THE EEG, CONSCIOUSNESS, AND SLEEP

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Introduction

Since the discovery of brain waves, considerable effort has been spent in linking this physiological activity to its psychological correlates. After more than a quarter of a century of research, this hope has not been sufficiently realized. Although clinicians and neurologists have found the EEG useful as a diagnostic tool, its contribution to the psychologist working with normal individuals has been slight, (Darrow, 1947; Lindsley, 1952).

The consciousness and unconsciousness of a normal individual, however, have been related successfully to changes in the EEG (Gibbs and Gibbs, 1950; Brazier, 1951). Just what "consciousness" is is difficult to define. Boring (1933, p. 230) writes, "Learning has been considered rightly as the criterion of consciousness of the animal scale." Of course, learning implies awareness, discrimination, selectivity, and organization, and is reflected in the simplest cortically originated response. Lacking these attributes, the state called sleep is generally considered to be an unconscious one (Kleitman, 1929).

The present paper will relate specific EEG patterns along the continuum between waking and deep sleep with the ability to respond and remember, the criteria used as a measure of consciousness.

Materials and Methods

Twenty-one normal, adult male subjects were selected on the basis of I.Q. (average or above) and a monopolar, occipital EEG showing a continuous alpha rhythm when they were awake and resting with their eyes closed. These "alpha-dominant" subjects were used in order to differentiate EEG patterns
during the period between complete wakefulness and the first stages of sleep. Since relationships between alpha and both intellectual and personality characteristics of the subjects have never been satisfactorily established, these subjects were considered as representative of normal subjects. Furthermore, in earlier exploratory studies no significant differences were observed between performances of "alpha dominant" and "rare alpha" subjects when it could be tested.

Since the alpha rhythm associated with wakefulness is best recorded from the occipital region while the effects of stimulation during sleep can best be seen at the vertex and parietal regions (Davis, Davis, Loomis, Harvey, and Hobart, 1939), vertex and occipital placements were used.

EEG electrodes were applied to the right occiput, the vertex, and the left mastoid process before the subjects retired for the night. The electrode wires allowed relatively free movement during sleep, and subjects suffered no discomfort from this arrangement. Two monopolar EEG recordings (right occiput and vertex) were made from each subject using a six-channel Offner EEG. A pen mounted on the inkwriter automatically marked the exact time an auditory stimulus was presented to the subjects. Three subjects could be studied simultaneously as they slept in separate, sound-proof, air-conditioned, electrically shielded booths. No artificial means of inducing sleep were used. After being pretested before retiring to see if they knew the answers to 96 questions, subjects were permitted to sleep for eight hours. Each question and answer was played to the subjects only once at five-minute intervals throughout the sleep period. Subjects were instructed to report immediately if they heard an answer. On awakening the next morning, subjects were given the questions and asked to write the answers. EEG's were taken
continuously during the experimental session and scored independently by two readers before the verbal tests were scored. An analysis was made to determine the relation between the EEG record at the time the answer was played—an indication of the depth of sleep of the subject—and his responsiveness and ability to recall those test items not known previously. A more detailed account of the experimental procedure can be found elsewhere (Simon and Emmons, 1955).

**Scoring the EEG**

Several aspects of the scoring system which apply to this study should be mentioned.

First, the scoring was based on a finite length of record, i.e., the exact time the answer was being given. This period ranged from 2.4 to 7.2 seconds, with an average length of 4.7 seconds.

Second, the only case where sections of the record other than the answer period were considered was when the alpha rhythm appeared in the thirty seconds before or after but not during the answer.

Third, since the question preceded the answer period by approximately four or five seconds, scoring the answer period meant scoring a record where some lightening of sleep may have taken place during the presentation of the question.

Fourth, all scoring was done by eye; activity within the alpha band was sometimes ignored when of very low amplitude or irregular, and if less than three cycles were observed.

