The effects of varied activities on the post-electroshock electroencephalogram

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Submitted to the Graduate Faculty of McGill University in partial fulfilment of the requirements for the degree of Doctor of Philosophy, August, 1951.

PREFACE

This work was done at the Allan Memorial Institute; the electroencephalography laboratory is under the supervision of Dr. L. G. Hisey. The research was supported by a Dominion-Provincial Health Grant, and a grant from the Cooper Fund of McGill University.

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INTRODUCTION

The electroencephalogram (EEG) has made a limited contribution to an understanding of psychological processes. Changes in the frequency and localization of the predominant background rhythms parallel physiological development from infancy to adulthood; variations of the normal EEG pattern also reflect changes in the states of sleep and waking. The presentation of varying kinds of stimuli, however, produces a dismaying uniformity of response on the normal EEG.

Effect of stimulation on the normal EEG. The wealth of material on the effects of stimulation on the normal EEG has been summarized by a number of writers (39, 46, 52, 63). Under conditions of relaxation, the EEG of the normal adult is characterized by the presence of the alpha rhythm. Stimulation of any modality can produce at least a transient depression of the alpha rhythm. In its place, a low voltage fast activity appears, usually referred to as an activation pattern, or arousal reaction. The EEG pattern most consistently found to be associated with problem solving and emotional situations is also that of low voltage, fast frequency activity. Kennedy and his associates (45) have reported that tasks involving thinking produce a specific EEG pattern - kappa waves - but this finding has not been confirmed by other workers as yet. Hoagland and his co-workers (32) reported that emotional stimuli in

adults produce an increase in slow waves, but subsequent investigations have not been able to reproduce these results (31, 53). Walter (86) has noted that emotional situations consistently produce an increase in four to seven per second waves in children under three years of age. This change may represent a relative increase in the amount of fast frequencies, and thus may be analogous to the increased fast waves observed in adults in emotional situations.

It has often been assumed that the suppression or blocking of the alpha is directly due to the desynchronizing effect of the afferent impulses arriving at the cortex. However, the latency of the arousal reaction is between two- and four-tenths of a second, longer than the time necessary for an afferent stimulus to arrive at the cortex. In fact, it has been shown that the motor response to a light stimulus in a simple reaction time test may precede the alpha blocking (79). Further, an activation pattern may be produced in the absence of afferent stimulation, as in trying to see in the dark, and alpha may persist in the presence of stimulation, as in the so-called adaptation of the alpha blocking to light. Thus many workers (41) have concluded that the background cortical activity must be regulated by a subcortical pacemaker. Recent investigations have demonstrated the existence of such pacemakers in the reticular formation of the brain stem and thalamus. An activation pattern can be reproduced by electrical stimulation with high frequencies of the reticular systems (40, 60), and appropriate stimulation

of parts of the thalamic reticular formation can reproduce a pattern similar to that of the normal rhythmic activity (40).

Although a wide variety of stimuli appear to be able to produce an activation pattern, the length of time for which this pattern is maintained does depend somewhat on the kind of stimulus situation. For example, the more difficult an arithmetic problem, the longer is the alpha usually suppressed. Jasper and Cruikshank (41) have concluded that it is the "attention value" of a given stimulus situation rather than the modal or intensity attributes of the stimulus that determine the extent of effect on the alpha rhythm. If it is assumed that the attention value of a stimulus derives from, or relates to, the complexity of the thought processes it arouses, then the maintenance of an activation pattern is dependent on the complexity of a thought sequence.

Darrow (18) has pointed out that a state of asynchronous excitation would be conducive to the maintenance of highly organized thought processes. The presence of rhythmic activity would render large groups of cells simultaneously refractory to stimulation, and thus limit the number of cells available for integration into thought processes.

If, then, the presence of the alpha rhythm is associated with a limitation of thought processes, it is pertinent to inquire whether a similar relationship exists between abnormal degrees of hypersynchrony and thought processes. However, few attempts have been made to investigate systematically

the effects of stimulation on pathological wave forms. The available evidence indicates that stimuli may have both an inhibiting and an augmenting effect on abnormality.

Effects of stimulation on the abnormal EEG. A wide variety of stimuli have been observed to inhibit slow waves. The bursts of slow waves occurring in idiopathic epilepsy can be inhibited by visual and auditory stimuli, or by the mental activity of solving an arithmetic problem. Barker and Barker (5) imply that this effect can be found in all cases; other workers (48, 80, 85) have observed it only in a small proportion of patients. Cobb has reported that visual stimuli may inhibit the rhythmic slow waves, either unilateral or bilateral, appearing with tumours (16) and head injuries (15). Intense concentration on a problem can suppress the slow waves occurring with prolonged deprivation of sleep (10). A few workers (35, 47, 49) have noted that the slow waves occurring after electro-convulsive-therapy can also be diminished by various stimuli, or concentration on a problem. Lesions of the posterior hypothalamus and brain stem reticular system produce slow waves that can be regularly inhibited by visual and auditory stimulation (36, 54).

These observations are consistent with the finding in the study of the normal EEG that a stimulus or thought may be incompatible with rhythmic activity. However, the evidence is still fragmentary. It is not clear from the

clinical reports how frequently this effect may be obtained for the various kinds of abnormality, how long the suppression of abnormality can be maintained, or what stimuli are most effective in producing the suppression. The animal studies clearly show that a state of wakefulness or activity inhibits the generalized slow waves produced by lesions of the reticular system. The extent of this suppression did appear to vary somewhat with different stimulating situations, but adequate comparative data have not been reported.

Although stimulation does appear to inhibit slow waves, many workers have reported that stimulation may also precipitate bursts of abnormality. However, these data are confusing, since a number of different phenomena appear to be involved. Four types of response to stimulation can be distinguished, of which only the first two can be considered to represent a precipitation of abnormality by stimulation. In the other cases, it will be suggested that the abnormality appeared when a thought process was disrupted, or completed.

(1) In certain cases of focal epilepsy, it is clear that an attack may be precipitated by a sensory stimulus that projects specifically to the pathological cortical area. In the electrographic study of one such case, it was found that the abnormal discharge appeared simultaneously with the stimulus (24). Thus, the precipitation of abnormality can

be attributed directly to the arrival of the stimulus at the cortex. However, it is interesting to note that stimulation did not produce an abnormal burst when the subject was warned that the stimulus (tap on left shoulder) would be applied. That is, although stimulation could elicit abnormality under certain conditions, this abnormality could, in turn, be inhibited by the presence of a particular thought activity (expectation of the stimulus).

Barker and Barker (5) have reported an exception to the general finding that only sensory stimuli related to the focus of abnormal discharge can precipitate an attack. These authors found that emotional stimuli could elicit abnormal waves in a case with a focal abnormality. However, the only evidence given is one example of "spiking" in the right temporal lobe; these waves look more like an electrocardiographic artifact than genuine EEG abnormality. The wave form, the amplitude, and the regular rate of discharge are atypical for a spike abnormality, but are consistent with the interpretation of an artifact synchronous with the heart beat. This artifact may simply have become more apparent when the alpha was inhibited by emotional stimulation, and thus could be mistaken for the precipitation of abnormality by the stimulus.

(2) The second type of response to stimulation refers to the observation that attacks may be precipitated in cases of myoclonic epilepsy by different kinds of stimuli - a sudden sensory stimulus, volitional muscular effort, and psychic

upsets (28). Dawson (19) studied the electrographic responses in a few such cases, using a tap on the patellar tendon as the stimulus. These records show, in contrast to the case of focal abnormality, that it is not the initial arrival of the stimulus at the cortex that elicits the attack, since the abnormal EEG discharge first makes its appearance about four-tenths of a second after the application of the stimulus. This latency is of the order of the alpha blocking to stimulation, and thus may be a precipitation of abnormality produced by a stimulus acting through a diffuse projection system. Although clinical evidence of attacks can be produced by other kinds of stimuli, it is not known whether a similar latency exists between the time of presentation of these other stimuli and abnormal bursts. It will be suggested later that the effect of "psychic upsets" in producing abnormality is not a simple precipitation of abnormality by an emotional stimulus.

(3) The third type of response refers to the appearance of rhythmic activity that occurs a relatively long time after the stimulus is first presented. In these cases, it is suggested that the abnormality indicates a state of relaxation, or a completion of the thought activity produced by the stimulus. Ingram and his associates (36) have reported that a sensory stimulus evokes a burst of rhythmic slow waves in animals showing savage behavior after bilateral lesions of the ventromedial nucleus of the hypothalamus. This discharge appears from one to three seconds after the stimulus, and

could be interpreted as a relaxation potential occurring after the response to the stimulus is over. Similarly, the observations that eye-closing may evoke bursts of rhythmic abnormality in cases with idiopathic epilepsy (85) and brain lesions (15, 16) may also be included under the category of a relaxation abnormality. That is, the abnormality is augmented after the visual stimulation has stopped. Hill (31) has reported that, under certain conditions, painful stimuli such as pin-prick can evoke rhythmic waves of four to seven per second in patients with abnormal EEG's. The Barkers (5) have reported that similar stimuli can produce abnormal bursts in patients with idiopathic epilepsy. Although these authors do not give precise information on the time relation between the stimulus and the appearance of the abnormal burst, the general description suggests that these, too, may be examples of abnormality appearing some time after the stimulus.

(4) The fourth type of response to stimulation refers to the report of Barker and Barker (5) that abnormality may be precipitated in epileptics by emotionally disturbing stimuli. They state that, in many patients, ".... bursts of abnormal waves occurred only with the interruption into consciousness of obviously significant thoughts and feelings" (p. 92). The case studies show that the abnormality occurred when the patient began to hesitate in his recounting of some information, apparently unsure of what to say next. As the authors have emphasized, this hesitation was apparently due

to a conflict of thoughts, or a sudden recollection of previously forgotten thoughts.

The Barkers then point out that the abnormal burst is, in turn, interrupted by the resumption of communication. That is, the discussion continues of the same "emotional" topic, yet without bursts of slow waves. The authors conclude that, "The convulsive reaction is, therefore, an accompaniment of the brief disruption of awareness and communication, that is, of integrative activity" (p. 92).

This latter statement seems to be an accurate description of the sequence of events, but does not ascribe any unique role to emotional stimuli in producing the convulsive reaction. The same conclusion could be drawn from the Barkers' own observations on the time of appearance of abnormal bursts during the non-emotional activity of solving arithmetic problems. The bursts occurred during long pauses between the answers in a serial arithmetic problem, or after the problem was completed. Again the convulsive reaction can be considered an "accompaniment of the brief disruption of integrative activity".

Assuming that thought processes are the neural correlates of the "integrative activity", these authors seem to be saying that slow waves appear in the absence of an organized thought sequence. That is, the abnormality appeared when the thought sequence was completed, as in the solution to an arithmetic problem, or when there was a disorganization of the thought process, as in the conflict of thoughts in the discussion of

personal problems. If it is assumed that a disorganization of thought processes occurs more readily in the discussion of emotional subjects, (or is characteristic of "emotion" (29)), then it would be expected that bursts of abnormality would occur under the conditions described by the Barkers. However, the implication of such results is not that an emotional stimulus ("obviously significant thoughts and feelings"), elicits abnormality in the way that a sensory stimulus may produce an abnormal burst in certain cases of epilepsy. Rather, it could be concluded that the distintegration of an organized thought provides an opportunity for other autonomous processes to control central nervous system activity. (In the normal case, the analogue of the abnormal bursts occurring in epileptics may be the "facilitation" of alpha occasionally found in emotional situations (82)).

Although the Barkers have made a most interesting and detailed study of the relationship between conditions of stimulation and changes in EEG pattern, it is rather difficult to generalize from their data. The subjects of their investigation represent a particular group of epileptics, those who showed little or no abnormality under the usual, relaxed conditions of recording. Information is not given of the number of subjects studied, or in what proportion were found the various effects that were described. The authors have focussed their attention on the time of appearance of the bursts of slow waves, but have not adequately compared the total amounts of abnormality occurring

under the various conditions. Also, it is not clear from their report whether an investigation was made of the frequency of bursts appearing with the discussion of non-emotional topics.

Statement of problem. It is clear from the data available that little is known of the effects of stimulation on abnormal slow waves. The evidence suggests that various stimuli or thought processes inhibit slow waves; the experiment to be reported here will attempt to study this phenomenon systematically. It is not known how frequently the suppression may be obtained with various types of abnormality, how long this effect can be maintained, or what stimuli are most effective in producing the suppression.

Such information would be relevant to an understanding of thought processes. It was previously pointed out that the presence of rhythmic activity would tend to limit thought by rendering large groups of cells simultaneously refractory to stimulation, and thus unavailable for integration into thought processes. The effect of stimulation on the normal EEG is consistent with this assumption since the alpha rhythm is inhibited by activity such as problem-solving. It is pertinent to inquire, then, whether a similar relationship exists between pathological rhythms and various kinds of thought processes.

The experimental study that is to be reported will be limited to the investigation of one type of abnormality, the rhythmic slow waves appearing after electroconvulsive

therapy. The electroencephalographic findings associated with electroshock will now be described, and the relevance of this experiment to an understanding of the mechanism of these slow waves will be pointed out.

