methodological shortcomings; when the latter were eliminated, a number of authors were unable to confirm the data (266,542, etc.).

The results of the first studies on EP's and attention were interpreted in relation to the ideas presented above: An increase in an EP accompanying attention was viewed to be a manifestation of active influences by the thalamic reticular formation, while the decline in an EP accompanying inattention was thought to represent inhibition of an irrelevant input by the descending reticular system. The experiments were conducted with extremely little thought given to their design. The instructions required the subjects to react in some way in response to a stimulus (count the stimuli, move in response to a stimulus, discriminate among stimuli, and so on); the EP following such an instruction was interpreted as an "attention"

EP, and it was compared with a "background" EP, recorded when the instructions did not require reactions or even emphasize that a subject was not to turn his attention to a stimuli if they arose.

The most frequent result of the numerous works of this sort was enlargement of the attention EP in comparison with the background EP, though as a rule the increase was not observed among all subjects, and it often involved different components (according to the data of different authors), while a number of works noted the directly opposite results--a decrease in the attention EP. The uncertainty of the background was the main shortcoming and the cause of the contradictory results of these works. The background state of the subjects could vary from near-drowsiness in relaxed people accustomed to such research, to extremely pronounced activation in persons finding themselves in the experimental situation for the first time, persons that were anxious and, perhaps, more attentive to all stimuli presented in connection with their apprehensions than after the effect of instructions requiring a particular action.

These shortcomings were eliminated with time, and comparison of attention and background EP's was substituted by comparison of attention EP's and "inattention" EP's. Stimulation took the form mainly of delivery of successive stimuli (usually two) of one or different modalities, where one or the other in alternation required some activity from the subject. Comparisons were made between EP's recorded in response to the same stimulus in a situation where activity was associated with the stimulus and in a situation where the same activity was associated with the other stimulus. On the whole, fewer discrepancies are observed in these experiments, and enlargement of component P150-200 and (much more rarely) N80-100, coupled with changes in other components in individual works, is the dominant result. However, even these experiments had a significant shortcoming (349,351): the predictability of the moment of delivery of the relevant stimulus, inasmuch as the stimuli succeeded one another uniformly or according to a rather simple rule. This meant that the observed EP changes could have been the product not of selective orientation of attention but of nonspecific increase in activity level by the moment of relevant stimulus delivery, in contrast to reduced activation upon anticipation of irrelevant stimuli. Naatanen (350) demonstrated in a special study that activation level fluctuates in connection with expectation of relevant and irrelevant stimuli, and that when signals follow one another strictly randomly, EP changes do not occur in connection with directed attention.

A number of studies performed in the early 1970's using random alternation of stimuli also failed to reveal changes in EP components arising within the first 250 msec following stimulus delivery (the principal result of earlier investigations) in association with selective attention; only an increase in a positive oscillation with a latent period of about 300 msec was observed.

Revelation of the Correlates of Selective Attention in Experiments With Randomly Alternating Stimuli

Hillyard et al. (1973) were the first to reveal changes in a negative oscillation with a latent period of about 100 msec associated with attention orientation in a random signal alternation situation. Let us examine this study in detail. Two different successions of tones were delivered separately to the right and left ear. The time between tones was varied randomly within 250-1,250 msec. Three series of experiments were conducted. In one of them the subjects read a book and were not to pay attention to the sounds. In the others they had to count infrequent changes in the pitch of tones delivered either to the right or to the left ear. EP's to tones delivered to the right and the left ear were recorded separately in all situations. A total of 1,024 responses were averaged. It was found that the amplitude of component N80-140 was higher following a tone delivered to the ear toward which attention was oriented than after the same tone heard while reading a book or when attention was oriented toward tones presented in the other ear (Figure 20). The difference was noticeably greater in the latter case than in the former. The amplitude of component P160 did not change significantly in these conditions.

Thus it was demonstrated that attention to one of two sensory inputs may be accompanied by an increase in the amplitude of N80-140 in responses to relevant stimuli, and a decrease in the same component in responses to irrelevant stimuli.

This fact was also confirmed in a later work, in which each of four tones of different pitch (500, 1,000, 2,000, 4,000 Hz) were delivered binaurally from a separate source (435). The sources were located at four different points on the scalp. At each of these points, the main tone was, on rare occasion, substituted by a tone differing slightly in pitch. Tones from the different sources were alternated randomly with an interval of about 225 msec. In different series of experiments, the subjects had to alternately count the changes in tone pitch at one of the sources and pay no attention to the others. In this study, as in the previous one, component P200 did not change in association with attention, component N80-140 increased after tones from the source toward which attention had to be directed, and component P300 increased only after the slightly differing, infrequent tones that had to be counted in the given series (Figure 21).

It was found that the degree to which component N80-140 increased in response to attraction of attention (defined as the ratio between the amplitude in the situation of attention and the mean amplitude of the same component in responses to tones from irrelevant sources) was greater than in the previous study. This amplification of the effect of attention could have had, in the opinion of the authors, two causes: an increase in the information load, and spatial separation of competing sources. They hypothesized that the degree to which component N80-140 increases in connection with attention grows as the information load of the assignment increases, and that it was precisely due to an inadequate information load (interstimulus

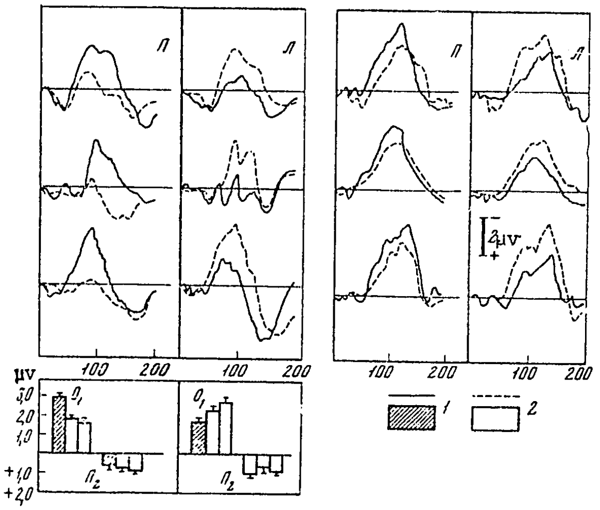

Figure 20. Changes in the EP's of Six Subjects in Connection With Attention: Changes in components N80-110 and P160-200 of six subjects are shown depending on attention orientation. Stimuli (standard and signal tones) were delivered separately to the right (П) and left (Л) ear. *1,2*--EP's in the case of attention to stimuli delivered to the right (*1*) and left ear (*2*). Columns show the means of the amplitudes (Hillyard et al., 1973).

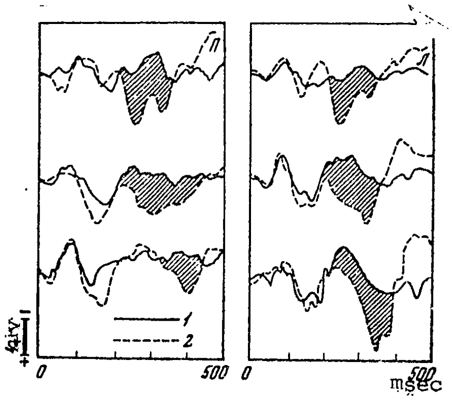

Figure 21. Changes in Component P300 Following Rare Changes in the Standard Tone Which Had to be Observed by Three Subjects: EP's were averaged on the basis of 90 or 110 responses. *1,2*--EP's to standard (*1*) and signal stimuli (*2*) (Hillyard et al., 1973).

intervals of too great a duration and readily distinguishable stimuli) that changes were not observed in this component in connection with attention in a number of works published during the early 1970's.

To test this hypothesis, the effect of selective attention upon EP's in conditions offering different information loads was studied (436,437). Different interstimulus intervals were used in one of the studies: short (350 msec on the average), moderate (960 msec), and long (1,920 msec). An increase in the amplitude of component N80-130 connected with selective attention was observed only with short intervals. This increase was also accompanied by higher sensitivity indicators (d'). Another study compared the degree of EP amplification connected with attention in response to delivery of (in different series) loud (60 db) and weak (20 db) tones on a background of maximum noise and on a quiet background. The greatest increase in the amplitude of N80-140 associated with attention was noted following quiet tones on the noise background, while the least increase was observed after loud tones without the masking noise. Thus the research confirmed that the influence of attention upon EP's increases as the information load rises.

The effect of spatial separation of the sources on the degree to which amplitude rises in attention situations was also demonstrated (438). The effect of attention on the amplitude of N80-140 was compared in three experiments. In the first experiment three types of stimuli differing significantly in pitch (800, 1,800, and 2,800 Hz) were delivered from the same source; the subject had to monitor slight changes in tones of particular pitch without paying attention to the others. In the second experiment the same tone was delivered from three spatially separated sources (they were located at the right ear, at the left ear, and midway between them). The subject had to note changes in tones coming from one of the sources. In the third experiment three tones of different pitch were delivered separately by each source. The sources were located as in the second situation. The subject had to note slight changes in a particular tone coming from one of the sources.

It was discovered that the amplitude of component N80-140 increases somewhat less in an attention situation in response to stimuli of the middle source (the 1,800 Hz tone in the first situation, and the tone from the source located at the middle of the head in the second and third situations) than in response to stimuli from the marginal sources. In this case the degree to which EP's to moderate stimuli increased in the situation where the subject had to orient his attention toward them was greatest in the third experiment, where the relevant source differed from the irrelevant source in both tone pitch and location. Activity indicators improved simultaneously as well. The obtained results agree well with data indicating that selective attention to one of two texts presented in parallel improved when the sources are located differently in space (496, 497). In all of the studies examined above, component N80-140 increased after all stimuli from the relevant source, while oscillation P300 increased only after those stimuli (usually occurring rarely) to which the subject had to react.

Thus the works examined above persuasively demonstrate an increase in component N80-140 following tones associated with the orientation of attention, an increase that is amplified by an increase in the information load or by spatial separation of competing stimuli, in parallel with an improvement in the behavioral manifestations of selective attention; we also showed that component P300 increases in an attention situation only after required stimulus reactions.

In addition, registration of responses from the cochlear nerve and registration of initial (brain stem) and early tonal EP components (arising in the first 50 msec following stimulus delivery) demonstrated absence of all changes in bioelectric reactions connected with attention within the first 80 msec following stimulus delivery (375). This means that the hypothesis that a peripheral filter operates in the auditory system as an attention mechanism was not confirmed.

Similar EP changes associated with attention were also demonstrated with auditory perception of verbal communications (this situation was closer to the natural conditions of human activity) (Hink, Hillyard, 1976).

Two different verbal communications were delivered to the subjects in parallel: one by a male voice to one ear and the other by a female voice to the other ear. After listening to the messages, the subject had to repeat the communication delivered either to one ear or to the other. A testing sound--an artificial phoneme recalling "ah" spoken by the same voice delivering the verbal communication--was delivered to each ear simultaneously with the verbal communication. EP's to the testing sound delivered to the ear requiring attention differed from EP's to the same sound delivered to the other ear in having a 25.3 percent greater amplitude for component P1-N1 and 47.1 percent greater for component N1-P2 (the latent periods of these components were 40, 100, and 190 msec respectively). The amplitude of P300 did not change in connection with attention.

The authors note that differences in EP's connected with attention were not revealed in similar research (462) in which clicks were used instead of an artificial phoneme, and they examine a number of possible causes of this: rarer delivery of clicks and associated arisal of an orientation reaction, slower word delivery rates, easier distinction of clicks than phonemes from words, and so on. It is important to emphasize all of the factors they examined so that they would be accounted for when planning experiments in attention research.

In our opinion we can explain the results of Smith et al. by the fact that attention directed at a verbal communication distinguished by voice in addition to the source's location in space, should extend to an artificial phoneme as well, but not at all necessarily to a click. Moreover, orientation of attention toward a particular voice should exclude attention to a click, irrespective of the ear to which it is delivered.

Existence of the correlates of selective attention in EP's was also demonstrated in relation to other modalities--somatosensory and visual.

Desmedt and Robertson (188) studied changes in EP's to electrostimulation of the fingers in connection with selective attention. They stimulated the last two fingers of each hand in pairs, the succession of stimuli was random and equiprobable, and the frequency averaged 100 stimuli per minute. The subject had to count the number of stimuli delivered to one of the fingers. Components N20 and P45 did not change, and changes in the EP associated with attention orientation were not observed until 55-135 msec after the stimulus. The increase in component N140 was most distinctly pronounced in response to stimulation of the fingers of the "signal" hand in comparison with responses to stimulation of fingers of the other, "non-signal". Some subjects exhibited an increase in component P100 instead of an increase in component N140. When stimulation frequency was decreased by a factor of four, and increase in oscillation N140 connection with attention was not observed. An attention-related increase in N140 once again occurred in response to infrequent but bisensory stimulation (electrostimulation of one of two fingers was alternated with delivery of one of two clicks). Component P400 arose only after signaling stimuli.