Fifth, all scoring was based primarily on the occipital pattern. The vertex provided supplementary information, such as the presence or absence of 14-cycle spindle activity, and aided in evaluating certain stimulus effects.
Sixth, when multiple cues lead to ambiguous scoring, the tendency was to assign the deeper of the alternative levels of sleep to the pattern.

Seventh, the results of the experiment are based on the initial scoring. However, the discussion of the EEG patterns may include material which was understood more clearly after subsequent analysis.

Alpha as an Index of Consciousness

The positive relation between alpha and consciousness has been noted by a number of investigators. Watson and Adams (1951) applied this knowledge clinically to detect consciousness in an almost totally paralyzed patient. Other studies (Loomis, Harvey, and Hobart, 1937; Blake, Gerard, and Kleitman, 1939) of the EEG and sleep have revealed additional relationships. Alpha tends to become intermittent as the subject becomes drowsy. If alpha is absent for a few seconds, a subject may report he has dozed. With a somewhat longer absence, a dream and its contents may be reported, although content may no longer be recalled if alpha is missing for slightly less than a minute.

Within a few seconds after alpha disappears, muscle tone diminishes to a point where the subject drops a spool; if the period after alpha disappears is much longer, he may not be aware that the spool has been dropped. Conversely, if alpha appeared for even a second during a "null state," subjects would report that they were conscious. In the present experiment, the period between wakefulness and sleep provided a means of studying the relationship between the quantity and quality of alpha and variations in consciousness.

Figure 1 shows sample EEG patterns from the right occiput along with

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Insert Figure 1 about here.
---
their corresponding measures of consciousness.*

*The total number of items used to compute the percentage recalled correctly was slightly less than the total number used to compute the percentage heard, since those items known on the pretest before training were not included in the former. Only the former are reported in all figures.

Consciousness was operationally defined by the ability of the subject to report immediately that he heard the answer to a question and by his ability to recall the answer during subsequent testing. The letters assigned to the sleep levels in Figure 1 correspond quite closely to those used by the Tuxedo Park group (Loomis, Harvey, and Hobart, 1937). Many patterns within these levels were observed; these will be discussed in the section of the paper on Stimulus Effects. Figure 1 illustrates that as the quality and quantity of alpha increases, so does the probability that a stimulus will be reported heard when it occurs and correctly recalled later.

Within Level 0, slight reduction in the amplitude of the continuous waking alpha both before and after sleep was related to a similar decrease in the probability that an appropriate response would be made.

Level A+ and A in this paper are artificial to the extent that they are based on the percentage of alpha or absence of alpha in specific lengths of record. If the length of the record had been shifted a second or two one way or the other, the pattern itself might have changed. Had several minutes of record been used, however, it is highly probable that the percentage of alpha in the entire length would no longer have been an adequate index. Since there is considerable variability from level to level throughout the night even within short periods of time (Loomis, Harvey, and Hobart, 1937;
Blake and Gerard, 1937), the present study suggests that if too long a record is taken, interpretative confusion can result from a combination of many consciousness levels. Averaging these levels hides information relating the EEG to consciousness that the analysis of the shorter records revealed.

Level A—combines a variety of EEG patterns. In this deep drowsy state, the waking alpha rhythm was no longer evident, yet signs of consciousness could be detected as long as cyclical activities within the alpha range (8 to 13 cps) were observed within the stimulus area or if alpha rhythms were observed within 30 seconds on either one side or the other of the stimulus period. The majority of these patterns will be discussed in the section on Stimulus Effects; only the slowed cyclical pattern will be discussed here. Less than one-fourth of the subjects showed continuous cyclical activity, approximately 2 cycles slower than their normal waking alpha rhythm. This, too, became interrupted by low-level, random activity and eventually delta waves. Approximately two-thirds of the subjects showed the interspersed "slow alpha" and random activity.

Some subjects failed to report while alpha was still present; whether or not this was a product of the subject's motivation and interest, it is difficult to say. However, when alpha had disappeared, no more reports or recalls occurred.