General character of the abnormality. The electroencephalographic abnormality found most frequently after electroshock consists of bursts of high voltage slow waves from both sides of the head. The slow waves occur predominantly in frontal areas (7, 17, 35, 64), although they may also spread to posterior regions. Other variations in the EEG pattern following electroshock have also been described, but these changes occur less consistently than the slow waves.

Some workers have found that the alpha rhythm becomes slower (44, 87); others report that the alpha frequency does not change (4, 34). Proctor and Goodwin (68, 69) have pointed out that this discrepancy may, in part, be due to the use of different types of stimulating current. Levy and his colleagues (49) have noted that a few records simply show increased random or beta activity; Calloway's data (13) suggest that this type of pattern is likely to occur at the end of a course of intensive electroshock. Although there are reports of individual records that show increases in fast waves, it has been found that the amount of fast waves is decreased in most subjects after electroshock (26, 33). The report of Gottlieb and his co-workers (26) has clearly shown that this decrease is due to the

effects of electroshock itself, and is not related to clinical improvement, as suggested by Hoagland and his associates (33). Since psychiatric patients show a higher proportion of fast waves than the normal population (12), the decrease after electroshock may not represent a change towards greater abnormality. For the purposes of this discussion, then, only the appearance of slow waves will be referred to as abnormality.

The frontal localization and bilateral character of the abnormality does not appear to be due to the position of the stimulating electrodes. Although it has been found that the area beneath the shocking electrodes may show earlier, and more pronounced, changes than other areas (11, 59), stimulation with varied electrode placements has indicated that the frontal areas are selectively susceptible to the development of slow waves (47). Regardless of whether the electrodes are placed on one, or both, sides of the head, the abnormality appears bilaterally (35, 51, 59, 64, 87). This is consistent with the finding that the stimulating current follows neuronal pathways, traversing both sides of the brain and into deep structures (55). On the basis of EEG studies during electrically-induced seizures, Bickford and his colleagues (8) have suggested that the seizure may begin only after the current has spread to subcortical structures.

Amount of abnormality. The amount of abnormality observed at any given time is largely dependent on the

stage of the treatment period at which the recording is made. Slow waves first appear after three to six treatments (7, 59, 69). The amount of abnormality is inversely related to the length of time elapsing between the last shock and the EEG recording (6, 17, 61). As treatment continues, the amount of abnormality increases, and the length of time for which the slow waves persist is also increased (7, 17, 34, 35, 61, 87). Calloway (13) and Honcke (34) have noted that the amount of abnormality tends to reach a maximum, after which further treatment does not produce an increased quantity of slow waves.

The amount of abnormality also appears to be directly related to the amount of electrical energy required to produce the convulsion (34, 51, 69, 87). Thus two factors in the method of treatment appear to contribute to the amount of abnormality observed. First, repetitive convulsions themselves produce pathological effects. Secondly, the extent of cell disturbance due to spread of current may be determined by the amount of electrical energy used to produce the convulsion.

The marked individual variability in the amount of abnormality (34, 35) produced by electroshock can be, in part, attributed to differences in age and pre-treatment EEG. Patients under 25 years develop more abnormality than those from 25 to 45 years (35, 87); the data also suggest that the abnormality increases again above the age of 45 years (87). More pronounced abnormality has also been

reported in patients showing abnormal EEG's prior to treatment; in those with a focal disturbance, the abnormal area was selectively sensitive (4, 34, 61, 64). It is interesting to note that Greenblatt and his associates (27), in a survey of the routine pre-treatment EEG's of psychiatric patients, similarly found a higher incidence of abnormality in patients below 25 years, and above 45 years, in comparison with those patients between these ages. Thus it is possible that the greater abnormality observed in young and old patients after electroshock may be related to an abnormal pre-shock EEG as well as to age itself.

Several reports have appeared describing changes in the amount of abnormality produced by various drugs. These findings will be reviewed later in the discussion of theories concerning the physiological changes responsible for the EEG abnormality.

Reversibility of abnormality. When treatment is stopped, the slow waves gradually decrease, and the EEG returns to normal. The record may remain abnormal for as little as a week, or occasionally as long as ten months (61). Unless a large number of treatments are given, the majority of records seem to return to normal within a month.

Callaway (13) has reported a somewhat different pattern of change in those patients given intensive electroshock. By the end of the last treatment, the EEG's no longer showed high voltage slow waves, but were characterized by low

voltage, fast activity. During the first three days following cessation of treatment, there was a marked increase in the amount of slow waves. This abnormality then decreased, and the EEG developed its normal pattern. It has been suggested that the slow wave increase following treatment may be indicative of a continuing pathological process (47). However, it could also be assumed that the slow waves represent the first stage of recovery from the depression of cortical activity observed by the end of the course of treatment. Jasper and his co-workers (42) have noted depressed cortical activity in severe head injuries, and report that recovery from this stage is accompanied by the appearance of high amplitude, random and rhythmic slow waves.

Although most reports say that the EEG returns to normal within a short time after treatment, the EEG may not return to its pre-shock pattern. It has often been observed that the post-shock alpha is of the same frequency as pre-shock, but of distinctly higher amplitude (7, 49, 64). Whether or not this indicates more normal function is a moot point; Schwab (76) has commented that an increased alpha is also seen after head injuries. Kennard and Willner (44) have found that after electroshock, a significant number of children's EEG's show an increased stability and uniformity of pattern, which may be the equivalent of the change of alpha pattern in adults. Lennox and her associates (47) have cogently

pointed out that the reversibility of EEG slow waves is not inconsistent with permanent pathological changes since electrographic slowing generally correlates only with acute cerebral insult. Finally, the observation (17, 34) that EEG abnormality develops more quickly in those patients who have previously had a course of treatment suggests that electroshock may leave neurophysiological changes outlasting those observed in the EEG by present methods.

Theories. Three types of theories have appeared concerning the physiological changes responsible for the EEG changes. EEG abnormality has been considered as due to (1) destruction or injury to brain cells without reference to the particular structures or areas involved, (2) disturbance in the metabolism of brain tissue, and (3) changes in specific neural systems.

(1) Walter (84), in discussing the finding that petechial heamorrhages may occur with electroshock, says " ... there is a possibility that the transient effect of such haemorrhages is responsible for the EEG observations" (p. 72). However, the finding of petechial heamorrhages after electroshock has not been confirmed by subsequent investigations (3). After an extensive review of the animal studies, Kalinowsky and Hoch (43) have concluded that electroconvulsive therapy produces no important morphological changes in the brain. Experimental studies

since then support this point of view (22, 23, 77). Thus it is unlikely that the EEG abnormality can be ascribed to structural damage of nervous tissue. However, one difficulty in generalizing from the experimental data to humans is the fact that monkeys, on whom most of the neuropathological studies have been done, do not show as severe or prolonged slow waves as humans (47). The few reports available on human material do not clarify the problem. The findings are contradictory (43), and must be evaluated cautiously since they represent a selected sample of the total group of patients treated with electroshock.

(2) Lennox and her co-workers (47) have suggested that anoxia may be one of the factors producing the EEG abnormality. These workers found that, in monkeys, the administration of benzedrine prior to electroshock markedly reduced the amount of slow waves usually found after the convulsion. The authors point out that benzedrine has a similar effect on the slow waves observed after anoxia. Although the mechanism by which benzedrine prevented the post-convulsive slowing is not known, the authors suggest that this effect is due to both the increased blood supply and the stimulating effects on the central nervous system produced by the drug.

Aird and his associates (2) have presented evidence to show that changes in the permeability of the blood-brain

barrier may be responsible for the EEG abnormality. These authors found that the permeability of the blood-brain barrier was increased in cats given electroshock. Half the animals were then injected with trypan red, a substance that decreases the permeability of the blood-brain barrier. The EEG's of these animals were normal, while those of the control group, without the drug, showed the usual amount of slow waves. Aird (1) has reported a similar increase in the permeability of the blood-brain barrier, and a reversibility of EEG abnormality with trypan red, in an experimental study of head injuries in animals. It is difficult to evaluate the significance of Aird's work since the amount of trypan red used to produce the normal EEG is considered to be a toxic dose (21). In fact, the permeability estimates after the administration of trypan red in conjunction with electroshock are significantly lower than the normal control values. Thus Aird's results raise the problem of how an abnormally decreased permeability of the blood-brain barrier can produce a normal EEG, whereas abnormal slow waves occur with a pathologically increased permeability. Since the normal state of permeability existing prior to electroshock is not restored by trypan red, it appears that this drug does not simply reverse the changes produced by electroshock.

In addition to the reports just discussed, other workers (11, 30, 43, 78) have suggested that an impairment

of cerebral metabolism may account for the EEG abnormality. However, this type of theory cannot be considered a complete explanation of the EEG changes. The various metabolic disturbances described are not specific to electroshock, but also occur under conditions in which the EEG is not the same as that observed after electroshock. Further, even if a pattern of metabolic changes were found to occur specifically in response to electroshock, it is still unlikely that the EEG findings could be explained without reference to neural organizations and connections. If cerebral metabolic dysfunction were the direct cause of EEG abnormality, then one would expect continuous abnormality, perhaps of a random and non-localized type. However, the EEG after electroshock is frequently normal for periods of time, with the abnormality usually appearing in the form of rhythmic bursts. Thus it is suggested that, although metabolic disturbance may be the primary cause of the fact that changes in neural functioning do occur, the kind of change must also depend on the organization of the central nervous system itself. That is, cumulative metabolic changes may selectively alter the activity of neural systems; the kind and extent of these latter neural changes would then determine the character of the EEG abnormality. The question of defining such neural changes is still unanswered. Finally, it might be pointed out that metabolic changes could also occur secondarily as a result of neural changes.

(3) The only hypothesis relating changes in the nervous system to the EEG abnormality is that recently proposed by Roth and McClatchey (73). These authors have suggested that electroshock blocks the brain stem reticular system, and releases the activity of the thalamic reticular pacemaker. However, this conclusion does not seem justified. First, the authors seem to assume that the normal activity of the thalamic centre produces a rhythmic three-per-second discharge, whereas Jasper (40) has suggested that this system is concerned with the regulation of the normal alpha rhythm as well as spontaneous pathological rhythms. Thus it may be correct to conclude that the activity of the thalamic system has been changed, but this change may not be a simple release phenomenon. Secondly, the conclusion that the activity of the brain stem reticular formation in particular has been blocked, is based on the observations of Moruzzi and Magoun (60) that barbiturates selectively inhibit the activity of this system. However, Roth and McClatchey have not reported control studies using sleep-producing agents other than barbiturates. Thus it is not known whether any sedative would produce the effect observed by these authors, or whether the results are due specifically to the action of the barbiturates on the brain stem system. While objectives have been raised to the specificity of the theory of Roth and McClatchey, their suggestion that electroshock produces a change in the activity of sub-cortical pacemakers can be considered to be a fruitful hypothesis.

Elaboration of experimental problem. The experiment to be reported of the effects of stimulation on slow waves is relevant to theories concerning the physiological changes responsible for this abnormality. If stimulation can alter the EEG pattern, then it is clear that neural connections, as well as metabolic changes, are determinants of the abnormality. Many studies have indicated that there are sub-cortical centres concerned with the regulation of cortical activity in states of excitation and rest. Thus a study of the relationship between activity and EEG abnormality may provide additional information on the neural changes occurring as a result of electroshock.

Also, such an investigation has methodological implications for studies attempting to relate observations on behavior to the abnormality found in the EEG. If stimulation can diminish slow waves, then it is necessary to know the extent of this effect under conditions comparable to those in which the observations of behavior are made.

In summary, then, the experimental problem is to investigate the effect of stimulation in reducing the slow waves occurring after electroshock. This study has implications (1) for an understanding of thinking processes, and (2) for theories concerning the neural changes produced by electroshock.

PROCEDURE

Electrode placements. The electrode placements used are shown in Figure 1. Four electrodes were placed on symmetrical areas on each side of the head; the EEG was recorded between fronto-central (F-C) leads, and parieto-occipital (P-O) leads, from each hemisphere. Preliminary work indicated that when the subject was doing the various tasks to be described below, least artifact was obtained with this recording arrangement. Electrodes were also placed near the right eye. Eye movements were recorded simultaneously with the EEG in order to distinguish the slow wave artifact caused by these movements from genuine abnormality. Silver - silver-chlorided electrodes were used. The patient lay on his back, in a semi-recumbent position, in a moderately bright room. The recordings were taken on a Grass EEG machine, console Model 111C.

Recording. The procedure was as follows:

4 minutes recording with eyes closed, relaxed

4 minutes recording with eyes open, relaxed

1 minute recording with eyes closed, relaxed

4 minutes recording with eyes closed, tapping

1 minute recording with eyes closed, relaxed

4 minutes recording with eyes closed, doing serial arithmetic problems

1 minute recording with eyes closed, relaxed

6 minutes recording with eyes closed, doing a reaction time test

4 minutes recording with eyes closed, relaxed

Electrode placements.