A number of works have demonstrated change in EP's in response to a light flash in connection with selective attention (18,52,53,202,351,492; Buchsbaum, Shechter, 1973; Puchinskaya, 1973; Zenkov, Panov, 1974; etc.). As an example, let us examine a study in which behavioral manifestations of attention were recorded in parallel with the EP, gaze fixation was monitored, and eye movements and blinking were recorded; EEG segments containing artefacts were dropped before averaging (506). Light flashes were delivered alternately, randomly, and equiprobably in the right and left half of the visual field (at an interval of 1-4 seconds in one series and 300-600 msec in another). About 10 percent of the delivered flashes differed from the principal ones in their brightness. EP's were recorded in three situations: passive (not requiring reactions), focused attention (signal flashes in one of the halves of the visual field had to be noted), and divided attention (arisal of signal flashes in either half of the visual field had to be noted). EP's were recorded in the occipital region and in the vicinity of the vertex. Components P105 and P223 in the occipital region increased significantly in connection with attention (oscillation N164 increased only in response to high stimulation frequency). At the vertex, oscillation N164 increased in connection with attention most of all, while P95 increased somewhat less; P221 increased only in response to frequent stimulus delivery. The most highly pronounced increase connected with attention was noted at the vertex for component N164, as measured from the base line or from the peak of the preceding positiveness, while the greatest increase in the occipital region occurred in component P223, measured both from the base line and from the peak of component N164.

Citing Lehtonen's data (313) on the differing nature of light flash EP components recorded in the occipital and central regions (particularly the hypothesis that the occipital component N1 reflects activity of the mode-specific cortex while the simultaneous negative component at the vertex reflects activity of the mode-nonspecific cortex) as well as numerous data on attention-connected changes in oscillation N80-140 recorded at the vertex following sound, the authors hypothesize that the part of the negative oscillation occurring at the vertex in the 90-160 msec period that is sensitive to attention reflects the activity of a mode-nonspecific mechanism of selective attention having limited power. The grounds for suggesting that its power is limited were the highly significant fact that the sum of the amplitudes of components N80-140 to a flash in the right and left halves of the visual field in the situation of divided attention was equal to the sum of the amplitudes of components to the same flashes in the situation of focused attention, which is the same as what had been demonstrated for auditory EP's recorded in response to delivery of stimuli separately to the right and left ear. Changes in the components of the occipital EP may reflect activity of mode-specific selective attention functioning in parallel. As was found in numerous studies with other modalities, component P300 increased only after those flashes that required a motor reaction.

And so, in addition to confirming the existence of correlates of selective attention in visual EP's, this work contains indications of the possibility for separately studying mode-specific and nonspecific mechanisms of selective attention.

Deeper analysis of results coupled with the use of attention models developed in the course of psychological studies is a significant feature of attention research in the early 1960's in comparison with earlier works. This analysis demonstrated that as is possible with data from a number of psychological studies, data describing changes in certain components of EP's elicited by mobilization of attention could be used to isolate two processes or two levels of selective attention (or two levels of information processes, each of which is associated with different attention processes). In particular Hillyard et al. (1973) suggested on the basis of their data (an increase in oscillation N80-140 following all stimuli from a relevant source, and of oscillation P300 only after stimuli requiring a reaction) that components N80-140 and P300 reflect two different processes of selective attention, described in the psychological literature under different names, for example stimulus set and response set (110), attention and abstraction (100), input and output standard choice (498), filter and standard (Worden, Galambos, 1972), and so on.

The first of these processes, in the opinion of the authors, is responsible for selective admission of a sensory input in a particular channel, while the second in responsible for selection of some sort of concrete sensory characteristics within the previously isolated channel (for example a tone of strictly determined pitch, and so on). It is also hypothesized that the first process is responsible for, in addition to selective amplification (admission) of a particular channel for subsequent perceptual analysis, simultaneous suppression or reduction of sensory influence in other, irrelevant channels. This process develops in the early stage of information processing on the basis of minimal (to the extent possible) information analysis. The physiological correlate of this process is amplification of component N80-140 following relevant stimuli and its decline following irrelevant stimuli. It is suggested in this case that the increase in the amplitude of component N180-130 more likely reflects a tonically maintained set of preference for a particular sensory input, than the result of active discrimination and identification of the given stimulus, one belonging to the selected input. In other words amplification of oscillation N80-140 is interpreted as reflection of a previously (prior to the stimulus) readied change in the functional state of systems reacting to a particular class of stimuli.

The second hypothesized level of attention having an increase in component P300 as its correlate manifests itself at a later stage of information processing, during which (according to the ideas developed by the authors) the sensory stimulus is compared with a prepared "standard" for the purposes of making a decision to react. The role of attention boils down at this level to facilitating recognition of a specific, "standard" signal relevant to the task at hand.

The two proposed processes (or levels) of attention "work" together. As an example the first is responsible for isolating sounds from a relevant source in space (making it possible to avoid analysis of sounds from other sources), while the second facilitates identification of that sound for which a reaction is required.

It should be noted that two stages (or two methods, or two levels) of information processing are distinguished in a number of other works as well (45, 256, 536; Strinberg, 1970; Fox, 1973).

Isolation of the electrophysiological correlates of different levels of selective attention opens up new possibilities for comparing the results of various works. By recording EP's in psychological experiments producing results that could be used to distinguish different levels of attention, either we could "combine" levels isolated in different studies under different names, or on the other hand we could demonstrate their differences and thus reveal a larger number of levels and compare the resulting schemes.

Existence of EEG correlates of different levels of attention also opens up a number of possibilities for psychophysiological study of the individual features of attention. In this regard EP's are an especially valuable indicator, inasmuch as they allow us to record reactions to stimuli that do not evoke any sort of other visible reactions. Comparison of the characteristics of component P300 in response to an orientation reaction--that is, in the presence of involuntary attention, and in response to voluntary selective attention, and analysis of their changes and relationships in ontogenesis may turn out to be useful to experimental development of our ideas about the ontogenetic relationship existing between voluntary and involuntary attention (Vygotskiy, 1956; Luriya, 1974).

EP's are also an irreplaceable indicator in revealing the degree to which different divisions of the brain participate in selective attention associated with different forms of sensory analysis. In this regard Kostandov and Vazhnova (34) obtained interesting data showing that the changes in oscillation P300 differ in different regions. In their research, different visual stimuli (a geometric shape and an arrow situated horizontally or obliquely) were delivered in pairs with an interval of 150 msec within each pair. The subject had to react as quickly as possible to the second of a pair of stimuli. The nature of the reaction depended on the position of the arrow, which was presented either in the first or in the second place within the pair, and the order was random and equiprobable. Thus for example, comparing EP's to presentation of a geometric shape with the arrow coming first in the pair, we can assess the influence of selective attention, inasmuch as the arrow is the relevant stimulus (the one determining the nature of the reaction). It was found that in comparison with what happened in the EP to the geometric shape, component P300 of the EP to the arrow, recorded at the vertex, exhibits an increase in amplitude and a decrease in latent period, with significant differences being absent in the occipital region. The authors associate the observed changes with the mechanisms of focused attention. There are also other indications that changes in the amplitude of component P300 in different regions of the head may reflect the activity of different functional mechanisms (164, 379,475).

Some authors (18,20,35) cite data indicating differences in the nature of interhemispheric asymmetry of EP's depending on the degree and orientation of attention, and on the sensory characteristics employed. We cannot doubt that research in this direction will develop intensively in the near future. The known fact that parallel performance of two assignments following "splitting" of the brain improves implies that interhemispheric interactions play a significant role in support of selective attention; it was hypothesized on the basis of this fact that the working hemisphere has an inhibitory influence upon the other hemisphere.

And so, EP's may be used as both an indicator (correlate) of attention and the tool of its study. In this case we must consider that instructions limited to "imposing" a particular orientation upon attention are not enough in attention research making use of EP's. We would also need a sufficient "information load"--that is, an assignment of sufficient difficulty--before changes would arise in component N80-140.

Analysis of Some Conflicting Data on Change in P300 Connected With Attention

The requirement that a reaction must occur to a stimulus is not always enough to cause attention-connected appearance or amplification of component P300.

This can be clearly seen from a comparison of the results of some studies in which oscillation P300 was recorded.

In most of the works component P300 appears or undergoes amplification in connection with attention only after stimuli requiring a reaction. But many studies have been carried out in which amplification of oscillation P300 is noted in the presence of attention not only after stimuli requiring reactions but also after stimuli similar to them (ones in the same stimulus class), even though the latter do not require a visible reaction. There is also an extremely small group of studies in which amplification or arisal of component P300 is observed in an attention situation following stimuli not requiring a reaction, a response that differs from that caused by stimuli requiring a reaction.

Let us cite a few examples. The study examined above can serve as an example of works in the first group (Hillyard et al., 1973). When the subject is required to note delivery of a signaling tone to one ear in a situation of parallel monaural delivery of two different sequences to the right and left ear, oscillation P300 arises only after the signaling tone delivered to the ear to which the attention is directed.

A different result was obtained by Smith et al. (1972), who also monaurally delivered two independent sequences of clicks with a frequency of one click every 5 seconds, separately to the right and left ear. In addition to the clicks, words were pronounced at a frequency of one per second: These words were numbers for the most part, but about one in every fifteen was a letter rather than a number. The subjects had to press a key either in response to a particular word (in different series) in response to clicks delivered to a particular ear. The principal result was a significant increase in component P300 in response to clicks when the subject was required to react to clicks, in comparison with the situation in which he had to react to words. In this case oscillation P300 increased identically after clicks delivered to the right and left ear, irrespective of the ear upon which attention was concentrated. The set to react only to sounds delivered to one ear does not differ from the assignment used in the research of Hillyard et al.; in the latter, however, component P300 arose only after signaling sounds delivered to the ear requiring attention, while in this case it arose after all clicks, irrespective of which ear was the focus of attention and which click the subject had to react to in correspondence with this. The data of the first of the works compared here show that the brain has the capability for selective attention relative to stimulation of the right or left ear. Why, then, does selective attention directed at the source of impulsation (the appropriate ear) not arise (judging from component P300) in the research of Smith et al.?

Let us examine where the difference in the experimental conditions lies. Smith et al. had an additional (verbal) sensory input from which the subject had to "disengage" when directing his attention to clicks. If we assume that organization of the attention field is aimed at economical fulfillment of a task at hand, which would require that irrelevant stimuli be filtered out at the earliest possible level of attention (at least prior to the information processing stage associated with arisal of component P300) naturally it would be "more advantageous" in this case to filter out the verbal input at the first level and to distinguish between signaling and nonsignaling clicks at the second (associated with P300) than to "filter out" the input of the appropriate ear and then determine, "at the P300 level," precisely what was presented--a click or a signaling word. In the former case the proposed second level of attention should be engaged every 5 seconds (at the frequency of click delivery), while in the second it should be engaged once every second (at the frequency of word delivery). If these suppositions are valid, then it also follows from the facts available that the possibilities for organizing the attention field (isolating the "channels") are limited: "Division" in accordance with the verbal stimulus-click characteristic precluded division in accordance with the right-left ear characteristic. Perhaps with prolonged training the capability for division in accordance with a composite characteristic, for example "nonverbal stimulus--left ear," might arise, and then oscillation P300 would appear only after signaling sounds, but apparently such immediate isolation of the characteristic does not occur. All of these hypotheses can be experimentally tested using the EP registration method. If they are valid, then a change in the frequency of stimulus delivery in the experiments of Smith et al. should cause a change in the results. If we deliver clicks at a high frequency and we deliver two different kinds of clicks with the requirement that the subject reacts to only one of the clicks delivered to one ear, and if we make word delivery infrequent and deliver identical words, then oscillation P300 should arise only after clicks delivered to that ear to which the subject must turn his attention.

The possibility for "filtration" or differentiation of the "input" of a level "lower" than the the level of P300 is apparently also governed by the difficulty of signal discrimination (the "resolution" of the mechanism at the first level). This is implied by the data of Ritter and Vaughan (404). In their research, the subjects were required to note infrequent (one out of ten) random changes in a standard signal (visual or auditory in different series); P300 arose only after detected signaling stimuli: This is analogous to the the result in all works in which component P300 was recorded only after stimuli requiring an external reaction. However, when the difference between stimuli was reduced and stimulus discrimination became very difficult, oscillation P300 was observed to an equal degree after standard stimuli and after signaling stimuli. Moreover the authors observed one more interesting fact--a decrease in oscillation P300 following one of the stimuli in response to "learning." At the beginning of the assignment, P300 arose after the signaling and nonsignaling stimuli, and later it disappeared after the nonsignaling stimuli. Amplification of component P300 in response to a decrease in the differences in signals was also demonstrated in (181). Apparently organization of the "attention field" has some sort of natural psychophysiological limitations associated in part with the capabilities of perceptor "analyzers" used in the concrete experiments (499).

The third group of works includes the previously mentioned research by Squires et al. (1975), in which it was shown that component P300 is not recorded after stimuli requiring a reaction, given a high probability of their delivery (0.9), even though the reaction to the stimuli is performed successfully. In these conditions we encounter the reverse, where oscillation P300 arises only in response to the infrequent stimulus (with a probability of 0.1), the one not requiring a reaction. Thus presence of a reaction is not the decisive factor for arisal of an LPO. Evidence of this can also be found in the no-less interesting data of Karlin and Martz (292), which at first glance are also completely paradoxical in light of the numerous data indicating an increase in an LPO only following a stimulus requiring a reaction. The authors compared EP's to stimuli succeeding one another equiprobably in a situation requiring the subject to perform one motor reaction or another to each sound, and to press a key only in response to one of them (choice reaction). It would have seemed that in light of all of the data presented above, oscillation P300 should be greater than (or it should arise only after) that stimulus to which a reaction is required. We find, however, that an increase is observed after the stimulus not requiring the reaction, the degree of the increase correlating directly with the rate of reaction to the second stimulus.