For the sake of completeness, the obvious should be emphasized. Lack of alpha does not guarantee lack of consciousness. It may disappear during excitement or when concentration takes place (Travis, 1937). Some examples of this kind of alpha depression will be discussed later in the section on Stimulus Effects. Furthermore, many normal individuals show little or no observable waking alpha rhythm. Therefore, we must conclude that although alpha may be used to identify consciousness, lack of consciousness, or
unconsciousness, must be identified in some other manner.

Delta as an Index of Unconsciousness

No learning or immediate responses to stimulation occurred below the
Level B (transition state) when delta was present.*

*Two items were reported heard and 3 other items answered correctly
out of a total of 508 test items in Levels C through E. In another
paper (Simon and Emmons, 1955), these are explained on the basis of
subjects' guessing habits, reminiscence, and questionable EEG
classifications and are not believed to be an indication of learning
during sleep.

Five representative EEG patterns during sleep are shown in Figure 2. Other

- - - - - - - - - -
Insert Figure 2 about here.
- - - - - - - - - -

patterns occurring during the sleep state will be discussed in the section on
Stimulus Effects. Although delta waves are larger at the vertex than at the
occiput, only occipital records are shown here since both were comparable in
form. Subjects were unconscious in all levels where delta activity pre-
dominated; they neither responded to nor recalled material presented when
these patterns were observed.**

**In another study (Emmons and Simon, 1956), between 19 and 82
repetitions of ten common one-syllable nouns were played when
subjects were in Levels B to E. The group could not pick these
from a list of 50 words any better than a control group could,
and no better than they themselves chose another untrained list
of ten nouns randomly chosen from the list of 50 nouns.
<table>
<thead>
<tr>
<th>Sleep level</th>
<th>Sample occipital EEG 1 sec</th>
</tr>
</thead>
<tbody>
<tr>
<td>B Transition state</td>
<td>No observable alpha frequencies; very low amplitude random activity</td>
</tr>
<tr>
<td>C Light sleep</td>
<td>Low amplitude random activity with appearance of sleep spindles (16 cps)</td>
</tr>
<tr>
<td>D Deep sleep</td>
<td>Delta activity increases to median amplitude</td>
</tr>
<tr>
<td>E Very deep sleep</td>
<td>Further increase in amplitude of delta activity; shift to slower frequencies</td>
</tr>
<tr>
<td></td>
<td>Maximum amplitude delta activity with waves from 3 to 16 seconds duration</td>
</tr>
</tbody>
</table>

Figure 2
Although little consciousness remains during the transition period, the presence of bursts of 14-cycle activity in Level C is the first sure sign of sleep. H. Davis et al. (1938) found that a subject turned off a tone presented during this B state, but not during the C state. As the subject goes deeper to sleep, the delta waves increase in amplitude and wave period. Although these patterns could not be differentiated by the measures of consciousness used in the non-sleep patterns, they agree quite well with EEG sleep patterns noted by other investigators. Independent evidence will be given in the next section on the Inertia Effect to show that the presence of delta is not only an index of unconsciousness, but that the changes in its pattern are also an index of the depth of sleep.

The Inertia Effect of Sleep

We have seen how the quantity and quality of alpha in a short record reflects the conscious state of the individual, and the presence of delta reflects his unconscious state. To what extent does the fact that the subject was awake or asleep sometime previous to the stimulus period have on his ability to respond or recall?

It has been observed that less is learned if training occurs just after awakening from sleep than after being awake for a longer length of time (Worchel and Marks, 1951). Blake et al. (1939) found that the longer the preceding period was without alpha, the less likely dreams would be recalled. The effects of sleep on shorter intervals of time are in part reflected in our A levels as shown in Figure 1; as the amount of alpha within the area diminishes, the less likely a subject is to respond or recall.
The above effects led to the formulation of the "inertia effect" principle. This principle states: During the presence of any waking EEG pattern, subjects who have recently been asleep tend to show a lower probability of response than those who have been awake previously.