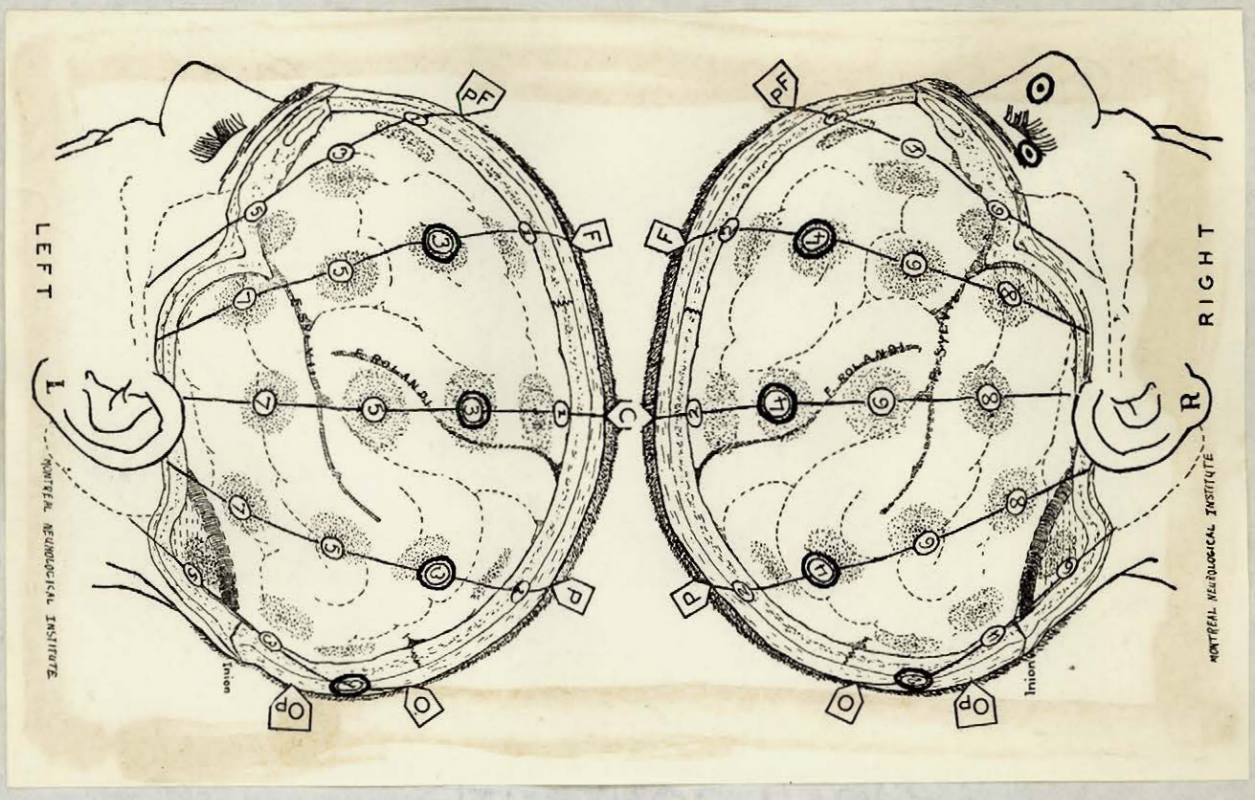

FIGURE 1

Electrodes were placed on the encircled positions.

In the samples of EEG records to be shown later,

FR-CENT refers to a linkage between F_3 and C_3, or F_4 and C_4;

PAR-OCC refers to a linkage between P_3 and O_1, or P_4 and O_2.

A few minutes of instructions intervened before each of the tasks. This time varied with the patient and the task, and was longest in the case of the reaction time test since the patient was given a few minutes of practice.

In the eyes open task, the patient was simply told to open his eyes and relax again. In the tapping test, the patient tapped with a metal stilette on a small metal plate so that the tapping was recorded simultaneously with the EEG. The patient was told to tap at any rate he wished, and that the speed did not make any difference to the test.

The serial arithmetic really consisted of several tasks. The patient was first told to start at one and add by threes until he came to 100. The other arithmetic problems were, in the following order, to count backwards by threes from 101, to count backwards by sevens from 100, to count backwards from 100 by sixes, and to count backwards from 100 by eights. The patient was given only enough problems to complete the four minutes of arithmetic, excluding the time for instructions for each new problem.

In the complex reaction time test, the apparatus described by Bjerner (9) was used. The patient pressed a small lever which provided the stimulus, and thus determined the rate of stimulation for himself. The stimulus consisted of either a bell, a buzzer, or the bell and buzzer together; the various stimuli appeared in random order. The patient responded to each of these stimuli by pressing the lever left, right, and up,

respectively. After each response, the lever automatically returned to its starting position; the patient then pressed it again, starting another cycle of stimulus and response.

With a small group of patients, the EEG was recorded continuously for 30 minutes under conditions of relaxation with eyes closed.

Scoring. Since the main interest in this study was the effect of the various tasks on the abnormal waves, the scoring was devised to measure the amount of abnormality present in the recording. Abnormality was defined as a series of waves of five per second or less that continued for at least one second with an amplitude greater than 20 microvolts. Six-per-second waves of greater than 50 microvolts were also considered abnormal, and, in those cases for whom pre-shock recordings under the test conditions were available, six-per-second waves of greater than 20 microvolts were similarly marked as abnormal if they had not appeared in the pre-shock record.

The length of time each series of slow waves was present, and the maximum voltage of each such burst, were recorded. An arbitrary unit of abnormality was then set up which utilized both the number of seconds during which abnormality was present, and the amplitude of the abnormal bursts. That is, the number of units of abnormality was equal to the total number of seconds of abnormality multiplied by the average of the maximum voltages, divided by 20. For example, 1 unit of abnormality would mean one second of abnormal waves with a maximum voltage of 21-29 microvolts ($1 \times \frac{21}{20}$); 2 units of abnormality could mean 2 seconds of

abnormal waves with an average maximum voltage of 21-29 microvolts, or 1 second of abnormal waves with a maximum voltage of 40-49 microvolts; and so on. In two cases with practically continuous abnormality, the average maximum voltage was calculated by averaging the maximum voltage in every five seconds of recording.

Since all reports describing the EEG abnormality after electroshock agree that the slow waves are maximal in frontal areas, only the fronto-central recordings were scored for abnormality. When the slow waves were not identical from both sides of the head, the measurements were taken from the side showing the higher amplitude, and more prolonged, burst.

The amount of time during which alpha was present was calculated for the parieto-occipital recordings, alpha being counted as present regardless of whether it appeared in one or both parieto-occipital leads. Any half-second containing waves from 8-13 per second and greater than 15 microvolts was counted as alpha. The alpha score was a rougher measure than the abnormality score since the varying voltage of the alpha in different parts of the record was not included.

Subjects. The subjects used in this experiment were psychiatric patients receiving electroshock. The main results deal with an analysis of 22 records obtained from 16 patients - one record from each of 11 patients, 2 records from each of 4 patients, and 3 records from 1 patient. When more than one recording was made on a patient, the several records were taken at different stages in

the course of treatment.

The 22 records were selected from a group of 40; the discarded ones could not be scored because of either absence of abnormality, or excess of artifact. Seven records were taken after 3 to 4 treatments, 11 after 7 to 9 treatments, and 4 after 12 to 22 treatments. Three recordings were taken 3 to 6 hours after a treatment, 17 were taken 24 to 30 hours after treatment, and 2 were taken more than 48 hours after treatment.

The group consisted of ten females and six males, of whom seven were diagnosed as having schizophrenia, three as having manic-depressive psychosis, five as having psychoneurosis with depression, and one as having involutional psychosis: melancholia. The mean age was 38 years, with a range of 18 to 66 years.

Pre-shock EEG's, recorded under the conditions of stimulation previously described, were also available for 13 psychiatric patients who were all candidates for electroshock. Six of these form part of the group of 16 patients whose post-shock EEG's were used for analysis. The group of patients with pre-shock EEG's consisted of eight females and five males, of whom four were diagnosed as schizophrenic, one as manic-depressive, five as psychoneurotic with depression, and three as melancholic (involutional psychosis). The mean age was 43 years, with a range of 22 to 66 years. With respect to sex, age, and diagnosis, then, the composition of the pre- and post-shock groups did not differ significantly from each other. Thus the performance of the pre-shock group on the various tasks used in the experiment was used as control data to evaluate the effects of electric shock on the performance of the post-shock group.

TABLE 1

Comparison of abnormality under varied conditions of recording

	RELAX 1	EYES OPEN	TAPPING	ARITH.	REACT.TIME	RELAX 2
(A) UNITS OF ABNORMALITY DURING FIRST MINUTE						
Mean	52	19	30	15	13	36
Range	0-294	0-72	0-250	0-191	0-110	0-211
Significant differences. Less abnormality was observed during:						
Eyes open	.02	—	--	--	--	--
Tapping	.02	—	--	--	--	--
Arithmetic	.01	—	.01	--	--	.01
Reaction time	.01	—	.01	--	--	.01
(B) UNITS OF ABNORMALITY DURING FOUR MINUTES						
Mean	209	105	175	85	72	208
Range	0-1136	0-396	0-998	0-618	0-525	0-1189
Significant differences. Less abnormality was observed during:						
Eyes open	.01	—	.01	—	—	.05
Arithmetic	.01	.02	.01	—	—	.01
Reaction time	.01	.02	.01	--	--	.01
(C) NUMBER OF SECONDS BEFORE ABNORMALITY APPEARED						
Mean	35	91	41	105	89	49
Range	0-240	3-240	3-240	5-240	2-240	1-240
Significant differences. Abnormality developed more slowly during:						
Eyes open	.01	—	—	--	--	.01
Arithmetic	.01	.05	.01	—	—	.01
Reaction time	.01	--	.02	—	--	.01
(D) LENGTH, IN SECONDS, OF BURSTS OF ABNORMALITY						
Mean	1.9	1.4	1.8	1.2	1.2	1.7
Range	1-5.0	1-4.2	1-4.5	1-5.5	1-3.8	1-4.7
Significant differences. The length of burst was shorter during:						
Eyes open	.01	—	.02	—	--	--
Arithmetic	.01	--	.02	--	--	.02
Reaction time	.01	.05	.05	—	--	.05

RESULTS

The results clearly show that less abnormality appeared when the recording was done under conditions of stimulation than under conditions of relaxation. Stimulation not only reduced the amount of abnormality, but also delayed the time of appearance of the first burst of slow waves, and shortened the length of the bursts.

Since the range of scores was very wide, and the distributions skewed, the chi-square method of evaluating the significance of the differences was used. The number of records showing increases and decreases in abnormality was compared to the number of such changes expected by chance. During the first minute of recording, each of the four methods of stimulation was effective in reducing the amount of abnormality compared to the first minute of the first relaxation period (Table 1,A). Except for tapping, stimulation also inhibited abnormality as indicated by the other measures used (Table 1 - B,C,D). That is, in comparison with the first relaxation period, stimulation reduced the abnormality appearing during the total four minute periods, delayed the appearance of the first burst of slow waves, and shortened the average length of these bursts. Although the emphasis in this investigation is on the control of frontal abnormality by stimulation, it was also noted that the parieto-occipital alpha, when it appeared, tended to be better organized under conditions of activity. Figure 2 illustrates the normalizing effect of stimulation on the anterior and posterior EEG patterns.