What seems to be a paradoxical situation arises. The moment we take component P300 to be a correlate of attention, we must assume that in the work of Squires et al. (1975), the subject "turns his attention" more to infrequent stimuli not requiring a reaction than to the frequent stimulus requiring a reaction. In precisely the same way the subject in the previously examined experiment conducted by Karlin and Martz (292) "turned his attention" more to the stimulus which does not require a reaction; in this case the degree of this attention to the "nonsignaling" stimulus, as determined from the amplitude of the P300 oscillation, correlates with the success of assignment fulfillment--with the time of the reaction to the signaling stimulus. Thus we find that "the more the attention is turned" to the irrelevant stimulus in comparison with the relevant one, the better is the performance of the activity.

From our point of view all of these facts, which appear to be contradictory at first glance, fall within a general scheme in which attention is interpreted as organization of successful activity in the most "economical" fashion. Presence of an initial set toward a particular group of stimuli requiring analysis, and of the required reactions, implicitly presupposes change in EP connected with attention, no matter what the nature of the research. This supposition is clearly worded by Squires et al. (1973). If we accept the notion that attention consists, in particular, of formation of the models of future events so as to create a maximum level of preparedness (in the perceptor system this "preparedness" is achieved through formation of a "standard" of the sensory stimulus, at the decision making level it is maintained by the "level of prejudice" or anticipation of a reaction, and in the reactive sphere it is insured by the level of preparedness of motor programs, muscles, and so on) for events anticipated at a certain moment in time, and that the amplitude of component P300 reflects the amount of the discrepancy between the prepared model of the near future (anticipation) and reality, the results examined above and appearing contradictory become fully natural and predictable.

In most attention studies employing registration of component P300, stimuli requiring a reaction are delivered rather infrequently (for example the ratio was 1:10 in a large part of the works of Hillyard et al.) on the background of the other signals. In this case a dominant set is created towards the event "frequent nonsignaling stimulus--absence of reaction." Naturally, as a consequence delivery of the signaling stimulus would usually elicit a discrepancy between the prediction and reality, and it would correspondingly be accompanied by a pronounced P300. The situation created by Squires et al. (475) is entirely different: The probability of the signaling stimulus is 0.9 and that of the nonsignaling stimulus is 0.1, with the subjects required to react to the stimuli as quickly as possible. Under these conditions anticipation of the situation "frequent signaling stimulus--reaction" dominates, and a discrepancy should be anticipated in response to delivery of the infrequent stimulus not requiring a reaction. This is precisely what is observed.

Let us examine a situation of equiprobable stimulus delivery. If the subjects are not required to react very quickly, rather than keeping all of the reacting systems "in a state of readiness," it would be more economical to anticipate the stimulus not requiring a reaction or, in other words, a situation of "absence of a meaningful event." Then delivery of the signaling stimulus would each time elicit a discrepancy and, correspondingly, a high-amplitude LPO, while after nonsignaling stimuli the LPO would be absent. This is precisely the pattern we observe in a large number of studies in which the subject was required to count particular stimuli or press a button in response to them, but in this case the reaction rate had no significance. However, if we stiffen the speed requirement, then the subject would maintain a set that would prevent him from attaining high speed. Two possibilities arise. In the first, the subject could to a certain extent "guess" the order of stimulus succession and create a set at times toward one and at other times toward the other stimulus (reaction) beforehand. In this case we would observe both coincidence (a shorter reaction time and an LPO with a lower amplitude, in our scheme) and, on the other hand, a discrepancy (long reaction time and greater LPO amplitude). (This makes it possible to experimentally test the supposed scheme by analyzing the amplitude of LPO's in individual responses.) The average EP would include both cases, and thus the LPO would be recorded after both stimuli--the one requiring a reaction, and the one not requiring it. However, not all reactions would be performed at top speed in this case. Faster reactions could be achieved by constantly maintaining maximum preparedness for the stimulus requiring a reaction and for the reaction itself. In this case if a reaction is required, it would be maximally fast, and a discrepancy would not occur, which would be expressed by absence or decline of the LPO. In the case of a signal not requiring a reaction, we would always observe a discrepancy and, correspondingly, a high-amplitude LPO, which is what was observed by Karlin and Martz

(292). They discovered that the amplitude of the LPO is lower after a stimulus requiring a frequent reaction, though the frequency of the stimuli themselves was the same and consequently the same cognitive assessment made of them from the standpoint of stimulus probability would be the same. The authors hypothesize that the observed effect is associated with arisal of a set toward frequent reaction in the subjects. Delivery of a stimulus requiring an infrequent reaction is associated with the need for "changing" this set. In their opinion the LPO is a manifestation of a momentary shift in the level of activation associated with the "force" of the shift in set. We will not dwell here on their interpretation of the nature of the LPO (whether it is a reflection of cognitive processes or of a shift in activation level associated with them); instead, we will only emphasize the idea that the LPO does arise or undergo intensification after stimuli requiring reactions that differ from the reaction that is basic to the initial step--that is, after stimuli eliciting a discrepancy.

The hypothesis that oscillation P300 is associated with disagreement explains the results, contradictory at first glance, of Picton et al. (375) on one hand and Nash and Singer (355) on the other. The latter compared EP's to two different clicks delivered randomly and equiprobably in the following situations: 1) while the subjects were reading a book and not paying attention to the clicks; 2) where they had to count the loud clicks; 3) while reading a book and simultaneously counting loud clicks. An LPO was not recorded at all when loud clicks did not have to be counted; during counting, however, it arose after both clicks, but the amplitude was significantly greater following a loud click. At the same time in the research by Picton and Hillyard (373), in which precisely the same situations were compared--reading a book and counting clicks, arisal of a positive oscillation in the 250-450 msec period was noted only after signaling clicks (that is, those which had to be counted). The differences in these works is that in the first, signaling and nonsignaling clicks were delivered equiprobably, while in the second the signaling clicks were delivered much more infrequently (with a probability of 0.2 and lower).

It follows from these examples that when signaling and nonsignaling stimuli are equiprobable, both may elicit an LPO; when their probabilities differ dramatically, the LPO arises following that stimulus which has the lower probability of arisal, irrespective of whether it is a signaling (requiring a reaction) or nonsignaling stimulus.

These results show that attention is a dynamic process, the visible manifestations of which may be the result of interaction between different structures or of different mutual relationships that change depending on the conditions. The same result of activity may be achieved in different ways. This means that searching for the neurophysiological correlates of attention without analyzing all of the conditions under which activity is performed would not be very productive, and we would have to presume that the results would be contradictory.

The nature of the physiological correlates of selective attention depends on the entire structure of the situation, and it cannot be prescribed uniquely by instructions containing only a verbal description of the end result of activity, without giving the details of the means of its performance. Attention research should mandatorily include concurrent registration of physiological indicators and behavioral manifestations.

There is one more remark that should be made in connection with the use of EP's to study attention. It is often presumed in such studies that if some components undergo change associated with attention to a stimulus, this would be proof of change in the afferent current of impulses (intensification in response to increasing amplitude, weakening in response to its decline) under the influence of attention. And yet this logic would be inapplicable to EP components with a latent period of 80-100 msec, inasmuch as changes in components falling within this period may be associated initially not with the nature of the afferent current of impulses but rather with differences in the reactions by brain systems to the incoming information. These changes may not reflect a proposed mechanism of attention, such as decline or intensification of sensory impulsation depending on its relevance; instead, they may be the consequence or a manifestation of some other factors responsible for attraction of attention to the stimulus (for example the significance of the stimulus), or they may reflect some phases of information processing (cognitive analysis, memorization, and so on).

These changes can doubtlessly be interpreted as correlating with attention (if the correlation is in fact sufficiently high and significant), but presence of correlation does not mean that they also are the mechanism of attention, representing a process facilitating isolation and analysis of relevant characteristics and suppressing impulsation from irrelevant inputs. On its own, in other words, a decline or increase in the amplitude of EP components is not a categorical indication of weakening or intensification of the sensory afferent current of impulses evoked by the given stimulus. It may be a reflection of information processing of some sort in the presence of a constant sensory input. Presence of an association between selective attention and certain EP changes is not enough from which to make categorical conclusions concerning the mechanisms responsible for the behavioral effects of attention. The results obtained in this area are only the first step--revelation of the relationship between certain physiological characteristics and behavioral correlates. The next step is to establish the relationship between these physiological indicators and that mechanism which is responsible for the observed behavioral manifestations.

EP Changes Connected With Other Forms of Attention

In conclusion let us briefly examine the use of EP's in research on other forms of attention, or phenomena associated with attention (habituation, EP changes associated with self-stimulation, and so on).

Studies of the relationship between EP's and variations in activity indicators associated with prolonged performance of an assignment produced contradictory results. Some studies arrived at a correlation between reaction time or detection indicators and different components, while others failed to reveal any correlations at all (106,198,250,533, etc.). Apparently correlations are revealed when among the numerous factors of different sorts governing the indicators under study, common factors dominate and vary according to a particular law. Numerous works in which EP's to a stimulus delivered at rest were compared with EP's to the same stimulus delivered in a situation of distracted attention or while performing an assignement associated with the stimulus produced contradictory results as well. In general, the dominant result (see for example (535)) is an increase in the amplitude of a positive oscillation with a latent period of about 200 msec, coupled with an increase in activation level.

Indications that EP's increase with a rise in activation level, but that beginning with a certain moment a further rise in activation causes a decline in the EP's, may be encountered in a number of works. We were unable to find studies that could afford the grounds for using EP's as a "gauge" or as an independent indicator of activation level. A researcher analyzing this question should consider that influences directed at raising a subject's activation level may concurrently act as a distracting factor, and it is this circumstance that may be responsible for the observed EP changes (351).

EP habituation is one of the phenomena that is doubtlessly associated with attention (see Chapter X). One of the proposed mechanisms of habituation is comparison of the perceived stimulus with a "nerve model" (63). It is hypothesized that if the acting stimulus agrees with a prefabricated model, we observe efferent inhibition of activating influences transmitted via collaterals from specific sensory pathways to the reticular formation and accompanying the first deliveries of the sensory stimulus. As a result the orientation reaction does not arise, and the amplitude of the responses declines. In other words habituation is interpreted as a result of inhibition of activating reticular influences in response to repetition of an indifferent stimulus, owing to formation of its model in the cerebral cortex. Formation of a model of an anticipated event is also necessary to development of voluntary selective attention.

Thus as with attention, habituation represents change, in reactions to stimuli, dependent upon prefabricated "models." This change consists either of a decline in the reactions (habituation), or of intensification of responses to significant stimuli and reduction of responses to insignificant stimuli (attention). Inasmuch as habituation is "stimulus-specific," the notion arises that it may be interpreted as maintained selective inattention. Judging from the ideas about the unity of habituation and attention, we would expect that habituation to indifferent stimuli would develop more quickly if the subject simultaneously performs some sort of assignment associated with other stimuli, one which should increase the demand for "economical distribution of resources." (This term represents the most significant problem of attention--the moment of resource limitation. Although neither psychology nor neurophysiology has a clear definition as to precisely what these resources are, it is clear that is is only in connection with this limitation that attention arises as a problem.)

In fact, Ohman and Laider (357) note habituation of EP's to stimuli only when the subject is performing some sort of assignment. This means for habituation to develop, concrete conditions, a particular information load for example, may be as significant as they are to development of attention (436,437). Moreover, does not, for example, a decrease in the amplitude of EP's to insignificant stimuli delivered in the conventional conditions of selective attention research reflect precisely the same phenomenon observed with reduction of amplitude in response to the action of indifferent stimuli in situations usually created to study habituation? The fact that what is described in habituation studies is change in the amplitude of component P200 and not the preceding negative oscillation may itself be the product of the fact that amplitude is usually measured from peak to peak and, moreover, a habituation situation is accompanied by a decline in activation level.

Are there separate, independent mechanisms responsible for reduction of amplitude and for its intensification associated with selective attention phenomena? In comparing EP's to significant and insignificant stimuli and recording the difference, we cannot determine whether this difference is the result of concurrent reduction of some responses and intensification of others, or just one of these phenomena, inasmuch as a difference would exist in both cases, and we do not as yet have a technique for measuring the "median" or the "null point," since we do not have a way to externally set a measured level of activation or attention. There are data arguing in favor of the presence of independent mechanisms for decline of amplitude in response to insignificant stimuli and its intensification in response to significant stimuli. The action of EP's in response to two drugs that disturb attention was studied by Koppel (1972, cited in (128)). It was discovered from behavioral reactions that thyroxine evoked an enlargement of EP's to insignificant stimuli while cortisone caused a decrease in EP's to significant stimuli.

Studying the individual features of EP decline and amplification connected with habituation and with selective attention, and determining the intra-individual correlations may be another way to analyze the commonness or differences of the mechanisms of habituation and attention.