Figure 3 shows the percentage of immediate responses and the subsequent correct recalls which occurred at any sleep level when the sleep level during a 60-second period five minutes previously contained or failed to contain alpha frequencies. Both responding and recalling are hindered when the preceding period showed no alpha and only delta frequencies and are favored when alpha frequencies were present. In general, these differences at each sleep level are statistically significant when a chi square test of the combined data was applied, the probabilities being less than one in a thousand times that the differences were obtained merely by chance.

Since items presented in sleep Levels B through E were not recalled, variations of consciousness during these levels could not be reflected by this measure of retention. However, the "inertia effect" principle enables an analysis to be made of these patterns to show that they do represent different depths of sleep. If a subject were more deeply asleep in Level E than in Level C, this should show up in its effect on a subsequent waking level if the "inertia" principle were operating. All of the items scored from 0 through B were divided into eight groups according to the sleep level existing during a one-minute stretch of record occurring five minutes prior to the presentation of the item. The percentage right and the percentage heard were then computed for each group. The results of the analyses are shown in Table 1.
Figure 3

In a 60-second length of EEG record five minutes earlier,
- ●●● ALPHA was present
- ○○○ No ALPHA was present

Percentage of items reported heard

Percentage of items recalled correctly recalled

Sleep level: O A+ A A- B
TABLE 1

<table>
<thead>
<tr>
<th>Sleep Level Observed Five Minutes Earlier</th>
<th>0</th>
<th>A+</th>
<th>A</th>
<th>A-</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean Percentage of Items in Levels 0 through B*</td>
<td>58</td>
<td>59</td>
<td>56</td>
<td>46</td>
<td>29</td>
<td>27</td>
<td>18</td>
<td>-</td>
</tr>
<tr>
<td>Recalled Correctly</td>
<td>70</td>
<td>60</td>
<td>59</td>
<td>54</td>
<td>39</td>
<td>26</td>
<td>22</td>
<td>-</td>
</tr>
<tr>
<td>Reported Heard</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*All levels based on a single case were not included in the computation of the mean percentage. The inertia effect of sleep as represented by the mean percentage of items in Levels 0 through B which were correctly recalled and reported heard when sleep levels five minutes earlier varied from 0 to E.
It can be seen in Table 1 that the deeper asleep a person has been five minutes before, the smaller mean percentage he will report hearing or will recall. Although the differences are small, particularly in the sleep states, the order is logical and consistent with the hypothesis. It is, therefore, quite likely that this is another indication that percentage of alpha and amplitude of delta are accurate indices of the state of consciousness and that the "inertia effect" is a valid principle.

The Transition State

When complicated patterns such as the EEG fall along a continuum, it is evident that drawing distinct boundaries between categories is somewhat difficult. Level B represents the change-over point. Level B represents the transition state in which alpha has apparently disappeared and delta is minimal. Although this level is occasionally considered a sleep state, subject to easy arousal, it is sometimes difficult to accurately classify its patterns since low-level alpha frequencies still may be present and masked by the presence of random activity. Thus occasional evidences of consciousness may still occur.
The major pattern of the B level consists of low amplitude random activity and is similar in appearance to the "null state" described by Blake, et al. (1939). The pattern has been observed as the individual goes to sleep and also as he passes from sleep toward wakefulness.

Although consciousness of exteroceptor stimulation is almost completely absent in Level B, little stimulation is needed to arouse the sleeping subject. Blake, et al. (1939) found that subjects reported they were conscious if even one second of alpha occurs during this null state.

Stimulus Effects

Unlike the EEG patterns shown in Figures 2 and 3 and discussed above, there are instances where marked alterations follow the onset of stimulation. When these stimulus effects occur during the waking period, they are called alpha blocks (Davis, P., 1939). Those occurring during sleep have been designated K complexes (Loomis, Harvey and Hobart, 1938).