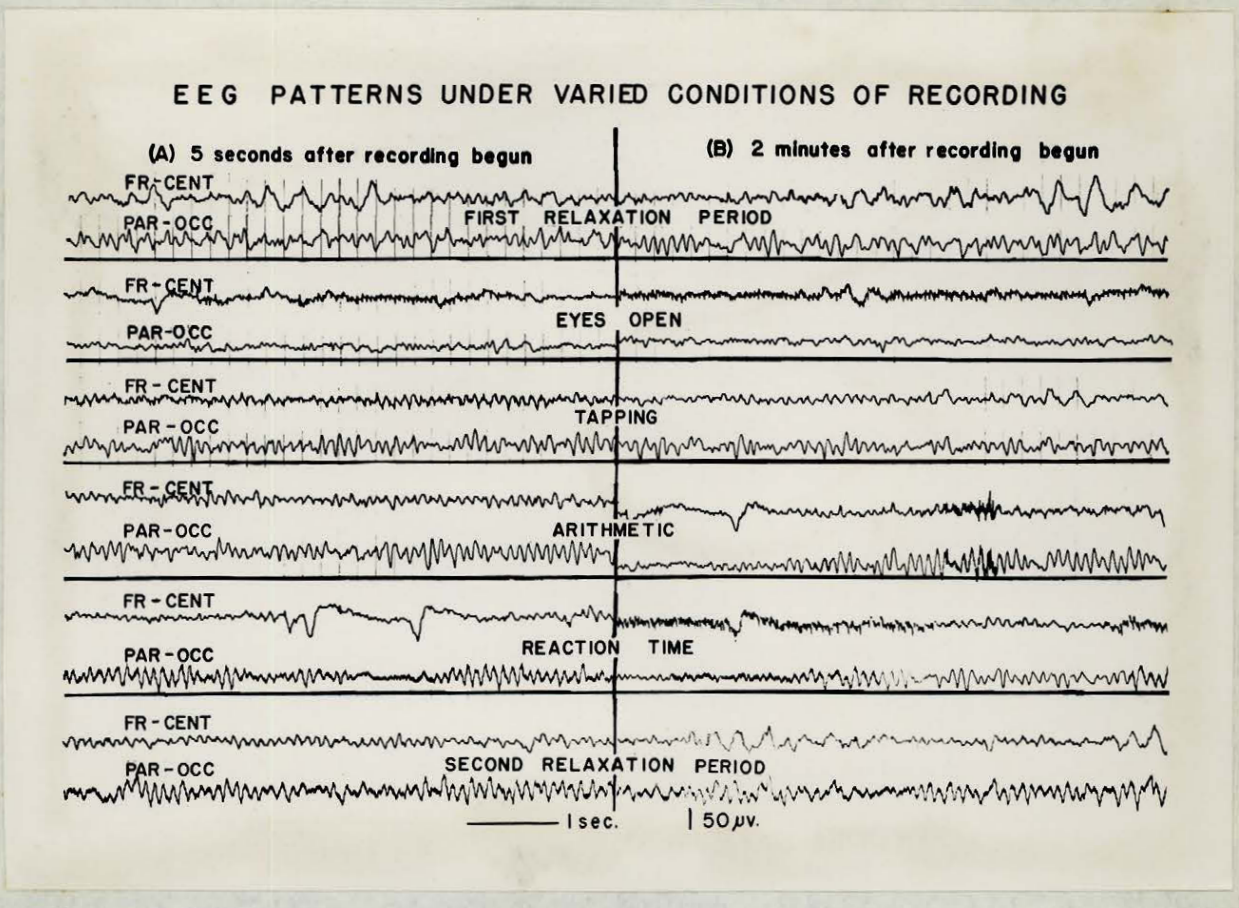

FIGURE 2

In order to obtain comparable records, samples were selected from the EEG of one subject at the same points in time for each of the recording conditions. The first samples were taken after five seconds of recording (A), the second after two minutes of recording (B).

The effect on the EEG of the tasks used in this experiment constitute the main source of evidence that stimulation reduces abnormality. Additional evidence of this effect was provided by other stimulating events occurring fortuitously during the recording. For example, it was observed that the effort to inhibit sneezing produced a prolonged and complete suppression of slow waves (Fig. 3,E). Parts A, B and D in figure 3 illustrate the effect of other spontaneous activities, or endogenous stimuli, in reducing abnormality. Unfortunately, the arrows marking the beginning of overt activity (A,D) are accurate only within one-half second; it would be of interest to know more precisely the time relation between the beginning of the motor activity and the disappearance of the abnormality. However, parts C and E of figure 3 suggest, respectively, that neither an external sensory input nor an overt motor act are essential determinants of a prolonged suppression of abnormality. Another example indicating that the thought process is important in decreasing the abnormality was the observation, in one record, that a sudden, frightening noise produced a very marked decrease in abnormality for several minutes.

Differential effects of the tasks. A more reliable source of evidence that the reduction in abnormality is not simply related to the amount of external stimulation or motor activity, is the order of effectiveness of the different tasks in suppressing the slow waves. The effectiveness of the various methods decreased significantly in the following order - (1) arithmetic and reaction time, (2) eyes open, and (3) tapping (Table 1). The

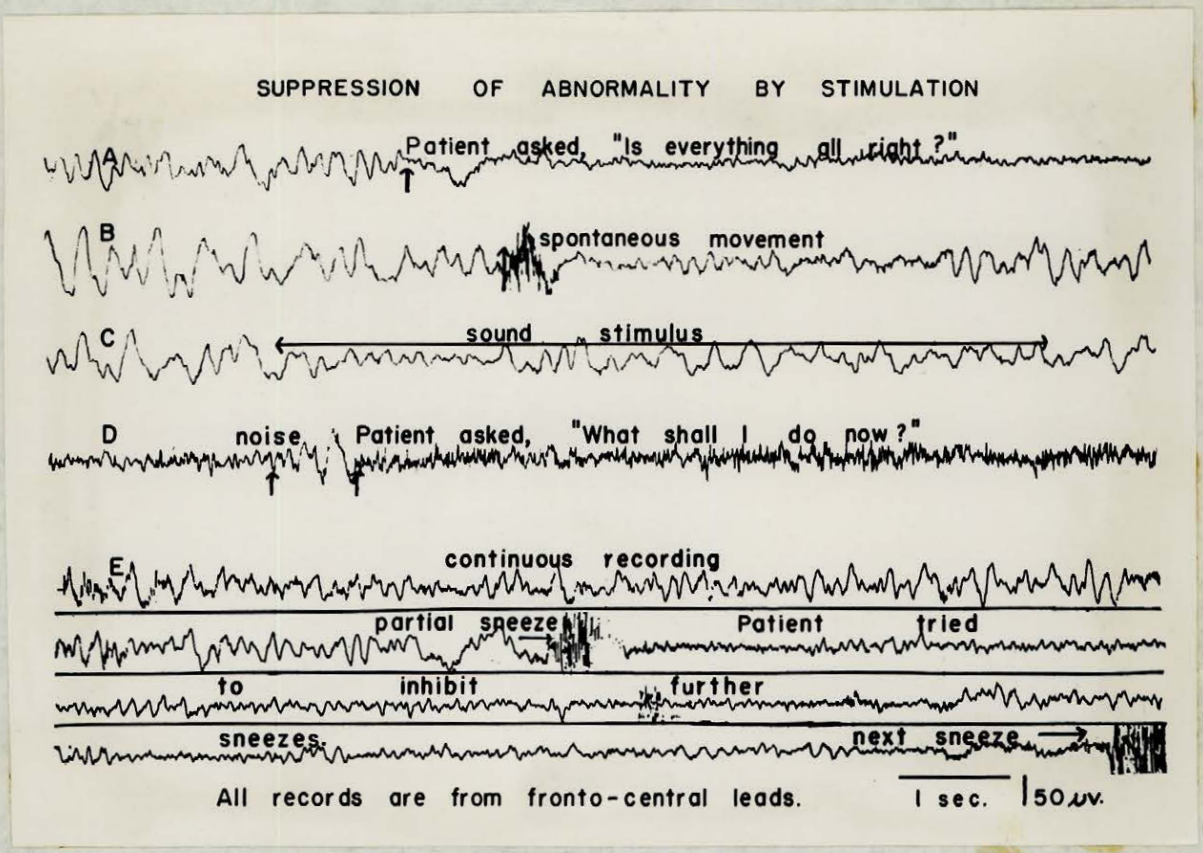

FIGURE 3

B - Spontaneous movements were frequently associated with a diminution in abnormality.

C - Note the adaptation to the stimulus.

D - The patient's question was response to the noise, and appeared to interrupt a burst of slow waves. However, it may be that the abnormal burst spontaneously terminated itself, and that the patient could ask her question only after this had occurred.

E - After the second sneeze at the end of the fourth line, the patient volunteered the information that she had been trying to stop this sneeze, but finally could no longer control it.

amount of motor and sensory stimulation involved in each of the tasks clearly does not follow this order. The arithmetic task provided the least sensory stimulation and motor activity since the patient gave a response, aloud, once every four seconds. Reaction time provided auditory and motor stimuli for two out of every four seconds; eyes open provided a persistent source of visual stimuli; tapping provided auditory and motor stimuli from taps at the rate of almost three per second.

Tapping has more of an effect on the abnormality than is apparent at first glance, although this effect is somewhat paradoxical. During the total four minutes, half the group increased in abnormality, and half the group decreased. Although these sub-groups did not differ from each other with respect to age, number of treatments, or lapse of time between the last treatment and the EEG recording, they did differ in amount of abnormality. The units of abnormality shown by the group that decreased during tapping were 361 and 278 during the first relaxation and tapping periods respectively. The same measures for the group that increased during tapping were 50 and 78 units. Thus the direction of change during tapping appeared to be related to the amount of abnormality initially shown in the first relaxation period. Seventy per cent of the records with less than 160 units of abnormity during the first relaxation period increased in abnormality during tapping, whereas every one of the seven records with greater than 160 units of abnormality decreased. Using chi-square with Yates' correction, this difference is significant beyond the .01 level.

It can be seen from figure 4 that there probably was a cumulative decrease in abnormality over the total series of recording conditions. Since all the methods of stimulation were used in the same order, it may be thought that the effectiveness of arithmetic and reaction time in reducing abnormality was due to their position in the sequence of recording conditions rather than to the properties of the tasks themselves. However, two sets of facts suggest that this was not so. First, if the observed effect of arithmetic and reaction time were simply a cumulative one, tapping should have had a greater effect than it did. Though tapping was the second stimulation, it did not decrease abnormality as much as either the preceding or the following stimulation. Secondly, figure 4 shows that the abnormality increased during each of the one-minute relaxation periods that followed the periods of activity. Thus, the level of abnormality, decreased by each task, had returned to approximately the pre-stimulation level before the next task was begun. Although there is a consistent decline in abnormality during the relaxation periods, the amount of abnormality during the first relaxation period is not significantly greater than any of the other relaxation periods.

The only task that produced a significantly prolonged inhibition of abnormality was reaction time, the last in the series of stimulating conditions. The amount of abnormality present during the first minute of relaxation after reaction time was less than that appearing during the first minutes of relaxation after tapping, and after arithmetic. These differences

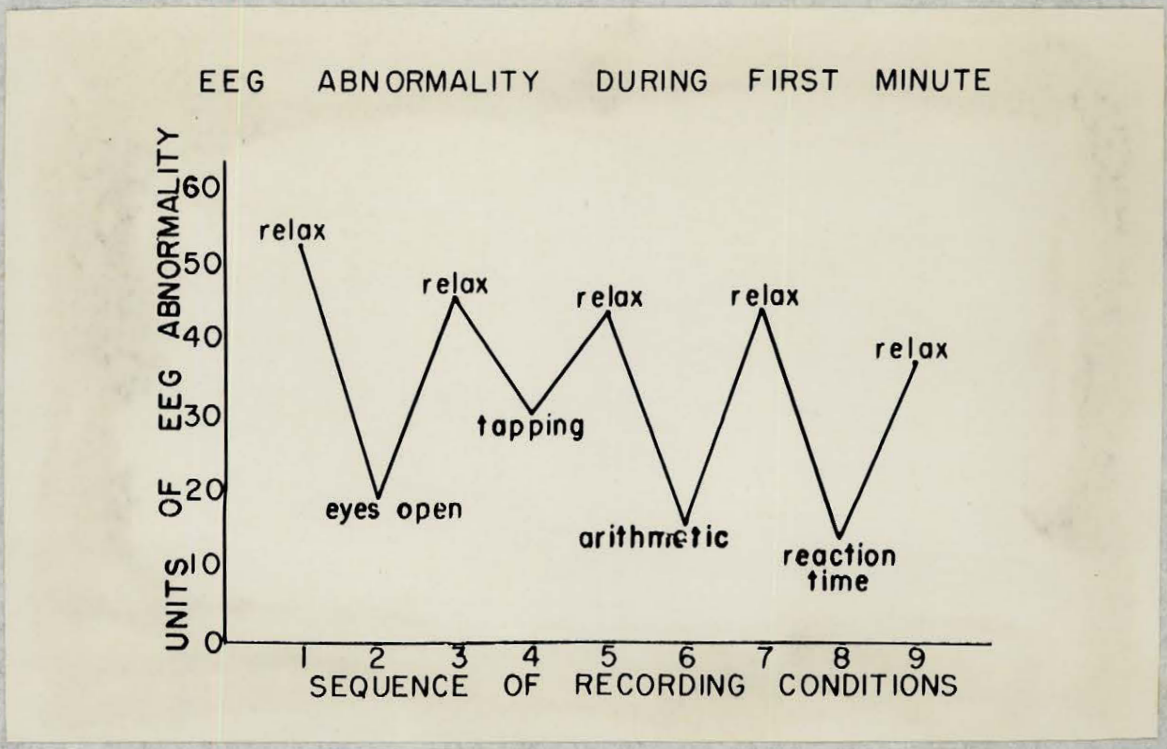
EEG ABNORMALITY DURING FIRST MINUTE
UNITS OF EEG ABNORMALITY
0
10
20
30
40
50
60
relax
eyes open
relax
tapping
relax
arithmetic
relax
reaction time
relax
1 2 3 4 5 6 7 8 9
SEQUENCE OF RECORDING CONDITIONS

FIGURE 4

are significant at the .05 level. The effect of reaction time in producing a more sustained decrease in abnormality than arithmetic and tapping may not be due to the quality of the stimulation itself, but to the fact that the reaction time task continued for six minutes whereas the other tasks lasted for only four minutes.