It would be interesting to note that the phenomenon of decreasing magnitude of a reaction to a stimulus due to coincision of expectation and reality, which expresses itself with increasing strength as the degree of coincision rises, is observed in a number of situations other than habituation. Boddy (104) demonstrated that in the situation of a simple motor reaction, presence of a preparatory stimulus reduces the amplitude of the EP to the triggering stimulus so much that it becomes lower than the amplitude of the EP to the same stimulus delivered at rest but without the preparatory signal (the reference is to component P200). It is known that the GSR declines and pulse changes in response to electrostimulation when the subject knows the precise moment at which the stimulus is delivered. It may be hypothesized that the increase in the degree of EP decline in response to repeated stimulation, which accompanies a decrease in interstimulus intervals at least within the range from 10 to 3 or 2 seconds, is the result of "more-precise" anticipation of the moment of stimulus delivery. Data describing the dependence of reaction time on the length of the preparatory period and special studies demonstrate that the precision with which the moment of stimulation is "predicted" decreases as the intervals between the fixed point of reckoning and the predicted moment increase.

The same mechanism--decline of an EP in response to "more-precisely anticipated" stimuli--apparently lies at the basis of the fact that EP's to rhythmically delivered stimuli are lower than those to arhythmical delivery. It has been demonstrated that the more unexpected a stimulus is--that is, the less predictable it is, the greater is the amplitude of the EP to it. A stimulus unexpectedly contained within a rhythmically delivered sequence of stimuli elicits an EP of greater amplitude than do stimuli of the basic sequence, even though the interstimulus interval for it is shorter (301). Fox (225) demonstrated on monkeys that the EP amplitude is lower in response to regular light flashes and flashes caused by the monkey itself than in response to aperiodic stimulation. The same was observed with self-stimulation (24). All of these facts deserve analysis in a consideration of the essence and physiological mechanisms of attention.

The EP method has created a new era in attention research, providing researchers with a new tool by which to test their theoretical schemes. The productivity of future research in this area will depend on how well present ideas on the nature of the physiological correlates of attention and the facts and ideas on attention accumulated in experimental psychology are accounted for when outlining the objective. Also important in this case is the researcher's general point of reference, which influences the fullness with which he embraces the experimental situation he creates. We believe that in light of the data accumulated in modern psychology and psychophysiology, and the ideas developing today, attention should be interpreted as one of the processes of self-regulation directed at organizing the individual's activity in such a way as to insure the best fulfillment of the tasks facing him at the least energy outlays, or while preserving and supporting a level of alertness optimum to the given individual. One manifestation of attention is economical organization of the sensory flow in accordance with current activity (isolation of relevant and irrelevant characteristics followed by analysis of the presently important sensory input in accordance with the isolated characteristics, distributed among different levels of sensory analysis, which is analogous to "inhibition" of some elements and "amplification" of other elements of the sensory input (377; Hillyard et al.), another is a similar organization of the hierarchy of the "states of readiness" of reacting systems (385), a third is change in the rate of some central processes (381,382), and so on. In this case the same result (for example an improvement of certain activity indicators serving as an attention characteristic) may be achieved in different conditions by different means, it may be the product of different structures, and correspondingly it may have different physiological correlates. In other words under different conditions, the same structure may be responsible for different functions and, on the other hand, the same function may be the product of different structures.

Presence of physiological correlates of the behavioral manifestations of attention allows us to identify, or at least define for practical purposes, some "levels" or "mechanisms" and compare the schemes arrived at in different studies.

CHAPTER XV

PSYCHOPHYSIOLOGICAL "FUNCTIONAL ANALYSIS" OF EP COMPONENTS. THE "ORIENTATION" LPO AND THE "ATTENTION" LPO

A new direction which can be referred to conditionally as EP "functional analysis" has arisen due to use of EP's to solve the problems of psychology and psychophysiology, and owing to the successes enjoyed by research in this area.

Predictably occurring changes in EP components connected with certain changes in experimental situations permit us to suggest that they have a relationship to the mental or psychophysiological variables which the experimenter hypothetically manipulates when he changes the situation. Analysis of the relationships between components and the hypothesized processes, or the "blocks" of the theoretical schemes of behavioral organization is being found to be useful as a means for testing the schemes employed, and in a number of cases it permits us to reveal differences in the nature of oscillations which at first glance appear similar in their amplitude and time characteristics.

An example of such EP analysis may be found in research on the nature of the late positive oscillation (LPO) with a latent period of about 300 msec, often designated as P300. This oscillation* was not discovered until the mid-1960's, when EP's to stimuli requiring cognitive assessment were recorded (173,487; Desmedt et al., 1965). This oscillation was subsequently recorded in a tremendous number of studies, but a comparison of the results reveals a certain contradiction. According to some data the LPO was recorded only after significant stimuli requiring attention, and it did not arise following stimuli not requiring assessment or a reaction. At the same time there were a number of works in which the LPO arose in response to unexpected change in an insignificant stimulus, or to delivery of an incidental stimulus during the time which the subject was performing an assignment associated with other stimuli. As an example the LPO arose in response to changes in an indifferent tone while the subject was reading a newspaper.

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* Katz (26) apparently observed this oscillation in an EEG without summation and response averaging.

The LPO was interpreted in works of the first type as a correlate of processes associated with reception and processing of significant information: decision making (48,462; Hillyard,1969; Rohrbach et al., 1974; etc.), acquisition of information or removal of uncertainty (488), stimulus "prominence," or "significance" (283,284; Sutton, 1971), cognitive stimulus assessment (404,405), and so on. Studies in the second group viewed the LPO as a correlate of the orientation reaction (413; Roth et al., 1973; etc.). Attempts at creating a single scheme for the origin of the LPO floundered in the face of the contradictions presented by the facts cited above. If, as was supposed in most works of the first group, the LPO is associated with selective attention and arises only after significant stimuli, its arisal in response to change in insignificant stimuli is entirely incomprehensible. If we interpret the LPO as a correlate of the orientation reaction, then we fail to understand why it arises only after significant stimuli and is absent after others, for example in situations calling for discrimination, even though both types of stimuli are delivered with equal probability, and their uncertainty or novelty is the same.

Examining these contradictory facts, Courschesne et al. (164) called them "a paradox calling for solution." Two works devoted to solving this paradox showed that in different experimental situations, LPO's viewed as the same oscillation may have differing nature. These works are so significant that they deserve detailed discussion.

The first in relation to time of publication is the work by Squires et al. (1975). They turned their attention to the fact that in addition to the differences noted above in the conditions of LPO arisal, there are significant discrepancies in the data of different works concerning the latent period of the LPO. The most frequently encountered value for the latent period is 300-450 msec, but concurrently we have reports of LPO's with latent periods as short as 220-250 msec (Roth et al., 1972). The thought that neighboring oscillations or ones of different nature overlapping in time are being described as the same thing arose in this connection. To test this hypothesis, Squires et al. compared LPO's and EP's to acoustic stimuli recorded from the same people in conditions where the stimuli were significant to the activity being performed and required attention, and in conditions where the same stimuli did not require any reaction from the subject, who was reading a book at this time.

The subjects were exposed to loud (90 db above threshold) and quiet (70 db) sounds randomly. The probability of the loud sound in different series of experiments was, sequentially, 0.9, 0.5, and 0.1. Three instructions were given, one in relation to each probability in succession: "Count the loud sounds," "count the quiet sounds," "pay no attention to the sounds--read the book." Then all of the same probabilities and instructions were employed once again in the reverse order. In a separate experiment precisely the same experimental design was used with the only difference that delivered sounds differed not in loudness but in frequency--high (1,500 Hz) and low (1,000 Hz). EP's to all sounds were recorded monopolarly in the frontal, parietal, and central regions.

In the situation of inattention to stimuli (reading the book), the EP to the loud sound delivered with a probability of 0.9 consisted of oscillations N80-100 and P140-190 (at the vertex) without any sort of later oscillations. If the stimulus (loud or quiet) was infrequent (0.1) in the given experimental series, then a sharp positive oscillation arose in the EP, attaining its maximum in the period from 220 to 280 msec, which was called oscillation P3a by the authors. It was usually preceded by a distinct negative oscillation with a latent period of 150-215 msec (N2). In the situation where the subject had to count the sounds, the EP to the frequent sound (recurring with a probability of 0.9) consisted, as in the case of inattention, of only components N1 and P2, irrespective of which sound had to be counted. In response to the infrequent sound (recurring with the probability of 0.1), a pronounced positive oscillation arose with a peak falling within the period from 310 to 380 msec, irrespective of whether the sound was loud or quiet and whether that sound or another had to be counted. This oscillation was designated P3b, in distinction from P3a. It was preceded by a negative oscillation with a latent period of 170-250 msec. In this case a positive "hump" or a distinct positive oscillation could be seen for most of the subjects in the EP to the infrequent sound, before oscillation P3b. On the basis of the similarity of latent period and some other characteristics, it was assessed as identical to oscillation P3a in the situation of inattention to stimuli, though less pronounced than in the latter case. This hypothesis that these oscillations are the same is also reinforced by the strong positive correlation existing between the amplitude of P3a in situations of inattention and attention. It was also confirmed by an analysis made by the main components method, which will be examined below.

The amplitude of N2, P3a in the situation of inattention and the amplitude of N2, P3a, and P3b in the situation of attention increased as probability decreased. Given equal probabilities, the amplitude of P3b was greater after the stimulus requiring the subject to count. The amplitude of P3a, measured from the peak to the base line, was greater in the stimulus counting situation than in inattention, but the authors feel that this is not the true amplitude of P3a, but rather the result of addition of the actual small P3a wave and the beginning of oscillation P3b. (The amplitude of oscillations N1 and P2 was greater for the loud sound than the quiet sound, and its increase in the attention situation as compared to inattention was statistically insignificant. The exception was the situation of equiprobable delivery of sounds, in which oscillation N1 following the loud sound decreased among all subjects during counting in comparison with reading a book--a paradoxical result in light of data on the relationship between EP's and attention. A decrease in the latent period of oscillation P2 from 165 to 145 msec was also noted to accompany a decline in probability from 0.9 to 0.1, which the authors explained by arisal of oscillation N2 in response to the decline in probability, "breaking off" development of P2.)

Analysis of the distribution of the amplitudes of different components recorded at different points on the scalp revealed a difference between oscillations P3a and P3b. The former has its greatest amplitude in the frontal-central region, while the second is greatest in the central-parietal region. A prolonged slow positive oscillation (SPO) was also observed in EP's recorded following infrequent stimuli, in the tone counting situation. The measurement given for it was based on the average of its amplitude in the period from 400 to 500 msec, but it was interpreted as having arisen sooner and being added to earlier oscillations. The topography of the slow oscillation is close to the topography of P3b, and the authors hypothesized that the change in amplitude of the components measured from the base line to the peak reflects the result of summation of concurrently existing oscillations produced by different, independent generators. To test this hypothesis and reveal the degree to which each of peaks P3a and P3b reflects independent processes, the authors analyzed changes in the amplitudes of different components in different situations by the main components method.

The analysis revealed presence of six orthogonally distributed factors causing change in the EP in connection with all of the isolated variables (attention, signal probability, electrode location). It was found that each of the factors was associated basically with the amplitude of one of the isolated components (N1, P2, N2, P3a, P3b, and SO). The fact that oscillations P3a and P3b fit with different factors confirms the hypothesis that their origins are separate.

Moreover additional statistical analysis showed that the level of attention is insignificant to the factor associated to the greatest degree with component P3a, while attention has significant influence upon factors associated predominantly with P3b and the slow positive oscillation. This once again corresponds to the idea that P3a arises both in the absence and in the presence of active attention, while component P3b and the slow positive oscillation are associated with active attention.

Slow oscillations were recorded with the help of a direct current amplifier from four persons required to count quiet signals (with a probability of 0.1) and while reading in order to permit deeper study of the characteristics of the slow positive oscillation. No slow oscillations were detected after component P2 in the EP to the frequent loud sound in either of the situations. Individually variable slow oscillations were observed after the infrequent quiet sound. In particular, a slow positive oscillation could be observed in the parietal region, reaching the base line 600 msec after the stimulus. At the same time the negative slow oscillation recorded from the frontal region attained the base line 350 msec following stimulus delivery. The positive oscillation of two persons did not return to the base line for the 1,900 msec of the analysis. Experiments in which tone frequency was changed produced precisely the same results.

The authors concluded that the terms LPO and P300 encountered in the literature stand for at least two different oscillations. In particular, in their work oscillation P3a is similar to the LPO described by Roth (1973), while component P3b and the slow positive oscillation are analogous to the LPO described in the works of Ritter et al. (405; Ritter et al., 1969), Picton and Hillyard (376), and others. Oscillation P3a reflects, in the opinion of the authors, a psychophysiological event entirely different from that reflected by oscillation P3b and the slow positive oscillation. They believe it is most probable that component P3a arises in response to any change in stimuli, irrespective of whether the attention of the subject is directed to such change. In other words component P3a reflects the actitivity of a sensory mechanism that records all changes in stimuli, possibly with the help of a neuron model of the stimulus (63) arising in response to repetition of stimuli. As the authors note, it would be premature to assign labels P3a and P3b to isolated "subtypes" of the LPO.