In Figure 4, patterns showing some of the effects of auditory stimulation are presented along with the percentage of items reported heard and correctly recalled when these patterns occurred. From Figure 4 it can be seen:

1) The ability of subjects to recall and to give immediate responses corresponds to the quality and quantity of alpha frequencies; and
2) when alpha and delta frequencies are mixed, the probability of recall is related to which of these components predominates. These relations between consciousness and the EEG correspond to those observed with patterns showing no stimulus effects.
In some cases, more than one pattern was observed when a person was aroused from sleep toward wakefulness during a single stimulus period. The order of appearance of these patterns corresponded to the order of patterns shown in Figure 4, with Ss going from deeper to lighter levels. Although the direction was always the same (to a lighter state), there was often a jump from one pattern to another, with the omission of several intervening patterns. The particular patterns observed were dependent on the level of sleep preceding stimulation, the level following stimulation, and the rate at which the change in levels occurred. In cases where the first indication of arousal is the appearance of the alpha rhythm, it is not illogical to assume that arousal was so rapid that it occurred within the latent period of the K complex, which may be as long as several seconds, (Davis, H., et al., 1939).

Stimulus effects were frequently observed following the onset of the question. At times alpha rhythms appeared immediately but disappeared prior to the presentation of the answer and did not reappear following the answer (Figure 4, Pattern Ab). At other times no alpha rhythms were observed during the question or answer but appeared during the 30 seconds following the cessation of the auditory stimulus (Figure 4, Pattern bA). In both of these cases, low-level or mixed-alpha frequencies occasionally were observed during the answer period but were disregarded in favor of the high amplitude regular alpha rhythm occurring outside of this period.

Those stimulus effects which occurred during the answer period were placed in three major categories containing items which occurred: 1) when the subject had been asleep but was not awakened by the stimulus (Figure 4, Patterns Ds and D); 2) when the subject was in a transitional state between
sleep and wakefulness and patterns contained characteristics of both states (Figure 4, Patterns A, A/d and a/D); and 3) when the subject was already awake (Figure 4, Patterns AbA).

When a subject had been in deep sleep and was not awakened, stimulation generally lead to an increase in delta amplitude (Pattern D). The appearance of spindle activity (Pattern Ds) indicated a shift to a somewhat lighter level of sleep. With these patterns the amplitude of activity was greater in the vertex placement.

If subjects were in a lighter sleep level, stimulation frequently resulted in a mixture of alpha and delta frequencies. Three patterns fell in this category and were differentiated by the proportion of alpha and delta which they contained and by the locus of the activity. In the deepest of these three patterns, high amplitude delta with superimposed alpha frequencies were recorded from both the vertex and the occiput (Pattern a/d). In this state, where delta predominated, no items were recalled or reported heard. In the transition state, mixed alpha and delta were present in the vertex placement while mixed cyclical activity within the alpha band of frequencies with minimal delta activity were present in the occipital placement (Pattern A/d). Finally, subjects in the deep drowsy state often showed mixed cyclical activity within the alpha frequency range with minimal delta in both placements during stimulation (Pattern A). As the proportion of alpha increased, so did the probability of recall and immediate responses.

When the subjects were awake and stimulation resulted in blocking of the alpha rhythm, the probability of recall and of immediate responses was nearly the same as in cases where alpha was not blocked by stimulation. This only re-emphasized the point made earlier, i.e. the presence of alpha
is indicative of consciousness but the mere absence of alpha is not indicative of unconsciousness. Delta is still the best indication of unconsciousness.

One pattern (x) was observed which did not seem to fit along the continuum just described. It contained no alpha or delta and was characterized by low-level, fast activity following the onset of stimulation when the subject was in light sleep or the transitional B level. This pattern is similar in appearance to the activation pattern described by Moruzzi and Magoun (1949). It sometimes occurs following an A/d pattern, although it may also occur without such an intervening pattern. It was not uncommon for the alpha rhythm to appear shortly after the cessation of stimulation when Patterns A, x, and A/d were observed during stimulation. As already stated, when alpha rhythms followed the stimulus period within 30 seconds, the patterns were classified bA. Patterns x and A/d were quite similar in regards to the percentage of items reported heard and later recalled and were, therefore, combined for the computation of these measures.