Although the various methods of stimulation do appear to have a differential effect on the amount of abnormality, this difference is least marked during the first minute of recording (Table 1A). However, all the tasks have their most marked effect on the abnormality at the beginning since the amount of slow waves appears to increase with time (Fig. 5). Thus the distinction between the various tasks seems to be in the extent to which they can maintain the low level of abnormality initially induced by a wide variety of stimuli.

Change in abnormality with time. Let us consider the change in abnormality with time since this characteristic of the EEG pattern after electroshock has not been previously described. An attempt was made to investigate this phenomenon by recording continuously for 30 minutes. However, it was found that it was difficult to maintain a state of relaxation in the subjects for this length of time. Noises around the laboratory changed the degree of alertness and the level of abnormality; the patients themselves interrupted the procedure to ask questions, which activity again changed the EEG picture. Another change in level of activity was that produced by the tendency on the part of

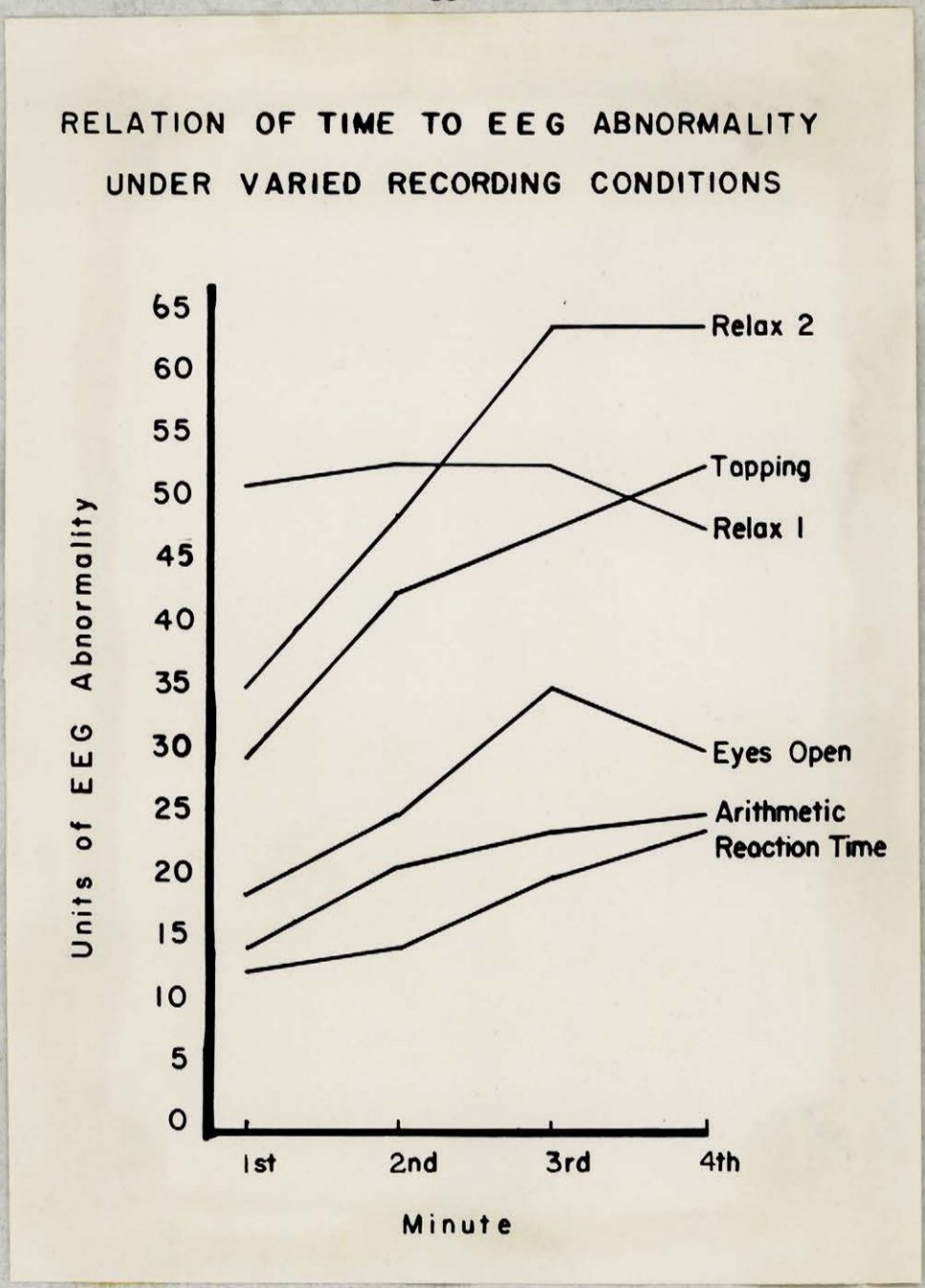
RELATION OF TIME TO EEG ABNORMALITY
UNDER VARIED RECORDING CONDITIONS
Units of EEG Abnormality
65
60
55
50
45
40
35
30
25
20
15
10
5
0
Relax 2
Tapping
Relax I
Eyes Open
Arithmetic
Reaction Time
1st
2nd
3rd
4th
Minute

FIGURE 5

most patients to oscillate between periods of wakefulness and what appeared to be light sleep. During these latter periods, the abnormality diminished; slight noises could produce greater wakefulness, and frequently a burst of slow waves.

In general, it was observed that the amount of abnormality increased, and then decreased, as the subject passed from a state of alertness to early sleep. Some of the specific patterns of change are shown in table 2. The results with patients A, B and C suggest that more abnormality is found during an uninterrupted period of wakefulness at the end of a half-hour recording than during a similar wakeful period at the beginning of the recording. Patients D, E, and F showed increases and then declines in the amount of abnormality with time; patient G showed an oscillating decline from the beginning of the recording. In patients D, E, and F, the consecutive periods during which abnormality was calculated were interrupted by an external stimulus, in the case of patient G, by the patient herself.

Figures 6, 7 and 8 illustrate decreases in abnormality concomitant with a flattening of the alpha, suggesting that these were periods of light sleep. It is often difficult to differentiate the EEG flattening of early sleep from the flattening of an arousal or activation pattern. However, figure 7 clearly shows that the flattening is associated with a brief "loss of consciousness", since the patient stopped tapping during the flat periods, and spontaneously resumed the task with the return of alpha and frontal abnormality. The record in figure 8 showed

TABLE 2

Changes in amount of abnormality with continuous recording

Patient	Units of abnormality during consecutive minutes																
A	0	0	0	5	.....	6	4	3	4								
B	0	3	0	4	.....	9	0	4	7								
C	19	26	18	53	.....	32	59	69	46								
D	28	53	50	38	70	59	29	22									
E	49	74	87	124	126	99	97	127	.....	35	34	17	42	65	24	31	27
F	294	351	339	330	330	333	357	354	.....	278	150	185	150	152			
G	49	38	35	41	29	20	37										

The dotted sections refer to a 20 to 30 minute period for which no measurements of abnormality were made.

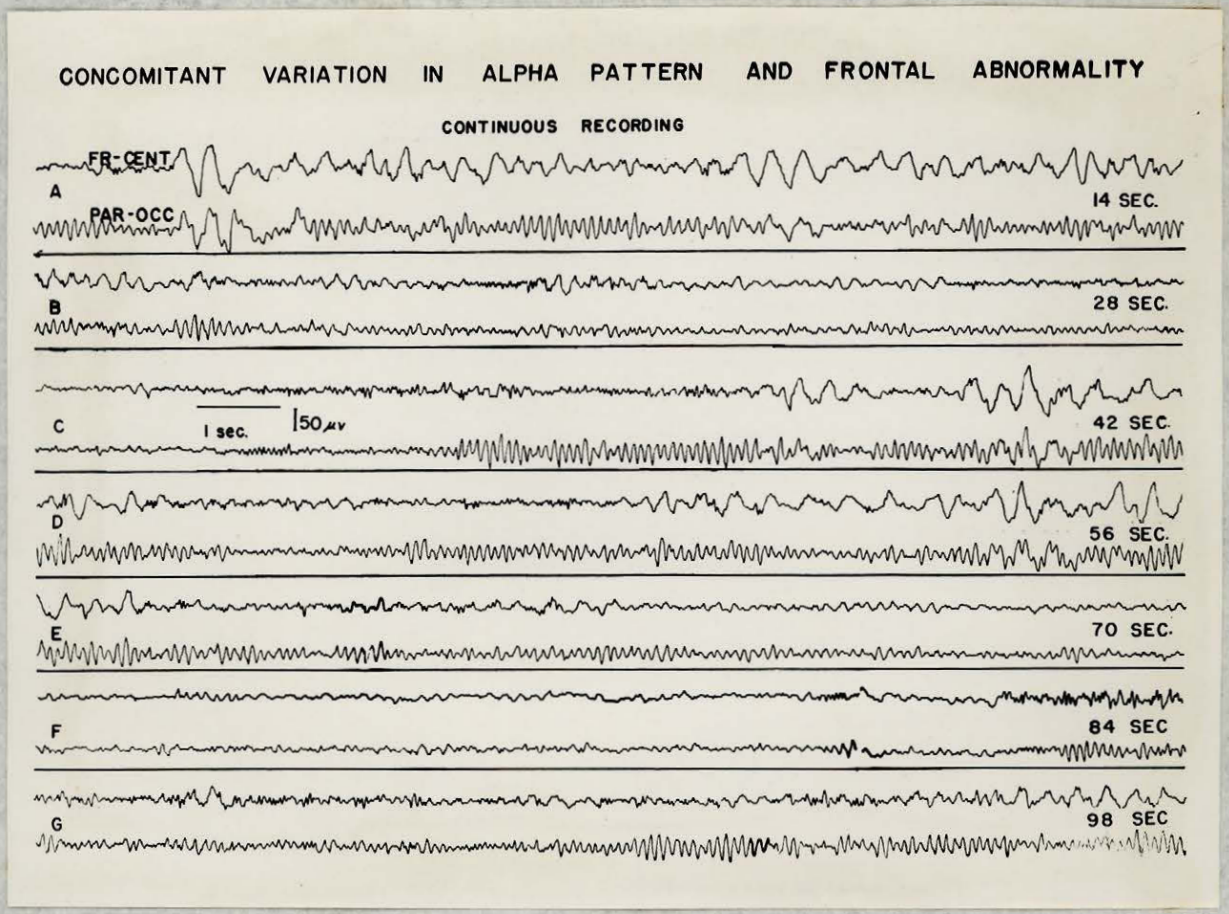
CONCOMITANT VARIATION IN ALPHA PATTERN AND FRONTAL ABNORMALITY
CONTINUOUS RECORDING
FR-CENT
PAR-OCC
A
14 SEC.
B
28 SEC.
C
1 sec.
50 μv
42 SEC.
D
56 SEC.
E
70 SEC.
F
84 SEC
G
98 SEC

FIGURE 6

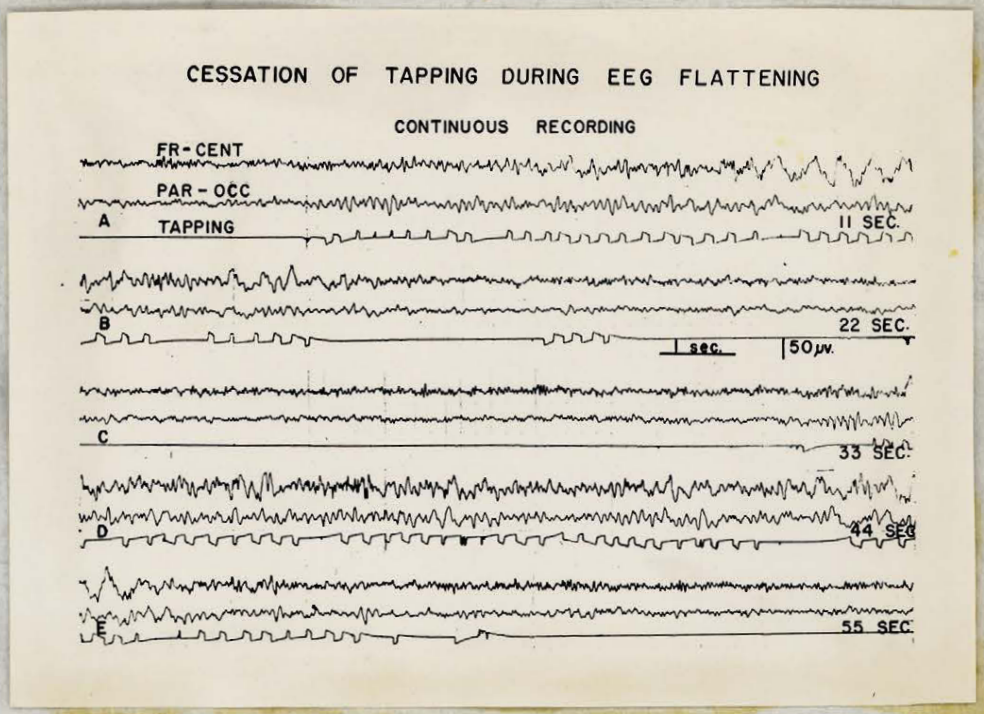
CESSATION OF TAPPING DURING EEG FLATTENING
CONTINUOUS RECORDING
FR-CENT
PAR-OCC
A
TAPPING
11 SEC.
B
22 SEC.
sec.
50μv.
C
33 SEC.
D
44 SEC
E
55 SEC.