Perhaps there are more than two positive oscillations of differing origin in the period under examination. Researchers cite the data of a number of authors indicating that the topography of the LPO differs in the case of a reaction to a "yes-no" choice and a reaction of only "yes", and in the case of discriminating a visual signal and after a completely unexpected and recognizable new signal. The latent period of the LPO can also vary as a function of decision making time (405) or of the information contained within the stimulus (472; Jennes, 1972). Therefore the authors emphasize that all they are doing is isolating oscillation P3a with a latent period of 240 msec, elicited by infrequent, unpredictable variations in the intensity or pitch of sound in a series of tones within a situation requiring inattention to sound, and oscillation P3b with a latent period of about 350 msec, arising only in the case of active attention to sounds (discrimination and counting of sounds). in response to an unexpectedly delivered infrequent sound, irrespective of whether this sound or another one of greater frequency had to be counted. Both of these oscillations are viewed as the same thing in the literature--P300 or the LPO.

A little after this study a work appeared (164) comparing LPO's arising in response to a new stimulus and to a known relevant stimulus. This work differs from the previous study mainly in that it specially studies the LPO in response to an unexpected new signal that is difficult to recognize. The experiment was conducted in the following way. EP's were recorded monopolarly from the frontal, central, and parietal regions of 18 subjects in response to tachistoscopically delivered visual stimuli. Four types of stimuli were delivered at random: the number 2--the most frequent stimulus (80 or 90 percent of all stimuli); the number 4, simple geometric shapes, and complex colored abstract patterns, the recognition and categorization of which was impossible. EP's were analyzed in four situations: The subjects simply watched the stimuli, or they counted the number of times number 4 appeared, or they counted simple figures and complex patterns, or they counted the number of times number 4 appeared, except that in this situation the complex patterns were presented not at random but only after number 4, being repeated twice in a row, of which the subjects were forewarned.

Components N1 (negativeness in the 160-240 msec period), P2 (positiveness in the 160-240 msec period), N2 (230-320 msec), and P3 (300-450 msec) were isolated within the EP. The LPO following delivery of the number 4 significantly increased during the counting of number 4 in comparison with the no-assignment situation; in this case the amplitude of the LPO was greater following complex patterns, and it was lower after the number 2 and after simple patterns than after number 4. Analysis of the distribution of LPO amplitude over the scalp revealed that the amplitude is maximum after number 4 in the parietal region, and after complex patterns in the frontal region. Parallel registration of a negative probability wave showed that the obtained results cannot be explained by features associated with the return of the latter to the base line. When subjects had to count simple figures and complex patterns, the LPO increased after these stimuli; in this case the increase was observed after complex patterns only in the parietal and central regions. The LPO following number 4 in this situation declined, and the decline was expressed mostly in the central and parietal regions. Changes were also noted in the other components, particularly an increase in oscillation N2 in situations where the LPO increased.

Thus it was revealed that the LPO arising after a new, unpredictable signal that is difficult to categorize--this is what the authors believed their complex colored and abstract patterns to be--has its greatest amplitude in the frontal region. The authors feel that all of the psychological correlates of the LPO suggested in the literature (information acquisition, decision making, comparison with a standard or recognition of an image, significance or "prominence" of the stimulus, and so on), recorded in a situation where known stimuli relevant to the assignment are delivered, are inapplicable to the LPO arising in the frontal-central region following an absolutely new stimulus. This stimulus, which elicited a frontal-central LPO, was not only irrelevant to the assignment (counting number 4), but it also differed in that its content could not be predicted (as, for example, in the case of number 2--also irrelevant to the assignment), or identified and categorized following delivery (as in the case of simple geometric shapes.

The authors hypothesized on the basis of these facts that the frontal-central LPO is a correlate of the cognitive component of the Pavlovian orientation reaction to new or unrecognizable stimuli. In their opinion it is impossible to distinguish what the LPO is associated with more--the orientational or the exploratory aspect of the reaction. Another possible explanation of differences in LPO's to irrelevant stimuli can be found in the hypothesis that the frontal-central LPO arises in response to complex recognition, while the occipital LPO arises in response to simple recognition.

Courschesne et al. (164) compared their data with those of Ritter et al. (403), in which the LPO in response to unexpected changes in tone dominates in the rear divisions; they noted that all orientation reactions or cognitive assessments of a repeating, easily recognizable stimulus such as change in tone are in principle different from those elicited by the very new, unrecognizable stimulus used in this work. The authors also dwell on the relationship, cited in the above work by Squires et al., between the frontal-central LPO to new stimuli that are hard to recognize, and dominance of oscillation P3a in the frontal divisions. Noting the differences in the conditions under which frontal-central oscillation P3 arose in their work and oscillation P3a in the work of Squires et al., the differences in the changes occurring in response to stimulus repetition, and the different latent periods and amplitude (360-450 msec and 12-15 μv in the first case and 220-250 msec and 6 μv in the second), the authors arrived at the hypothesis that these oscillations reflect the activity of different systems, even though both oscillations arise in response to unexpected changes in a sequence of stimuli. They suggest in conclusion that in general, the LPO is not a unitary process, but rather the end result of numerous oscillations of different origins, ones influenced in different ways by the novelty, recognizability, and relevance of the stimulus, and in this connection they emphasize the importance of analyzing the distribution of LPO amplitudes over the scalp.

The question as to the relationship this oscillation, which Ritter and Vaughan interpret as the "cortical associative potential," has to oscillations P3a and P3b in the work of Squires et al. or with the different LPO's seen in the research of Courschesne et al. remains open.

It would be interesting to note that similar division of initially "monogeneous" oscillations into two oscillations of differing nature occurred in relation to slow negative oscillations in the period between the preparatory and triggering signals in tests involving determination of reaction time. A number of authors (323,324,522; Loveless, Sanford, 1974) distinguished two types of oscillations in this period: an orientational oscillation (the O-wave), and a preparatory, or anticipatory oscillation (the E-wave, identical to Walter's E-wave). These oscillations are distinguished in particular on the basis of the difference in their behavior in response to change in the duration of the interval between the preparatory and the triggering stimulus, and on the basis of the difference in their dependence upon the intensity of the preparatory signal and upon the motor or sensory set created in the instructions. The O-wave always arises after the preparatory signal, its amplitude depends on signal intensity, but it does not depend upon whether or not the instructions change the criteria for making a decision in response to the triggering signal. (that is, on whether a motory or a sensory set is created). The O-wave reveals itself distinctly when intervals between stimuli are irregular and when the E-wave does not arise, and it is represented by a negative oscillation with a peak occurring 1 second after the preparatory signal, followed by a gradual decline. When the intervals between the preparatory and triggering stimuli are kept constant, an E-wave with duration dependent on interval size is superimposed over the O-wave.

Special research by Loveless (323) showed that in a situation requiring "yes-no" signal detection, the preparatory signal elicits a rise in sensitivity to subsequent stimuli, being most pronounced in the first 1-2 seconds, followed by a significant decline in sensitivity after 6 seconds. He also demonstrated that when weak signals are detected in the interval between the preparatory signal and the moment at which the near-threshold signal was delivered, an O-wave was recorded. He suggests that the O- and E-waves reflect different mechanisms and possess different generators. The former is associated with a rise in sensitivity, it dominates in the frontal divisions, and it recalls orientation reactions to nonsignaling stimuli (323), while the latter is associated with a rise in motor activity, and it dominates in the contralateral cortex. These data imply the need for precluding differences in the O-wave and the E-wave in the corresponding situations, these differences being a possible cause of the difference in distribution of P3a and P3b components.

And so, an LPO which initially appears to be homogeneous is actually a reflection of oscillations of differing nature. The different above-described oscillations falling within this period most likely do not exhaust all of the possibilities (283,284,379).

Deserving of attention in this aspect are data cited by Kostandov (30), who describes changes in oscillation P300 either in the occipital region or at the vertex depending on the experimental conditions. In particular, when emotional significance was imparted to a visual stimulus, oscillation P300 grew larger in the occipital region while its amplitude remained constant at the vertex; on the other hand when the visual stimulus predetermined the nature of the following reaction, in distinction from the situation in which it served only as a warning stimulus, component P300 grew in intensity only at the vertex.

We must apparently exercise caution when interpreting LPO's, recorded in different experimental situations, as oscillations of the same nature. Before we make such an interpretation, we would have to make sure that the oscillations believed to be identical satisfy the criteria of common oscillation nature: they should exhibit the same potential distribution over the scalp, they should be recorded in equivalent experimental conditions, they should be identically related with behavioral indicators, they should be identically sensitive to pharmacological substances or injuries, and they should have similar mutual relationships with other cerebral generators (Hillyard, 1975). In practice, far from all of these criteria are satisfied in discussions of results.

The Relationship Between LPO's and Discrepancies

That the nature of the LPO differs in the case of the orientation reaction and in the situation of attention does not answer the question as to what process or moment of processing of information contained within the stimulus is associated with this oscillation in one case and in the other. It was mentioned above that different authors associate the LPO with decision making, stimulus prominence or significance, cognitive assessment of the stimulus, difficult sensory analysis, removal of uncertainty, and so on. It would not be difficult to note that all of these processes coexist in the short time interval between stimulus and reaction, and their "separation" in an experiment is not always possible. All decision making acts occur in connection with sensory analysis, and cognitive assessment requires isolation of significant stimuli.

All of these hypotheses were equally suited to explaining the experimental results as long as significant stimuli requiring a reaction were presented infrequently on a background of other stimuli (as was the case in most early studies in which LPO's were recorded). The LPO was recorded in these studies (with the exception of those dealing with especially difficult discrimination) only after stimuli requiring a reaction, which fell within the implicitly existing scheme, according to which a significant stimulus is one that require a reaction, cognitive assessment, and a decision. With time, however, facts contradictory to these ideas accumulated. It was found that in a number of situations typical of attention research (discrimination of two stimuli and reaction to one of them), the LPO is recorded only after stimuli not requiring a reaction, or it grows in intensity in response to transition from a simple motor action to a choice reaction, following a stimulus not requiring a reaction (294,405; Squires et al., 1975). This means that we must either review our ideas about the relationship between the LPO and decision making, cognitive assessment, significance, and so on, or we must assume, contrary to custom, that cognitive assessment and decision making may occur only after a stimulus not requiring a reaction, and that it is precisely a stimulus of this sort that is significant.

However, if we consider the hypothesis that the LPO reflects the degree of discrepancy between an expected event and a real event, the noted contradictions disappear, and the contradictory fact presented above becomes understandable and predictable. This hypothesis was already mentioned in Chapter XIV in our explanation of some data that appeared contradictory at first glance. Let us examine it in somewhat greater detail. It was first stated in connection with experimental data describing change in the LPO in response to sudden change in the nature of an equiprobable sequence of two stimuli, one of which required a reaction (29). When the equiprobable sequence was suddenly substituted by delivery of the same stimulus repeatedly, the LPO first increased somewhat, and then it dropped significantly, once again rising dramatically in response to a sudden return to equiprobable delivery of the two stimuli. The authors hypothesized that the amplitude of the LPO depends not on the probability of the stimulus (or the reaction) but rather on the size of the discrepancy existing between the probabilistic prediction (anticipation) and the real event (the stimulus or reaction).

The results of a following study (59,407) confirmed this hypothesis. The research was performed following the same experimental design used in the previous research: Two flashes--bright and dim--alternated equiprobably, and the subject had to press a button as fast as possible in response to the dim flash. Suddenly, without warning, the equiprobable sequence was substituted by delivery of only the dull flash 70-90 times in a row, after which, again without warning, the equiprobable sequence was resumed; after a certain while the latter was once again superseded by delivery of just one type of flash, the bright one this time. After 70-90 bright flashes the equiprobable sequence was resumed, after which the experiment ended. EP's were recorded separately in response to the bright and the dim flash. Two EP's were recorded in each situation--equiprobable sequence (1) and repetition of the same type of flash (2): The former was recorded immediately following change in the nature of the sequence, and the latter was recorded after the passage of a certain amount of time (offered to the subject by the experimenter) during which the subject "assimilated" the change in nature of the sequence. On the average the LPO amplitude was greater with the equiprobable delivery than with repeated delivery of the same type of flash. However, in this case the amplitude of the LPO in the EP averaged from the first 30 light flashes following the switch from an equiprobable sequence to dull flashes was greater (in relation to most of the subjects and on a group average) than that in the LP recorded in response to the 30 flashes following. This decline was evaluated as a manifestation of redrafting the prediction in accordance with the altered reality (during the time that the first 30 flashes were repeated), as a result of which the discrepancy that arose at the first moment following the sudden change disappeared. The new shift in the nature of the sequence (resumption of equiprobable alternation of the flashes) led once again to a discrepancy, and to an increase in the LPO amplitude, which did decline later, but which in general remained significantly higher in the equiprobable sequence situation than when the same stimulus was delivered repeatedly.

A most interesting fact was revealed in individual analysis of changes in the LPO and in reaction time in the course of the experiment. Reaction time changed in the same way for most of the subjects: When dim flashes were delivered repeatedly, it increased at first (after the first 6-10 flashes), and then it dropped significantly in comparison with the average reaction time seen with the equiprobable sequence. However, the situation was different for two people--they exhibited a decline in reaction time in response to repeated delivery of the dim flash; in this case they did not react to some of the flashes, obviously perceiving them to be bright ones (though they did not make any errors during the time of the equiprobable sequence). One of them exclaimed at this moment: "Oh, I forgot which ones were the bright flashes," while the other said after the experiment that she was waiting all the time for the bright flashes, which suddenly became very infrequent for some reason, to increase in their frequency. These subjects also differed in relation to the changes exhibited in LPO amplitude--the decrease in amplitude in response to repeated delivery of the same flash, typical of all of the other subjects, was not observed for them. We can see from the absence of a decline in reaction time, from the arisal of errors, and from the reports of the subjects that redrafting of the prediction did not occur, and thus the discrepancy persisted, being sufficiently expressed to keep the LPO amplitude as high as it was before (in the equiprobable delivery situation). The fact that the LPO declined faster in response to the second substitution of equiprobable delivery by repeated delivery of the same kind of flash also indicates that discrepancy plays a role in the genesis of the LPO. This also agrees with the verbal reports of the subjects, who noted that when the same light flash began repeating itself the second time, they quickly deduced that the sequence had changed. One of the two subjects discussed above was an exception. When bright flashes were repeatedly delivered he also made errors that had not occurred with the equiprobable sequence; during the experiment he failed to notice that the same type of flash was being delivered repeatedly, occasionally taking a dim flash for a bright flash, and vice versa. He never did reveal a distinct decline in the LPO following the second repeated delivery of the same kind of flash either.

Extremely similar results were obtained in experiments of similar nature (84,85,482) using acoustic stimuli. In the first of these studies EP's to tones of high and low pitch were recorded monopolarly from the vertex of six subjects. The subject had to press a key as quickly as possible in response to the low tone. In different series the subjects were presented only the low tone requiring a reaction, only the high tone, not requiring a reaction, and then a random sequence of low and high tones (requiring a choice reaction) with a low tone probability of 0.25 or 0.75. Prior to each series the subjects were warned of the nature of the sequence to be presented. The fourth, falsely mixed series consisted of deliveries of only the high tones, though the subjects were told that they were going to hear the high and low tone with the same probability of the previous series. The authors analyzed changes in the LPO in the falsely mixed series depending on which sequence preceded this series and which was promised by the instructions. An analysis of the results showed that in the course of delivery of the falsely mixed sequence, the amplitude of the LPO decreased, and the rate of decline depended on the promised and the preceding probability: The greater the difference between the expected probability and reality, the faster the LPO amplitude declines (in other words the greater the discrepancy, the faster is the prediction redrafted). When the promised probability of the high tone was 0.75, the LPO dropped to the level of the LPO recorded in the series in which only the high tone was presented after 30 stimuli, it did so after 10 stimuli when the promised probability was 0.5, and it occurred in less than 10 stimuli when the promised probability was 0.25.

Later the authors substituted the random sequence of two tones without warning by repeated delivery of the high tone; after a certain time period (determined in preliminary studies from the time required for the late positive oscillation to decrease) the low tone was delivered several times, and then the high tone was delivered repeatedly once again. When a sequence of two signals was substituted by repetition of the same signal, the LPO soon dropped and disappeared; after several low tones were delivered the LPO immediately arose once again, and then it disappeared at the same rate as with the first change in the nature of the sequence. The authors explained this by the fact that a neuron model of the probability characteristics of stimulation forms in the brain (similar to Ye. N. Sokolov's "neuron model of a stimulus"), which remains within the memory after its reformation under the influence of the first change in nature of stimulation, and which is "retrieved" in response to several deliveries of the low tone, to once again determine the prediction of probabilities and the subject's behavior, independently of objective characteristics. They hypothesized that the LPO reflects comparison, within the brain, of the parameters of expected stimuli and of the real stimuli, and evaluation of the significance of the stimuli on the basis of the comparison results and the comparison made between the assessment (of the result or reaction) obtained in this fashion and the predicted assessment. They believe that their interpretation corresponds to the idea (404) that the LPO reflects "cognitive assessment of the significance of a stimulus" and to Ivanitskiy's hypothesis (22) that late EP components reflect information on the biological significance of a stimulus.

It seems that the data cited by Angelov and Stomonyakov contain the grounds for "stronger" or more-substantial hypotheses on the origin of the LPO than the suggestions they make. The latter are first of all too general, and what is most important is that they are incompatible in this form with the fact that the LPO disappears in, for example, a reaction to the highly probable stimulus used in the research by Squires et al. (1975). If a reaction proceeds adequately, this means that a cognitive assessment is made and information on biological significance is available, but the LPO is absent. The data of Angelov and Stomonyakov, meanwhile, clearly imply a connection of the LPO precisely with the moment of discrepancy. This means that it is not the process of comparison itself, and it is not the assessment itself, but only the presence of a discrepancy that causes the arisal (or amplification) of the LPO.

Data describing the relationship of the LPO to a discrepancy between a prediction and a real impending event are also contained in research on the connection between EP's and probability (487,488,502) examined in Chapter X. This research also showed that the amplitude of the LPO depends not so much on the objectively prescribed probability of the stimuli (or events) as on the degree to which the expectations of the subject coincide with real events. The greater the coincision, the lower the LPO.

Apparently a relationship arises between the LPO and probability basically because objective probability shapes the expectations of the subject (a more-frequent stimulus is anticipated more strongly, while a rarer stimulus is anticipated more weakly), and thus it determines the degree of discrepancy.

The term "expectation" or "probabilistic prediction" should be defined in somewhat greater detail. The idea that at every given moment the individual expects different events (stimuli and reactions) to occur with varying probability determined from his past experience arose rather long ago, and independently, in various areas of psychology and psychophysiology on the basis of a tremendous quantity of diverse facts. In particular, two similar conceptions--probabilistic prediction (68,69) and "constant expectation"

(240,241)--were formed on the basis of numerous data concerning the relationship of reaction time to the probability characteristics of stimuli and reactions in a reaction choice situation, as well as on the basis of the results of research on the relationship between predictions in a guessing game and the probability of stimuli, the probability of success-failure, and so on. According to the first conception the brain constantly possesses a probability model of the future--a probabilistic prediction that is shaped in accordance with the probability structure of previous experience. The subject constantly undergoes preparation and retuning for action anticipated with the greatest probability on the basis of the probabilistic prediction. This is what explains the decrease in reaction time to highly probable stimuli. (This conception agrees fully with the idea developed by Chuprikova (25) that changes occurring in the excitability of the central nervous system prior to stimulus response are a mechanism through which the number of stimuli and reactions exercises an influence upon reaction time.) According to the theory of constant expectation, different stimuli are expected at each moment in time in a choice reaction situation, to a varying degree depending on stimulus frequency, and the degree of expectation of the given stimulus influences the rate of its identification, and consequently the reaction time.

It would not be difficult to note that the concept of expectation, of preparedness, is common to both conceptions, but that the first places its accent on the preparedness of reacting systems, on preparations for action, while the second deals mainly with the influence expectation has on reaction time in the stimulus identification and (or) reaction choice stage. According to both conceptions, the greater the *a priori* preparedness and anticipation of the stimulus and (or) the reaction, the shorter is the reaction time when expectations coincide with the real event, and the longer it is when there is a discrepancy between them.

If the hypothesis concerning a relationship between LPO amplitude and discrepancy magnitude is valid, we would expect that an intraindividual or an interindividual comparison of changes in reaction time and LPO in response to change in the probability characteristics of the situation should reveal a parallel in these changes. In particular, when equiprobable stimuli are delivered and LPO's recorded in parallel in response to each of the stimuli in successive time intervals are compared, we would expect that an increase occurring in an LPO following one of the stimuli would combine with a decrease in an LPO following the other. This should occur when one of two stimuli is expected more than the other, and when the cases of discrepancy following this stimulus are correspondingly fewer. In this case those periods in which we observe a decline in the LPO to the signaling stimulus and its increase in response to the nonsignaling stimulus should be accompanied by a decline in reaction time. We should also expect that individual features of reaction time changes resulting from sudden change in stimulus probability must coincide with the initial changes in the LPO. In particular, the greater (faster) reaction time decreases in response to substitution of an equiprobable sequence of two stimuli by repeated delivery of the same stimulus, the more (faster) the LPO should decline.

A special experimental study conducted by the author of this book confirmed both hypotheses. A comparison of EP's recorded together with reaction times in successive time intervals during the performance of a choice reaction revealed a parallel in the changes occurring in these indicators: An increase in the LPO coincided with an increase in reaction time. Moreover an increase in the LPO following one of the stimuli coincided in a significant proportion of the cases with a concurrent decrease following the other. The relationship between LPO amplitude and reaction time revealed itself especially clearly in response to sudden change in the characteristics of the sequence: The greater the change in the LPO was, the greater was the corresponding change in reaction time.

The hypothesis that the magnitude of discrepancy is reflected in the LPO amplitude also makes understandable the contradictions mentioned at the beginning of the chapter: registration of an LPO in some studies only after stimuli requiring a reaction, and the reverse in others--after stimuli not requiring a reaction. Presence or absence of an LPO is not governed uniquely by a need for reacting to a stimulus (and by the significance of the stimulus in this sense); instead, it depends on the subject's general set, and on the arising hierarchical system of expectations and state of readiness, which is significantly influenced by (in addition to other factors) stimulus and reaction probability (see Chapter XIV). As long as presence of a reaction to a stimulus coincided with a low probability of this stimulus and, correspondingly, with expectation of the other, the highly probable stimulus, the research results were identical: The LPO appeared only after significant stimuli. But when the significant stimulus, the one requiring a reaction, was highly probable, the LPO arose after the stimulus not requiring a reaction because expectation of the first was dominant, and thus delivery of the stimulus not requiring a reaction produced a discrepancy. Given an equal probability of stimuli, the LPO may arise after either of the stimuli depending on the subject's strategy; in particular, it may arise after each stimulus if expectation develops equiprobably in correspondence with the probability structure of the situation.

The two-factor scheme of LPO generation developed in a number of works (472,475; Hillyard et al., 1974; etc.) is very close to the hypothesis examined above on reflection of discrepancy in the LPO amplitude. Let us briefly examine the history of this scheme. In the research of Hillyard et al. (1971), subjects performing signal detection assessed their certainty in a response on an eight-point scale. EP's were recorded separately for responses of equal certainty. It was found that under otherwise equal conditions, the greater the subject's certainty in his response, the greater was the LPO amplitude. The authors concluded on the basis of this fact that the LPO amplitude reflects the subject's certainty in a response. The results of this research reinforced the initial scheme suggested by Hillyard et al., according to which an LPO arises only after those stimuli toward which attention is directed. Orientation of attention toward a stimulus is interpreted as formation of a standard of the stimulus (Sokolov's "neuron model" or Treisman's "characteristic analyzer" (498)) and subsequent comparison of the incoming real stimulus with its standard. An LPO arises only when the stimulus coincides sufficiently with the standard; in this case the greater the similarity between the stimulus and its standard and, correspondingly, the subject's certainty in his decisions, the greater is its amplitude. Let us note that this idea is contrary to the hypothesis that the LPO increases when the discrepancy increases; it is suggested here on the contrary that the greater the coincision between the expected stimulus (standard) and the real stimulus, the greater is the LPO amplitude.

The hypothesis proposed by Hillyard et al. differed favorably from other hypotheses concerning the origin of LPO's in that it suggested certain quantitative mutual relationships between certainty and LPO amplitude which could be tested experimentally. This advantage was not slow in revealing itself in one of the subsequent studies in which Hillyard participated (Squires et al., 1973), the results of which failed to correspond to the initial scheme. In this study a comparison was made between EP's recorded in response to a feedback signal indicating correct or incorrect performance of a tone discrimination assignment. The assignment was difficult, and the number of correct responses did not exceed 75 percent.

After the subject made his response (by pressing one of six keys corresponding to the nature of the response and the subject's certainty in it), a red lamp turned on if a loud tone was delivered, and a green lamp turned on if the tone was quiet. EP's in response to the lamp flashes were analyzed, and responses to red and green flashes were averaged separately in cases of confirmation and disconfirmation. It was found that an EP in response to a flash having the same physical characteristics is significantly greater if this flash indicates a discrimination error than in the case where it confirms the correctness of the subject's response. It was also found that the greater the subject's certainty in a response that turned out to be wrong, the greater was the amplitude of the LPO recorded in response to the signal error. For confirmed signals, on the other hand, the greater the certainty of the subjects in the response, the lower was the LPO amplitude. These results did not fit at all into the initial scheme. The degree of similarity between the real lamp and its standard, as well as the distinguishability of the red and green lamps, did not change depending on whether the particular lamp served as a signal of an error or a correct response. (Note that the facts listed above correspond completely with the hypothesis that a direct relationship exists between the LPO and the magnitude of discrepancy: A signal confirming a subject's response is expected more, and correspondingly its delivery should elicit a smaller discrepancy and a lower LPO than would delivery of a stimulus indicating an error.) To explain the results the authors suggested an entirely new, two-factor scheme of LPO origin, within which the initial scheme suggested by Hillyard et al. was preserved as a part.