FIGURE 7

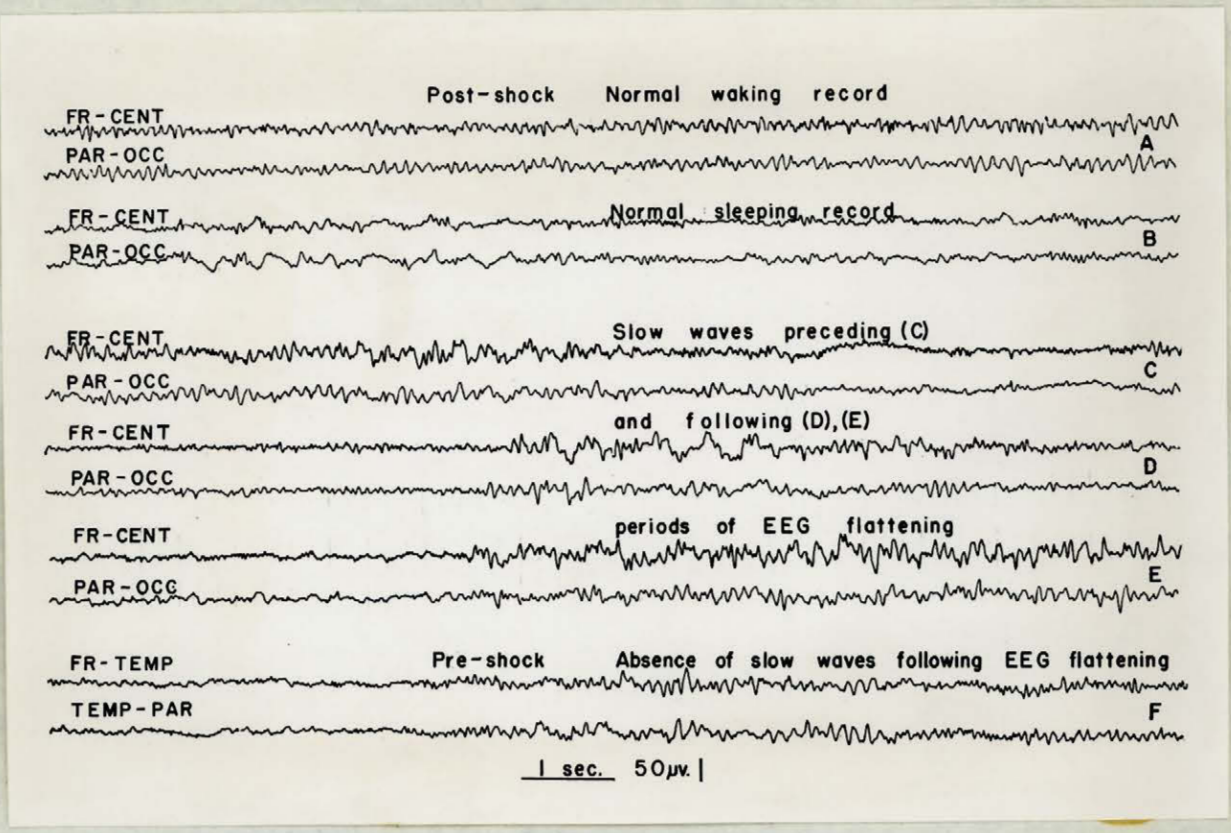

FIGURE 8

Sample F: FR-TEMP refers to placements F_3 and C_7 in figure 1.

TEMP-PAR refers to placements C_7 and P_3 in figure 1.

irregular bursts of slow waves only before, and after, periods of light sleep. This pattern seems to exemplify, in the extreme, the general finding that slow waves were most prominent under conditions of maximal relaxation, and then decreased again as relaxation merged into sleep.

Additional observations on the effects of stimulation. During the relaxation periods in which no abnormality was present, it was noted that frequently a noise would produce a brief inhibition of alpha, followed by a return of alpha and a burst of frontal abnormality. Abnormality appearing a few seconds after the stimulus is referred to as the delayed response in figure 9. The appearance of this delayed response was noted in approximately half the records. In the previous discussion of a similar effect reported by other workers, it was pointed out that the burst of slow waves following stimulation may indicate the return of a relaxed state after the arousal response to the stimulus itself is over. The fact that the reappearance of the alpha coincides with, or frequently precedes, the burst of slow waves is consistent with this interpretation. In a few records, a somewhat different effect was observed; a burst of abnormality followed almost immediately after the stimulus. Although the delayed and immediate responses have not been investigated systematically, these observations seemed worthy of report as phenomena meriting further study.

Observation have also been made that suggest that the effect of stimulation in suppressing or eliciting slow waves is not limited to the abnormality occurring after electroshock. Figures

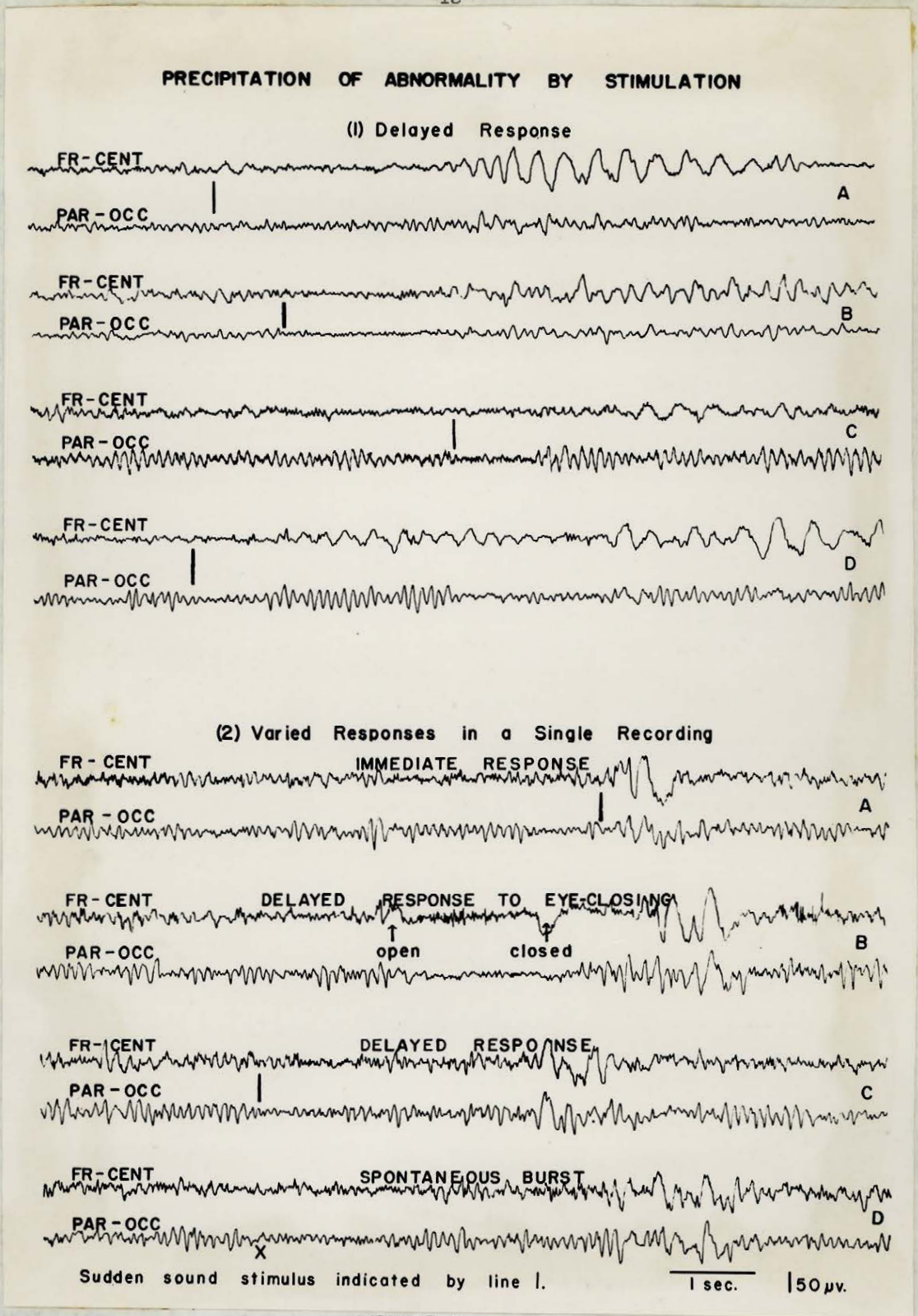

FIGURE 9

In the delayed response to stimulation, the EEG seems to follow a pattern of suppression of the alpha by the stimulus, then a return of alpha followed by a burst of fronto-central abnormality. Note the similarity to this sequence of events in the case of an apparently spontaneous burst in (2) D, starting at the point marked X.

10 and 11 illustrate the results of stimulation observed in some records of psychiatric patients with abnormal EEG's. Again, these data are not presented as proof that stimulation affects the slow wave pattern, but merely as observations suggesting other areas for investigation with the present procedure of recording under conditions of activity.

Alpha changes. The arithmetic and reaction time tasks appeared to produce a more marked inhibition of parieto-occipital alpha in the pre-electroshock group than the post-shock group. The amount of alpha was less during arithmetic and reaction time than during relaxation in 81 per cent of the subjects in the pre-shock group. This change is significantly different from chance at the .05 level, and is consistent with the reports in the literature that arithmetic decreases the amount of alpha. In the post-shock group, 55 percent decreased during arithmetic and 68 per cent during reaction time; neither of these changes is significantly different from chance. It might be suggested that increases in amount of alpha in the post-shock group occurred as part of the "normalizing" effect of stimulation, with which this study has been concerned. However, a consistent relationship between amount of alpha and amount of abnormality was not found.

While the pre- and post-shock groups do appear to differ in the extent to which the alpha is decreased during activity, the results must be interpreted cautiously since these groups do not differ significantly from each other. If the data from the two groups are combined, on the assumption that they are drawn

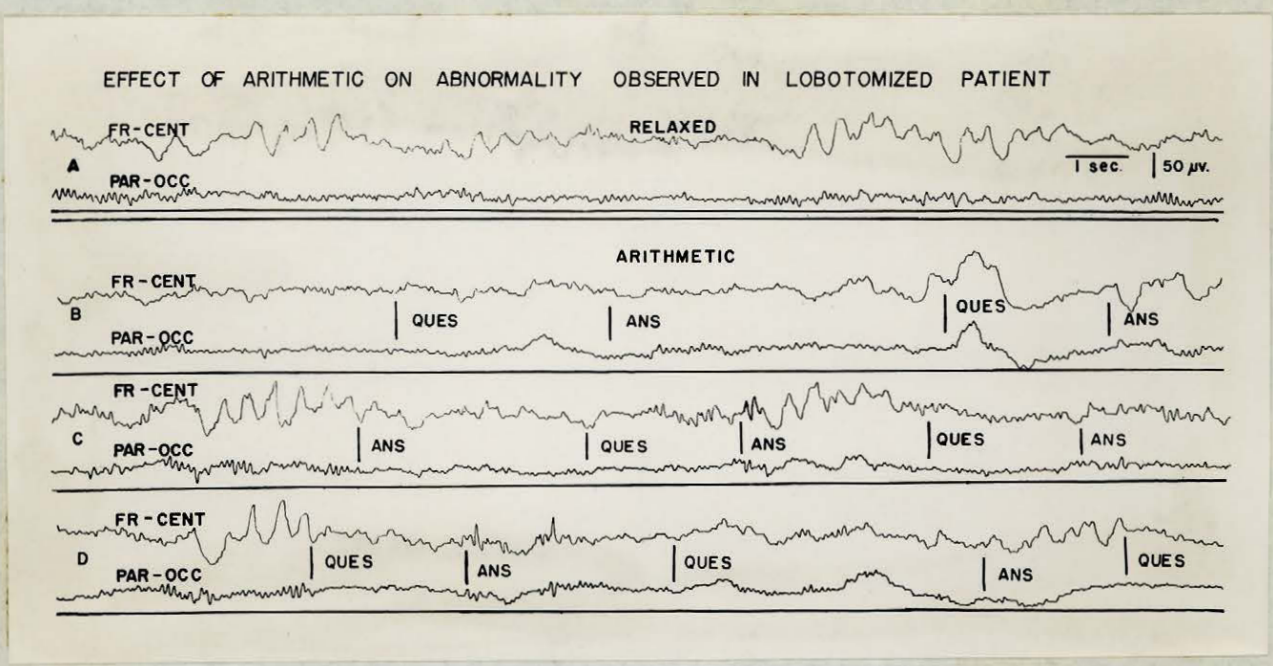

FIGURE 10

Individual arithmetic problems were given to the patient; the beginning of each problem is marked QUES., the end is marked ANS. In line D, note the apparent interruption of abnormal bursts by the presentation of a problem.

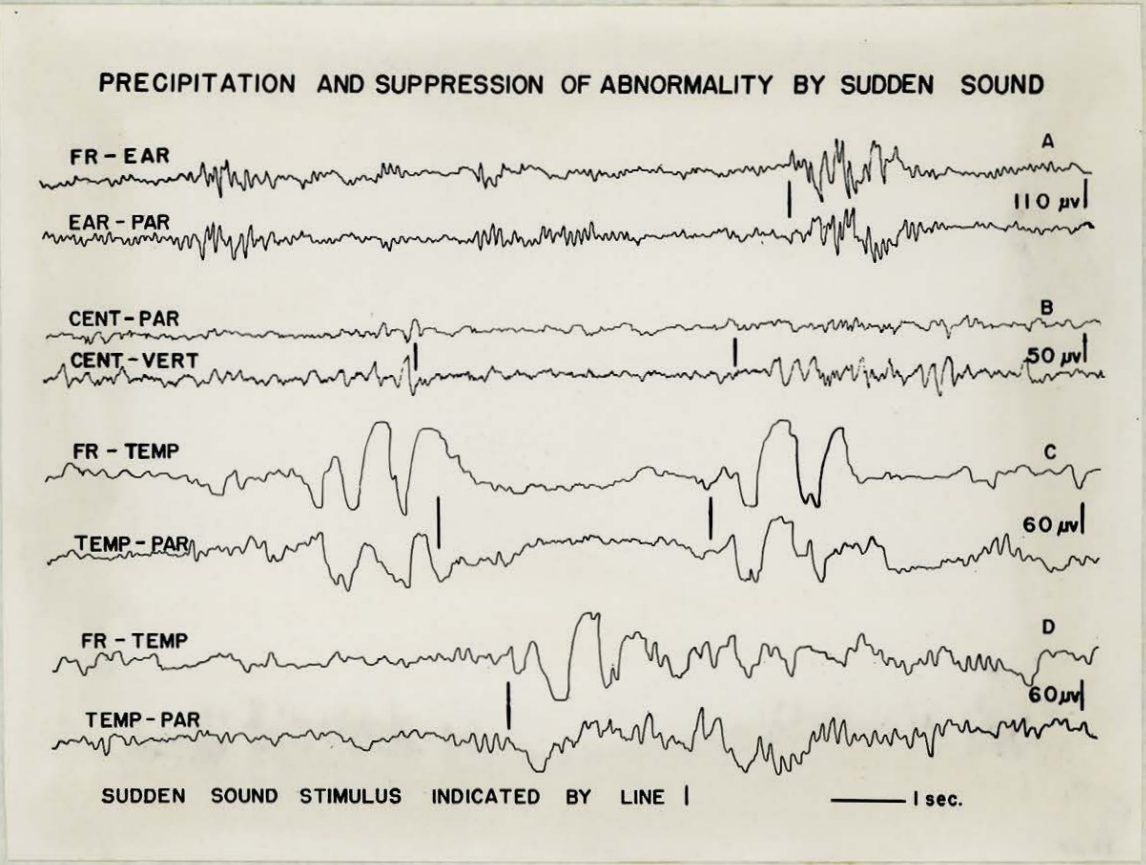

FIGURE 11

A - Precipitation of an abnormal burst. This patient was a 28-year-old woman diagnosed as a chronic anxiety state.

B - Suppression and precipitation of abnormality. This patient was a 25-year-old woman with a differential diagnosis of anxiety depression or idiopathic epilepsy.

CENT-PAR refers to placements C_3 and P_3 in figure 1.

CENT-VERT refers to placements C_3 and C midline in figure 1.

C and D - Suppression and precipitation of abnormal bursts. This patient was a 17-year-old girl diagnosed as a behavior problem.

from the same population, the percentage of decreases in alpha during activity is not different from that expected by chance. The reports in the literature, however, consistently lead one to expect a significant decrease with tasks such as arithmetic. Thus the data suggest two possible interpretations. Either the whole psychiatric population differs from a normal group, or the pre-shock group is not different from the normal population, but is different from the post-shock group. (A third possibility, of course, is that these particular samples were not representative of the general populations.) A more sensitive measure than that used here for evaluating the difference between the groups would be a comparison of the means of groups matched for the amount of alpha present during relaxation. This method could not be used with the data obtained in this experiment because the amount of alpha present during relaxation was greater in the post-shock group than in the pre-shock group.

Task performance. The last point for consideration is the relation of the performance on the various tasks to the EEG measurements. Despite the consistent increases in abnormality during the four minute recording periods, there were no significant changes in the performance of the tapping and reaction time tests. Since the arithmetic problems tended to increase in difficulty throughout the task, the performance at different points in time could not be compared. There was also no difference in the tapping behaviour between those records that increased, and those that decreased, in abnormality during the tapping period.

The reaction time test provided an excellent opportunity for evaluating the time relation between bursts of slow waves and periods of stimulation and relaxation, but a quantitative analysis of this material has not yet been done. However, inspection of the records suggests that abnormality appeared most frequently during the intervals between a response and the next stimulus (Fig. 12). It is interesting to note that a discernible latency often appeared between the sounding of the stimulus and the suppression of the abnormality (Fig. 12).

When the pre-shock group is compared with the post-shock group, no difference is found in the performance on the arithmetic or reaction time tasks. In the tapping test, however, the control group tapped at a rate of 58±7 times in 30 seconds, the shocked group at a rate of 83±9 times in 30 seconds. This difference is significant at the .05 level.

In those patients for whom more than one post-shock EEG was available, the task behavior was considered in relation to the increased abnormality. There was a tendency for the tapping rate to rise with greater abnormality, but the groups were small and the difference was not significant. With the arithmetic, there was a tendency for the time and errors to increase with greater abnormality, but again this difference was not statistically significant.

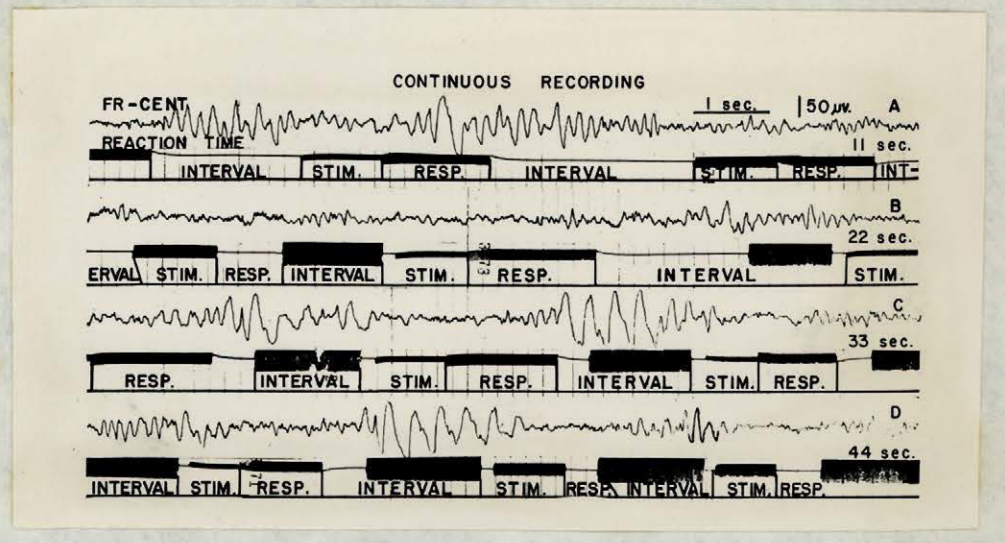

FIGURE 12

The abnormality may overlap the stimulus (the second stimulus in C, the three stimuli in D), but does not appear to overlap the beginning of the response.

It is interesting to note that the most prolonged period during which abnormality was absent occurred after the last response in line A, the only incorrect response in this particular section of record.

DISCUSSION

Some simple techniques have been described with which to investigate the effects of thought processes on abnormal slow waves in a systematic and quantitative manner. The results have clearly shown that the slow waves appearing after electroshock can be inhibited by thought processes; the extent of this effect appeared to depend on the complexity of the conceptual activity. These findings have implications for an understanding of the neural changes produced by electroshock, and the physiological basis of thought processes.

The discussion will deal with an elaboration of the following two points. First, the fact that the amount of slow waves is related to the level of alertness suggests that electroshock produces a disturbance in the neural systems maintaining the normal state of wakefulness. Secondly, the results indicate that there is an incompatibility between thought processes and slow waves. As the study of the effects of varied activities on the normal EEG has also shown, conceptual activity tends to be associated with an asynchronous firing of cells.

EEG changes following electroshock. Before discussing the neural changes produced by electroshock, some of the EEG findings associated with electroshock

Relationship between slow waves and state of excitation

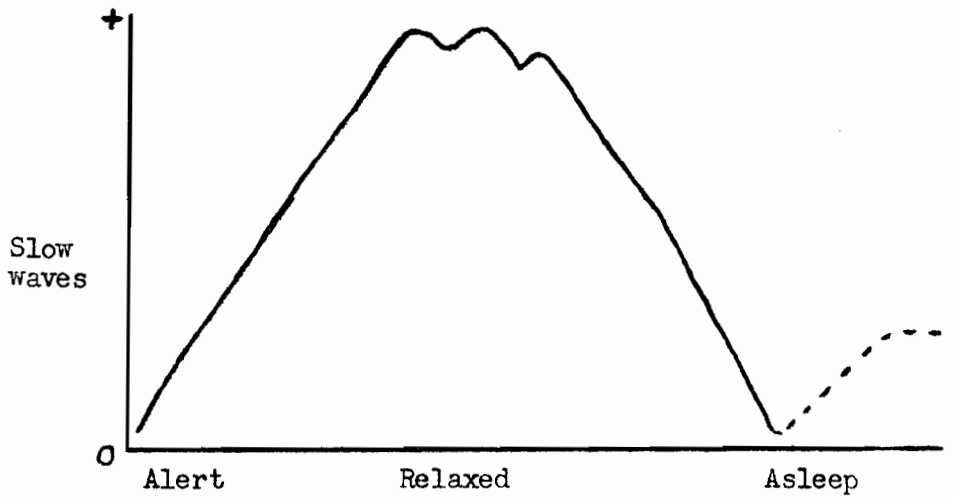

FIGURE 13

—— abnormal slow waves

- - - slow waves occurring in sleep

will be considered in greater detail. The results previously reported on the relation of abnormality to the state of alertness can be summarized by the hypothetical curve of figure 13. This relationship is consistent with the finding that benzedrine increases alertness and decreases slow waves (47), and that barbiturates increase slow waves just prior to the first signs of sleep (73). The finding that the abnormality decreases with a state of extreme relaxation may be helpful in understanding (1) the EEG findings with intensive electroshock, and (2) some of the more detailed results of this experiment.

(1) Callaway (13) reported that the amount of slow waves increased during the first few days of intensive electroshock, and then decreased, at which time the patients frequently appeared sleepy and inactive. After treatment was stopped, there was a transient increase in slow waves before the EEG gradually returned to normal. If the EEG "flatness" at the end of the course of treatment is related to an extremely relaxed, stuporous state, then it would be expected that the first sign of increased alertness and recovery would be the increase in slow waves observed by Callaway. This hypothesis could be tested by recording the EEG under conditions of relaxation and activity at the end of the course of intensive treatment. If the EEG is abnormally flat under conditions of relaxation, it is suggested that simple

activity (e.g., tapping) would increase the amount of slow waves.

(2) In the experiment reported here, the distribution of abnormality during the four minute recording periods was markedly different in the first and second relaxation periods (Fig. 5). During the first relaxation period, the amount of abnormality was the same during each of the four minutes. During the second relaxation period, the amount of abnormality increased strikingly from the first to the fourth minute. When the recording for the first relaxation period was begun, the spontaneous level of alertness was not controlled; that is, some patients were likely to have been very alert, and others rather relaxed. Thus the group as a whole would not be expected to show consistent changes with time, and the curve of abnormality for the four minute period would be rather flat. At the beginning of the second relaxation period, however, the subjects were all likely to be in a more similar state of alertness because of the previous performance of the various tasks. Hence the direction of change would be relatively uniform for the group as a whole, and the curve of abnormality for the four minute period would be expected to increase as the group passed from alertness to a more relaxed state.

Consider next the effects of tapping an abnormality. In the group with the greater amount of abnormality during

relaxation, tapping decreased the abnormality; in the other group, tapping increased the abnormality. In the latter group, the lesser amount of abnormality observed during the relaxation period may have been due to a stronger tendency on the part of these patients to shift quickly to the light sleep part of the curve. During the tapping task, however, the activity would have been adequate to prevent sleep, or at least shorten the periods of sleep, yet not sufficiently stimulating to maintain a state of alertness. Thus the amount of slow waves present during tapping would be greater than during relaxation.