First of all they explained the details of their model of the decision making process, suited to the basic structure of all experiments involving the registration of LPO's (except for the novelty or orientational LPO). A common characteristic of the latter is presence of an external stimulus relevant to the assignment; being perceived (recognized), this stimulus evokes a motor or a cognitive reaction. Thus a certain stimulus-reaction set is always created in the subject of such experiments. The authors suggested that a decision making mechanism consisting of two stages is also created. The first stage consists of comparison of the real stimulus with a prepared standard. The "output" of this stage (possibly a current of impulses, but in general the "output" concept is not explained concretely) is proportional to the similarity of the stimulus to the standard. In the second stage the output of the first stage is summed with a certain pre-existing degree of prejudice or bias, which is defined by the subject's degree of expectation, the latter being determined by the probability of the stimulus and (or) reaction, and by other factors. When the sum of the output of the first stage and bias attains a certain critical level (the latter may change depending on various causes, but it is thought to be fixed prior to the stimulus), a decision is made. A significant property of the second stage in decision making is that the sum of the output of the first stage and bias cannot exceed a certain magnitude, subject to variations but fixed prior to each occurrence, which may be figuratively referred to as the "ceiling." In the opinion of the authors the LPO amplitude corresponds to the upward shift in the level of bias existing prior to stimulus delivery, occurring in response to the influence of the output of the first stage, but inasmuch as this shift cannot exceed the "ceiling," then if the bias level is high (close to the "ceiling" for example), the LPO amplitude would not be great. For example when we deliver a highly probable stimulus that the subject expects with high probability, the bias is high and the LPO amplitude is low.

And so according to this scheme, LPO amplitude is a function of two factors--the greater the correspondence between the stimulus and its standard, the larger is the amplitude, and the greater the stimulus expectation and, correspondingly, the bias associated with arisal of the given stimulus, the greater is this amplitude. This scheme was able to explain the facts obtained. The authors explained the increase in the LPO following a signal indicating the subject's error as a result of weak expectation (the subject is certain in the correctness of his response, and he does not expect a signal indicating an error) and, correspondingly, as a result of low bias in the examined decision making mechanism. On the other hand when a response confirmation signal appears, the expectation is high, the bias level is high, and the possibility of change occurring before the sum of bias and the output of the comparison stage reaches the "ceiling" is low; therefore the LPO amplitude remains low, even though the degree of stimulus coincision and the output of the standard comparison stage are the same as for the case of the error signal. In addition to different LPO amplitudes, the authors also noted shorter latent periods following confirming signals than after disconfirming signals. The authors explained this within the framework of their model by citing the rules of perception formulated by Bruner (115). According to them, the higher the stimulus expectation, the less information about it need be analyzed (in the comparison stage) prior to making a decision as to its presence. A somewhat different version of the explanation is that the latent period depends upon successive comparisons of the signal with a set of standards, beginning with that most expected and ending with the least expected.

The proposed two-factor scheme also made it possible to explain the results of other works that had not corresponded with the previous, one-factor scheme. As an example Paul and Sutton (365) studied the dependence of LPO amplitude (in a signal detection situation) on the criterion employed by the subject. The criterion was changed by changing the *a priori* probability of signal delivery or of the payoff table. In both cases the authors revealed a direct correlation between the magnitude of the decision making criterion and the LPO amplitude. The stricter (higher) the criterion, the greater is the LPO amplitude. And yet given a strict criterion in the case of stimuli of low probability a high LPO amplitude did not at all coincide with higher response certainty or with greater coincision of stimulus and standard, than in the case of highly probable stimuli. The two-factor scheme, meanwhile, easily explains these data by variations in bias associated with stimulus probability.

It would not be difficult to see that the second factor of the proposed scheme agrees completely with the hypothesis that a direct relationship exists between the LPO and the magnitude of discrepancy, since the term "greater discrepancy" necessarily coincides with "low predisposition" for arisal of a given stimulus. There is, however, the significant difference that in the two-factor scheme, a discrepancy arising in the course of comparison of the stimulus and its standard is interpreted as the cause of not an increase but a decrease in the LPO. We should add to this that the initial scheme was expanded somewhat in connection with the data of Karlin and Martz (292), according to which LPO amplitude is associated via a feedback not with stimulus probability but rather with stimulus-reaction (event) probability or with stimulus-reaction set. In light of these data, bias began to be interpreted not as a function of the probability of the stimulus itself, but rather as a consequence (manifestation) of the subject's general set in relation to pairs of stimuli and reactions. It is hypothesized that in each concrete case, the subject develops a certain hierarchy of sets (states of readiness) toward particular combinations of stimuli and reactions: Some are expected more, and others less.

We will not make a detailed comparison here of the "explanatory power" the two LPO'schemes have in relation to the facts available today, with the hope that time will answer the question as to which is closer to the truth or, to put it more precisely, as to whether or not a direct relationship exists between LPO amplitude and the degree of coincision between the stimulus and a prepared standard. We will note only a few facts that can be explained more economically by the one-factor scheme, and in relation to which the two-factor scheme would require a number of new assumptions, inasmuch as contradictions do arise. The well known research of Klinke et al. (301) revealed the arisal of an LPO at the moment of unexpected nondelivery of a stimulus within a series of rhythmically delivered stimuli. This fact is predictable within the framework of the one-factor hypothesis: When a signal is not delivered, a discrepancy arises between expectation and the real event--absence of a stimulus. A new assumption would have to be made if we are to explain this fact by the two-factor hypothesis. We would have to assume that a standard is also formed for the case of rare events, stimulus nondelivery in particular. It is believed that this assumption is confirmed by the faster increase in LPO in response to missed stimuli in the case where the subject has his attention on a series of stimuli (for example he is counting them) as compared to a situation of inattention to stimuli (376). But even this fact is also predictable within the framework of the one-factor scheme: Attention to stimuli results in more-pronounced expectation of a stimulus at the appropriate moment in time, and a stronger discrepancy in the event of its absence.

Incidentally, the fact that a direct relationship exists between LPO amplitude and response certainty, a fact which served at the grounds for hypothesizing that the degree of coincision of stimulus and standard is reflected in the LPO amplitude, can also be interpreted differently. This fact was observed in a situation requiring detection of weak, near-threshold signals. It may be hypothesized that when a subject detects weak, near-threshold signals, he forms a standard for signal absence, inasmuch as a model for it is always present in the real world, and inasmuch as signal absence is a more-probable event at each moment in time. In this case the reaction (a "stimulus present" response) arises only when the discrepancy between this stimulus absence standard and the real event achieves a certain threshold value. If we accept this assumption, then we would have to expect an increase in response certainty mainly when the discrepancy between the stimulus absence standard and the real event--stimulus delivery--increases. In similar fashion we can also interpret a number of other facts without bringing in the two-factor scheme. At the same time there are data that contradict the notion that a direct correlation exists between LPO amplitude and response certainty or the degree of coincision of standard and stimulus: An increase in LPO amplitude has been demonstrated in response to growth in the complexity of discrimination in the presence of unchanging probabilities (181,404).

A direct relationship apparently arises between response certainty and LPO amplitude only when the two indicators possess a common factor at their basis. In and of itself, subjective certainty in a response may occur with equal probability together with both high amplitude and low amplitude or absence of an LPO (for example, low amplitude accompanying confident responses to highly probable stimuli and high amplitude in the case of confident responses to stimuli of low probability).

No matter how the question concerning the "first factor" is resolved in future studies, the two hypotheses examined here are similar in that LPO amplitude reflects the magnitude of discrepancy.

The hypothesis that discrepancy is reflected in LPO amplitude is supported by research on the mutual relationship existing between the amplitude of P300 and stimulus probability varied within the range from 0.1 to 0.9 at an interval of 0.1 (201), which confirmed presence of feedback between LPO amplitude and the *a priori* probability of the stimulus. This research also demonstrated that the amplitude of P300 associated with a single probability level is lower following stimulus repetition than following stimulus alternation.

Squires et al. (1977) conducted a detailed study of the independent influence stimulus probability and the structure of the delivered stimulus succession have on LPO amplitude in relation to visual and auditory stimuli. They showed that in addition to probability, the structure of the stimulus sequence does have an influence upon the amplitude of the LPO, N200, and slow-wave late components. The greatest amplitude was observed after a stimulus preceded by four successive repetitions of different stimuli (aaaA), and the least was observed following five successive repetitions of the same stimulus (AAAAA). To explain the results the authors introduced the concept of "expectancy"--a variable associated with LPO amplitude by a feedback. According to the model they proposed, *a priori* stimulus probability and the structure of the stimulus sequence influence expectancy independently. The stimulus sequence exerts its influence in two ways: through assimilation of the stimulus succession structure, and through the indirect action of short-term memory (a stimulus delivered at one moment facilitates perception of the same stimulus delivered again immediately after), which exhibits different characteristics in relation to different modalities.

Squires et al. also present interesting data on the influence exerted by the level at which information contained within the stimulus is transmitted, and by the distinguishability and relevancy of signals upon the studied EP characteristics. The obtained results confirmed the modal specificity and endogenous nature of P300. A formula proposed in their work for determining expectation includes all of the three factors named above: probability, stimulus sequence, and the rate of extinction of a trace from the immediate memory. The concept of expectancy introduced in this work is in full agreement with that used in the hypothesis on the relationship between the LPO and discrepancy.

We cannot fail to note in connection with the expectancy model suggested by Squires et al. that research on the relationship between the LPO and the probability characteristics of the environment passed through the same evolution that was experienced by similar research on reaction time. As the number of experimental situations broadened, laws which at first appeared simple and which unambiguously reflected the quantity of information contained within a stimulus began to exhibit such a large number of situational and individual deviations that their explanation came to require assumption of the existence of a mediating link, through which probability influences, together with other factors, the indicator being recorded. An example of this can be found in the work of Johnson and Donchin (289), who concluded from an analysis of LPO changes that stimulus significance would better be ascertained from subjective behavior than from any instructions the experimenter might give. The authors believe that any change in the LPO implies change in significance or uncertainty, and if such a change catches the experimenter by surprise, he should analyze the situation in greater detail.

The expectancy model proposed by Squires et al. is essentially very close to the conception of probabilistic prediction and the theory of constant expectation, which arose within the mainstream of research on the mutual relationship between probability and reaction time.

One important factor of the expectancy model is that expectancy is viewed as a function not only of probability (that is, it is not analogous to the concept of subjective probability, often used in psychological studies to designate the subjectively assimilated probability characteristics of the environment, in contrast to those prescribed by the experimenter), but also of other factors, particularly the distinctness of the trace left by the previous stimulus within the short-term memory. This model will probably expand as the range of experimental situations expands. Loveless (324) interprets his results as an example of the fact that the biological significance of a stimulus may influence expectancy more than would probability.

Temporal uncertainty doubtlessly influences expectancy. This was demonstrated many times in research on reaction time. The influence exerted by temporal uncertainty upon the LPO was demonstrated in research by Ruchkin and Sutton (419). In this study the subjects had to predict whether or not a stimulus would be delivered, and they had to determine the moment at which it would be delivered following a preparatory signal--either 700 or 1,500 msec. The amplitude of P300 was lower with stimulus nondelivery than with stimulus delivery, and the difference was greater following the 1,500 msec interval. The individual variability of P300 following signal nondelivery coincided with the variability of time interval determination.

Using as our basis the dependence demonstrated in this work between the LPO and the closeness with which the real and expected moments of stimulus delivery coincide, we can reexamine the interpretation of the results of Donchin et al. (197). EP's were recorded in this work after each of two equiprobable visual stimuli: the letters A or B, presented 1,400 msec after a preparatory signal. The delivery of the letters was varied in different series from sequences fully known to the subject beforehand on one hand, to random delivery on the other. The dependence of the amplitude of P300 on signal predictability was compared in two situations: in a guessing game, and during performance of a choice reaction requiring a maximally fast and precise motor reaction to one of the stimuli. It turned out that in the guessing game, the amplitude of P300 depended on stimulus predictability: The highest amplitude was recorded with random delivery, and the least was recorded when the subject had a precise knowledge of what each successive stimulus was to be. In the choice reaction situation this difference did not occur: P300 was well expressed in all series, independently of stimulus predictability. The authors concluded from this fact that uncertainty is a sufficient but not a necessary prerequisite of LPO amplification. But another interpretation is possible as well. It may be thought that if the subject has to react as quickly as possible and if he has a precise knowledge as to which stimulus will be delivered, the subject tries to guess the moment of stimulus delivery as accurately as possible, and presence of a discrepancy between the expected and the real moment is a reason why the LPO does not decline.

This thought could be confirmed by an experiment identical to that described above, but without requiring the subjects to react quickly or to count stimuli. If the interpretation given above is true, we would expect the decline in the LPO accompanying transition from random delivery to a known sequence to be the same as that accompanying guessing.

The results of a number of other works can also be interpreted without contradictions in light of the hypothesis that a relationship exists between LPO and discrepancy. Thus a decrease in LPO amplitude accompanying an increase in the number of stimuli (Roth et al., 1974) may be the product of a consequent decrease in the probability of each stimulus and a corresponding decrease of expectation, and not of an increase in search time within the short-term memory prior to making a decision, as is suggested by the authors.

An increase in the latent period of the LPO shown in another work (78) in response to enlargement of the number of positive stimuli from 1 to 9 may be the product of the fact that a discrepancy may arise only after the short-term memory is searched for the purposes of decision making. This does not contradict the hypothesis suggested by the authors that the latent period of the LPO is associated with searching time in the short-term memory, required by the assignment at hand.