Neural changes produced by electroshock. The results have clearly shown that the amount of EEG abnormality produced by electroshock is related to changes in the level of wakefulness. Much evidence is now available to indicate that the sleep-waking cycle is controlled by centres in the diencephalon and brain stem. Jasper and his co-workers (40) have suggested that the thalamic reticular system is concerned with the regulation of spontaneous waking cortical rhythms such as the alpha rhythm. There is some overlap of this system with the area from which sleep may be obtained by electrical stimulation (40). The work of Nauta (62) suggests that the anterior hypothalamus also constitutes part of the sleep system. The posterior part of the hypothalamus and the brain stem reticular formation clearly appear

to be concerned with the maintenance of a waking state (36, 54, 71). Lesions of these latter waking centres have produced behavioral evidence of somnolence, and slow waves in the EEG that can be inhibited by sensory stimulation (36, 54).

These electrographic effects appear to be analogous to those observed after electroshock. That is, intrinsic regulating processes were unable to maintain the normal state of wakefulness after electroshock; the EEG was characterized by an hypersynchrony that could be inhibited by stimulation. Thus, it may be suggested that the EEG slow waves occurring after electroshock are not directly due to a generalized, abnormal firing of cells as a result of injury or metabolic disturbance. Rather, the particular form of the EEG abnormality seems to depend on changes in the functional relationships of diencephalic and brain stem systems controlling spontaneous rhythms. This hypothesis is similar to that recently proposed by Roth and McClatchey (73), although certain objections were previously raised to some of the specific conclusions of these authors.

Until more information is available on the interrelations of the thalamic and brain stem reticular systems, the locus of the changes produced by electroshock cannot be precisely defined. It can only be suggested that the predominant change is a defect of the systems maintaining the normal state of wakefulness,

since apparently normal records can be obtained under conditions of extreme alertness and light sleep. This conclusion is consistent with clinical and physiological studies indicating that the hypothalamus and other subcortical centres are affected by electroshock (20, 25).

Although the systems controlling the normal state of wakefulness appear to be disturbed in all the patients studied, the results obtained during tapping suggest that, in some patients, the sleep centre has become dominant over the waking centre. It was previously pointed out that the effect of tapping in decreasing abnormality in the one group, and increasing abnormality in the other group, was related to the amount of slow waves shown during the period of relaxation. Since the number of treatments and age distribution was the same in both groups, it was suggested that the lesser abnormality shown by one group may have been due to the fact that these patients reached a state of extreme relaxation (early sleep) more quickly than the patients of the other group. That is, the recording procedure used in this experiment may have distinguished two types of reaction to electroshock. In one group, electroshock may have shifted the balance between waking and sleeping centres so that the sleep centre assumed a relative dominance. In the other group, the activity of these centres may have been disturbed without any shift in the dominance. It is interesting to note that some workers

have reported that the clinical results appear to be better in those patients with less EEG abnormality (34, 69); other writers have commented that electroshock is most effective in those patients with sleep disturbances (57, 74). The tentative hypothesis can be made, then, that a better clinical result is obtained in those patients in whom electroshock produces a dominance of sleep centres over waking centres.

Pattern of firing associated with thought processes. Assuming, now, that the waking system does not function normally after electroshock, the problem arises of how the activation pattern[x] associated with thought processes can be produced. There are two possibilities. First, the arrival of afferent impuleses at the cortex may itself produce an activation pattern. Secondly, Lindsley and his colleagues have suggested that "It seems more likely that such activation develops upon arrival of afferent impulses at the thalamus....." (54, p. 497).

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[x] Some liberty is being taken with the use of the word, "activation pattern". This term is usually meant to refer to a waking pattern of low voltage, high frequency waves. In this discussion, the term is used to refer to a relative activation, that is, the replacement of high voltage, slow waves by either a low voltage, high frequency wave-pattern, or an alpha rhythm.

This latter possibility seems more consistent with the fact that a discernible latency appeared between the stimulus and the appearance of the desynchronized activation pattern in the records observed in this investigation, and is also evident in some of the illustrations of Lindsley, Magoun, and their co-workers (54, 60). This latency, comparable to that of the normal arousal reaction observed in the blocking of the alpha to stimulation, is longer than that to be expected if the stimulus arriving at the cortex produced the asynchrony.

In discussing the mechanism for arousal after electroshock, it is not necessary to assume that the centre for activation is above the rostral end of the brain stem since it is unlikely that electroshock exerts an effect similar to the cutting of pathways as in the experiments of Lindsley et al. It may be that electroshock causes a change in the spontaneous discharge of the brain stem reticular system, which can, however, be aroused to a more normal state of activity by stimulation. The main point to be noted is that the initial arousal, at least, is more likely to be caused by the stimulus acting through a diffuse projection system than through the specialized sensory projection systems. (This diffuse system will simply be referred to as the reticular system without any distinction between thalamic and brain stem components.)

Once the activation pattern has appeared, the length of time for which it is maintained varies with different

thought processes. It is possible that the characteristics of the afferent stimuli first arousing the reticular formation can excite this system to varying degrees, although it is difficult to see how stimuli varying in quality rather than intensity could exert such an effect. At any rate, there is no evidence yet available that could demonstrate such an effect, since the single stimuli used in this investigation, or those used by other workers, have usually lasted long enough to overlap the appearance of an arousal reaction.

The more relevant problem for this experiment is a consideration of how more prolonged activity can exert a differential effect on the maintenance of the state of arousal. The relative effectiveness of the tasks used in this experiment suggest that it is the complexity of the thought processes or concepts that is related to the maintenance of the state of arousal. Tapping was a relatively simple, monotonous task, with repetitive auditory stimulation. Eyes open provided a small range of different visual stimuli; these stimuli might be considered to be particularly effective in arousing conceptual activity because of the primary role that vision plays in the activity of the human organism. Arithmetic and reaction time were problem-solving tasks.

The presence of a thought process presumably involves the firing of a certain number of cells. If it is assumed that the more complicated this process, the more cells it controls, then the number of cells available for synchronous

firing would be inversely related to the complexity of the task. That is, less abnormal slow waves would exist with greater conceptual activity.

Since the timing involved in the maintenance of this thinking process would be very delicate, it is suggested that a relatively constant background of facilitation from the reticular system is necessary to enable the thought sequence to persist for any length of time. The state of excitation of the reticular system may depend on the downward flow of impulses from the cortex; thus, the complexity of the thought process could also control the degree of facilitation provided by the reticular system. The mechanism for the inhibition of slow waves, then, can be considered as one of mutual facilitation between waking centres and the pattern of cortical firing, with the diffuse projection systems providing the initial arousal that may be the only condition under which the thought process can begin. In the task situation, this initial arousal was present before the actual performance began, since the explanation of the task to be done and the instructions to begin produced a state of alertness.

Now one may ask why the thought process is not associated with a constant amount of abnormality; that is, why do the slow waves increase with time? Hebb (29) has suggested that certain changes occur in the neural organization of a thought sequence with time. Practice or performance of a task may so strengthen some connections

that less fibres are then necessary for the arousal of the particular concept. In a larger thought sequence, practice would allow the sequence to run off with the actual omission of some groups of cells originally necessary for its establishment. This process, affecting both single concepts and more complicated thought sequences, would thus leave more cells available for synchronous firing as the performance continued. Consistent with this hypothesis is the fact that there was no decrement in the actual performance of the tasks with time. If the activity were continued for a longer time and the abnormality increased, however, it may be that at some point the performance would change, or the abnormality would decrease or remain more constant. A similar kind of process to that just described may also account for the fact that the performance of a strongly habituated task may continue through a petit mal attack (65).

Behavioral changes produced by electroshock. The EEG findings can also be related to some of the changes in behavior observed after electroshock. The EEG picture is one in which intrinsic regulating processes appear to be inadequate to maintain a normal state of wakefulness for any length of time; instead, an abnormal hypersynchrony develops. However, these abnormal slow waves appear to be incompatible with complex thinking processes and are associated with simple, or habitual, thought activity. Thus one may infer that, after electroshock, there is a paucity of thought content under conditions of relaxation

with a minimum of external stimuli. This would be consistent with the finding that both human patients and rats receiving electroshock are frequently lethargic and show a decrease in spontaneous activity (43). There is also the interesting case report (58) of a patient, blinded as an adult, who experienced an intolerable sense of emtiness and a loss of the capacity to control his attention voluntarily while receiving electroshock. This symptom was relieved by external stimulation, such as other people's talking to him, touching his hands, and so on. The authors state that this phenomenon is sometimes found in the non-blinded, but in an abortive form, since vision continually stimulates the stream of thought.

The difference in amount of abnormality present under conditions of spontaneous relaxation and under conditions of external stimulation may have other parallels in behavior. Kalinowsky and Hoch (43) have pointed out that the procedure of testing the memory defect after electroshock has revealed less loss than would be expected from clinical observation of patients during their spontaneous activities. Janis (37) has made the interesting observation that some patients report that they can recall events if they <u>try</u> hard enough. Masserman and Jacques (56) noted a loss of efficiency in problem-solving tasks in cats subjected to electroshock, but found that more adaptive behavior appeared under conditions of strong motivation. If

the degree of motivation is considered to refer to the persistence of firing of a particular pattern of cells, then it may be that a strong motivation simply maintains a normal background of cell activity for a long enough period of time so that complex, adaptive behavior is more likely to occur.

The effect of stimulation in decreasing abnormality is most marked at the beginning; the slow waves tend to increase as a repetitive activity is continued. This increase in hypersynchrony with time may provide an explanation for the apparently discrepant effects of electroshock (66, 70) and frontal lobotomy in easing persistent pain, and yet not changing the response to brief, painful stimuli (14). If the decreased reaction to pain is dependent on an hypersynchrony, then a reaction of pain would be produced upon the initial presentation of a noxious stimulus, but would change as stimulation persisted, and the slow waves returned.

The fact that the thought process controls less of the cortical firing with time may also be related to the phenomenon of distractibility and the decreased capacity to maintain a set found after electroshock (38). Distractibility may simply refer to the lack of a prolonged control of cortical firing by a thought process, and the consequent return of a hypersynchrony. This is precisely the condition under which a new stimulus can assume control of cortical firing; that is, evoke an activation pattern, which would be equivalent to "catching

the attention" of the subject. The rapidity with which this cycle of events is repeated would be expected to vary with the degree of interest in, or difficulty of, the task. Pribram (67) has recently reported that lobotomized monkeys, who showed a decrease in the ability to maintain a set under normal testing conditions, improved in performance when tested under conditions that would contribute to the development of a strong motivation.

This discussion has suggested that some of the behavioral changes occuring after electroshock may be due to the fact that the thought process controls less of the cortical firing with time. The objection might be raised that this process is not peculiar to brain-injured patients, but occurs normally. For example, the alpha blocking to stimulation also "adapts" with repetition of the stimulus. However, the important difference is that the degree of hypersynchrony present in the normal case is much less than that present in the abnormal case. In the latter, both anterior and posterior regions participate in the hypersynchrony, whereas in most normal cases the anterior regions do not show a well-regulated rhythm. Also, the abnormal bursts of high voltage slow waves involve the control of larger groups of cells than those controlled by the faster, lower voltage alpha rhythm. Thus it is likely that more sustained conceptual activity could occur in the presence of a normal degree of hypersynchrony than could occur with an abnormal hypersynchrony.

SUMMARY AND CONCLUSIONS

This experiment has investigated the effects of various activities on the abnormal slow waves appearing after electroshock. The EEG was recorded under the standard conditions of relaxation with the eyes closed, and under the following conditions of activity: eyes open and relaxed, tapping with a metal stilette, doing serial arithmetic problems, and performing a complex reaction time task.

The amount of abnormality appearing under conditions of activity was significantly less than that occurring during relaxation. The extent to which the abnormality was inhibited varied with the different tasks. The effectiveness of the tasks in reducing the abnormality decreased in the following order: (1) arithmetic and reaction time, (2) eyes open, (3) tapping.

For any of the four minute periods of recording under one set of conditions, it was found that the amount of abnormality increased from the first to the fourth minute. With longer periods of continuous recording under conditions of relaxation, it was noted that the increase in abnormality tended to reach a peak, and then declined as the patient reached a state of early sleep.

The significance of these results can be briefly summarized. (1) First, some simple techniques have been described with which to investigate the effect of stimulation on EEG abnormality in a systematic, quantitative manner.

(2) The results suggest that the EEG abnormality occurring after electroshock is predominantly due to a disturbance of the waking systems in the diencephalon and brain stem. In addition, the tentative hypothesis is made that electroshock produces a relative dominance of sleeping centres over waking centres in some patients, and that this effect may be positively related to clinical recovery.

(3) Complex thinking processes appear to be incompatible with the abnormality occurring after electroshock, and it is suggested that this relationship also exists with other types of rhythmic, slow wave abnormality. The more complex the thought process, the greater the number of cells that appear to be involved in an asynchronous firing pattern.

(4) The results also suggest that the neural pattern (of a thought sequence) changes as a repetitive activity is continued; these changes are consistent with Hebb's hypothesis of the effects of practice on the organization of thought processes.

(5) Finally, it is concluded that the reticular systems of the thalamus and brain stem are important in the regulation of thinking processes, and may, as Jasper has suggested, be related to the phenomenon of "attention".

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