Nor does the hypothesized relationship between LPO and discrepancy contradict the so-called noncognitive interpretation of the LPO (291,292,293), according to which the LPO is a "common denominator" of different cognitive processes leading to change in state in response to a stimulus, marking a certain "turning point" in the course of activity. Close to this point of view are the suggestion that component P300 is associated with growth in emotional tension (Vasil'yeva and Farber, 1977), and Kostandov's hypothesis (30) that additional activation of cortical neurons, elicited by psychological significance, participates in the genesis of P300.

Presence of a relationship between the LPO and discrepancy says nothing about the functional role or the meaning of this oscillation, about the sort of phenomena or processes with which it is directly associated, and so on. A choice reaction may have a shorter latent period than the LPO, and consequently all proposed stages in which a discrepancy could occur precede the LPO. This means that the LPO is directly associated not with presence of a discrepancy itself but rather with some sort of processes that arise only in the event of a discrepancy and are associated with it quantitatively. These processes may include changes in activation level and further processing of obtained information. As an example it may represent the process of recording something in the memory: This would be natural, since this would have to happen in the event of a discrepancy or if a prediction has to be redrafted. Deserving of mention in this connection is the fact that more-pronounced LPO's were found to correlate with better learning in the learning of paired associations (370). This process could be a dramatic phasal shift in the activation level connected with the need for reorganizing an existing set in the event of a discrepancy, as is hypothesized in the works cited above by Karlin et al.

Donchin et al. (197) ventured the thought that P300 might serve as a gauge of the use of an intracortical processor, one employed in the implementation of the most diverse programs, the sole common characteristic of which is a certain degree of performance accuracy.

All of the facts examined above pertain to the "attention" situation, and correspondingly to oscillation P3b. Perhaps, however, it may also be valid in relation to the "orientational" LPO--P3a; according to Squires et al. (474) P3a arises when a discrepancy occurs between reality and an unconscious prediction, which is often revealed only owing to presence of an orientation reaction. P3b arises only in an attention situation, in which "standards" of relevant events, necessary for the performance of a task, are formed, and it reflects the discrepancy between this "prepared," voluntary formed standard and the real event.

The reader might suspect a certain contradiction between the author's desire to demonstrate the almost universal applicability of hypotheses on the relationship between the LPO and discrepancy, and the previously emphasized possibility that LPO's recorded in different experimental situations may vary in nature. Naturally even LPO's that are recorded in situations that appear similar at first glance may reflect different mechanisms. The difficulty of comparing and interpreting the results of earlier studies is aggravated by the fact that under different conditions, both the use of the same structures by different functional systems and inclusion of different structures into the same functional system are possible.

Nevertheless it would make sense to further development of the research to create an economical scheme permitting us to explain, without contradictions, the largest number of revealed LPO relationships by the least number of variables.

In conclusion we should make mention of a study of the possibility that a recorded LPO may be a combination of a "true," or "independent," LPO and a positive oscillation reflecting poststimulus return of a negative probability wave to the base line (501). The hypothesis that the LPO reflects only poststimulus return of a negative probability wave to the base line was completely rejected, inasmuch as it was shown that an LPO is observed after stimuli prior to which a negative probability wave is not recorded (Donchin et al., 1972; Jennes, 1972; etc.), and that it changes independently of the negative probability wave (Paul, Sutton, 1971; Friedman, 1971; Mac Adam, Rubin, 1972). However, these facts do not preclude the possibility that an additional positive wave is "superimposed" over the LPO due to poststimulus "resolution" of the negative probability wave. It is also possible in this case that the probability wave and the LPO vary identically in connection with change in activation level. But in those cases where parallel changes of identical direction were observed in a negative probability wave and an LPO, the mutual relationship is found to be low; a strict quantitative dependence has not been shown yet in any of the studies. Changes experienced by an LPO are often three to four times greater than concurrent changes in a negative probability curve (Friedman, 1971; Hillyard et al., 1971). The mutual relationship seen in a number of works between a negative probability wave and an LPO may be the product of various causes. It is possible that although both oscillations reflect independent experimental variables, a correlation may be revealed between them, inasmuch as these variables could change simultaneously in some experiments. A second possibility is that we are dealing with a mutual relationship between the prestimulus negative probability wave and the poststimulus positive shift occurring in combination with independent changes in the "independent" LPO. The facts available correspond equally well with both hypotheses, and presence of "intrinsic" LPO mechanisms remains doubtless in either case.

A similar approach (revealing correlation with mental processes or with particular elements of hypothetical schemes describing behavior) is also applicable to all other EP components. For example it has been hypothesized that the amplitude of N1 reflects the magnitude of a real "sensory event" (Squires et al., 1973). This hypothesis is associated in particular with data cited by Tanis (491) indicating a correlation between the amplitude of N1 and the psychophysical assessment of intensity in sound discrimination experiments. N1 was observed to have its greatest amplitude when a louder signal was presented and when it was assessed as loud; the amplitude next in magnitude (in the direction of decreasing amplitude) was noted after weak signals assessed as loud; this was followed by the amplitude observed after strong stimuli assessed as "weak," and finally the least amplitude was observed following a weak signal assessed as weak.

Squires et al. noted growth in the amplitude of N150-200 in response to an increase in the certainty of weak signal detection. In a situation of maximum certainty in threshold signal detection, the amplitude of the oscillation was equal to the amplitude of the same oscillation associated with passive perception of a sound 8 db above threshold. Considering the data of psychophysical studies indicating that the signal intensity at which detection errors disappear differs from that observed when reactions are random by 7-11 db, the authors concluded that the amplitude of N1 reflects a real sensory event, and that if a signal elicits a larger N1 oscillation (irrespective of whether this happens due to change in signal intensity or in connection with superimposition of spontaneous activity), the probability of its detection and the degree of detection certainty increase.

Loveless (324), who discovered an increase in component N1 in response to a choice reaction in comparison with a simple reaction, and a direct relationship between N1 amplitude and reaction time, suggests the hypothesis that an increase in the amplitude of N1 reflects an increase in the discrepancy between the neuron model of the stimulus and the real stimulus.

The two hypotheses turn out to be not so contradictory when we assume that a neuron model of signal absence exists in the weak signal detection situation, and that a discrepancy between reality and the model of sufficient size (as determined with the adopted criterion) is taken as a sign of signal presence.

Simson et al. (458) studied differences in EP's recorded in response to signaling and nonsignaling stimuli in a discrimination task in which the reaction was deferred to a later time. They subtracted the EP to the nonsignaling stimulus from the EP to the signaling stimulus. The difference was a biphasal oscillation: Negativeness began 130 msec after the sound and attained its maximum after 200 msec, while the subsequent positive oscillation attained its maximum after 350 msec. The same oscillations had the following respective temporal characteristics in relation to visual signaling stimuli: 170, 310, and 470 msec.

The distribution of the amplitudes of oscillations isolated in this fashion turned out to be comparable to the distribution of the amplitudes of negative and positive oscillations arising in response to unexpected stimulus nondelivery within a rhythmical series of stimuli. The authors suggest that the negative oscillation occurring together with the act of discrimination and with stimulus nondelivery is modally specific, and that it arises in secondary reasons of the visual or auditory cortex, while the positive oscillation accompanying an act of discrimination and stimulus nondelivery is modally nonspecific, and it arises in the lower parietal associative cortex. The authors interpret the negative oscillation arising after a signaling stimulus in a discrimination situation as a reflection of the activity of the discrimination mechanism, which goes into action following structures associated with component P200. Inasmuch as the instructions permitted deferment of the reaction to the signaling stimulus, they believe that the oscillation they isolated reflects "pure" manifestations of discrimination. We would have to note, however, that any differences in EP's recorded in response to signaling and nonsignaling stimuli that are not associated with physical differences in the stimuli may reveal themselves only following discrimination.

This paper was interesting as a demonstration of the fact that change in component amplitude may be the result of not change in the given component but appearance of a new oscillation having another generator in the same time interval. We note that presence of a different generator for each component is not something that is *a priori* undoubtable. As an example in Naatanen's opinion (351) there exists a long slow positive oscillation, beginning 50-100 msec following stimulus delivery and lasting for not less than a second, upon which two negative waves--N1 and N2--are superimposed, and that all of this taken together defines the shape of the EP.

Presence of several different hypotheses concerning the functional relationships typical of the same component, each of which is based on its "own" facts, may reflect the polygenic nature of the component which, given the spatial closeness of the structures generating the oscillation, would not reveal itself in any way other than through functional heterogeneity. Another possible cause of the multiplicity of hypotheses concerning the same component could be reflection, in different conditions, of different influences upon the structure generating the given component.

"Functional" analysis of EP came into use relatively recently, and it appears highly promising. The multiplicity of occasionally contradictory hypotheses and the swift rise and fall of different ideas in this area should not serve as a discouragement. A statement by Lyubishchev would be pertinent in this regard: "The swift rise and fall of theories in the most progressive sciences has evoked an impression of the bankruptcy of science in the minds of laymen. This is on the contrary a sign of developing science. The opposite situation--constancy of theories--is generally a sign of stagnation, and it is entirely natural that sciences in a state of stagnation have little attraction to young searching minds" (34, page 71).

CONCLUSION

The development and spread of the EP registration method proceeded so quickly that the literature has become difficult to grasp in its entirety, and it is impossible to illuminate all of the areas of this method's use in a book of limited volume. As an illustration it would be sufficient to cite the names of collections devoted to the use of EP's in different areas published just within a single year: Desmedt, J. E. (Editor), Auditory Evoked Potentials in Man. Psychopharmacology Correlates of Evoked Potentials," Vol 2, Basel, Karger, 1977; Desmedt, J. E. (Editor), "Language and Hemispheric Specialization in Man. Cerebral Event-Related Potentials," Vol 3, Basel, Karger, 1977; Desmedt, J. E. (Editor), "Attention, Voluntary Contraction and Event-Related Cerebral Potentials," Basel, Karger, 1977; Otto, D. (Editor), "Multidisciplinary Perspectives in Event-Related Brain Potential Research," Washington, D.C.: U.S. Government Printing Office, 1977; Desmedt, J. E. (Editor), "Cognitive Components in Cerebral Event-Related Potentials and Selective Attention," Basel, Karger, 1978.

My objective was, in addition to creating a brief general summary of data predominantly involving areas least illuminated in the domestic literature, to examine basic changes occurring in ideas about the nature of EP's, and the present trends in approaches to analysis of the neurogenesis and functional meaning of EP's. A shift has occurred from categorical and simplified interpretations* to the understanding that any oscillation recorded from the scalp may be an algebraic sum of numerous different oscillations arising in different divisions of the brain, and that both early and later components could reflect neuron events occurring in both primary and secondary projection zones, and equally so in associative zones of the cortex and other divisions of the brain. It was also discovered that oscillations recorded at different points on the scalp or at the same point but in different situations could differ in nature even though their amplitude and time characteristics are similar.

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* Components were divided into early and late, and they were defined categorically as, respectively, primary and secondary, specific and nonspecific, reflecting either physical characteristics of the stimulus or its biological significance, and so on.

It became clear that hypotheses concerning the neurogenesis of components require special examination and proof with a consideration for the distribution of potentials over the scalp. The categorical interpretation of the decrease-increase in component amplitude of a decrease-increase in excitability or functional state of structures or systems generating the components was also superseded by an understanding of the need for special evidence to confirm occurrence of certain changes in the nervous system in response to EP changes. At the same time we observe an "attachment" of researchers to particular components as "units of analysis," and continuation of a search for their nervous substrate and functional meaning, or their basic functional relationship.

More and more data are accumulating on independent, simultaneous changes occurring in EP's in different divisions of the brain, implying that they differ in their neurogenesis or that they are made up of independent components.

An example of a significant shift in the methodological level of experimental design can be found in research on selective attention, in which the use of the achievements of psychology in setting up initial conceptual schemes and designing experiments, as well as of concurrent registration of the behavioral indicators of attention, has led to doubtless successes.

Such trends can be noted in perception research, particularly in attempts at correlating the basic concepts of signal detection theory with data on the work of the nervous system acquired by means of EP's (9,37), in research on differential individual differences (23,25; Sil'verman, Bukhsbaum, 1969; Sil'verman, 1972), and in other areas.

The accumulated facts are doing more and more to free researchers from the myth of behavioral indicators free of the influence of culture (25), and they are directing their efforts at using EP's to study environmental influences affecting the individual's nervous system within his own lifetime.

Despite the impressive growth of information on EP's, much in this area still remains at the level of swiftly changing, sometimes debatable ideas, rather than rising to the level of dependably and conclusively established knowledge. This is not a hindrance to productive use of the EP as a correlate (indicator) of metal processes or states, and as a tool with which to study the physiological mechanisms of behavioral organization. Concurrently with this, research on EP's themselves is continuing, the method is enjoying further development, new description and analysis techniques are being sought, significant characteristics are being isolated, neurogenesis is being studied, and so on.

Surveying the significant successes attained in our understanding of brain mechanisms with the help of EP's despite the immeasurable complexity and limited possibilities of correlating bioelectric indicators with intracerebral processes, I would like to rephrase one of Einstein's famous quotations: "Nature is intricate, but it is not insidious."

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IN
AND PSYCHOPHYSIOLOGY

24 JULY 1980 BY E. M. RUTMAN 3 OF 3

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