Alpha, Movement, and Consciousness

Movements during sleep are generally associated with a shift to a lighter level (Blake et al., 1939) although Loomis et al. (1937) found that at times movements and sleep states shifted independently. Kleitman, et al. (1933) found that the frequency of movements increased at the end of a night's sleep where sleep was supposedly lighter. Blake and Gerard (1937) reported that if subjects were asked if they were awake a few seconds before a movement, they seldom responded, while a few seconds afterwards, they would reply. In light sleep, however, they noted the subject would often respond without movement,
while in deep sleep, he'd move without responding. Jackson (1941) found a relationship between movement and blood circulation; he suggested that movements could be initiated by internal stimulation resulting from a constriction of circulation without requiring a conscious recognition on the part of the subject.

Can the movement of a subject during sleep be used as a criterion of consciousness? What is the relation between alpha, movement, and consciousness as measured by immediate responses and subsequent recall? Table 2 shows the percentage reported heard and the percentage recalled of items which occurred during movements. Since cortical potentials were partially or completely obscured by movement artifacts, it was impossible to assign these items to specific sleep levels. However, the presence or absence of alpha in the vicinity could be detected. When alpha rhythms were found during or at the end of the movement, hearing and recalling tended to be high; when no alpha was observed, subjects heard and recalled practically nothing. These results corresponded with those for alpha and non-alpha periods without movement. Thus, two conclusions can be drawn: 1) It is possible to have movement without an apparent presence of the waking alpha; and 2) The presence of alpha and not movement is the critical criterion for conscious responses.

Summary and Conclusions

Monopolar occipital and vertex EEGs were taken from 21 normal, male, alpha-dominant adults during an 8-hour sleep. Information was presented by
TABLE 2

The Relation of Movements, Alpha, and Consciousness

<table>
<thead>
<tr>
<th></th>
<th>Percentage Reported Heard</th>
<th></th>
<th>Percentage Recalled Correctly</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Alpha</td>
<td>Non-alpha</td>
<td>Alpha</td>
<td>Non-alpha</td>
</tr>
<tr>
<td>Move</td>
<td>57</td>
<td>8</td>
<td>35</td>
<td>2</td>
</tr>
<tr>
<td>No Movement*</td>
<td>63</td>
<td>3</td>
<td>56</td>
<td>3</td>
</tr>
</tbody>
</table>

*Where cortical patterns were not obscured by movement artifacts, the alpha category corresponded to Levels C, A+, A, A- and the non-alpha category to Levels B, C, D, E including stimulus effects.
means of a tape recorder during this period. Subjects reported if they heard the information during stimulation and were later tested, upon rising, to see if they could recall it. These two variables were correlated with electroencephalographic patterns occurring during the information presentation. The following conclusions were drawn:

1. The probability of remembering and responding to meaningful auditory stimulation increased as the quantity and quality of waking alpha within the immediate vicinity increased.

2. The absence of alpha does not mean unconsciousness.

3. The presence of delta is an indication of unconsciousness. Unconsciousness is directly related to delta amplitude and inversely related to delta frequency.

4. Several seconds of EEG scored by eye is a reliable measure of the state of consciousness.

5. Awakening from sleep or the borderline of sleep as a result of auditory stimulation may lead to patterns showing special stimulus effects which fall along a consciousness continuum relative to the amount of alpha and delta within a pattern.

6. For any particular EEG pattern, persons who have been asleep prior to stimulation absorb and retain relatively less information than those who have been awake.

7. Movements per se are not a good criterion of consciousness.


Loomis, A. L., Harvey, E. N., and Hobart, G., Cerebral states during sleep, as studied by human brain potentials. J. Exp. Psychol., 1937, 21, 127-144.


Simon, C. W., and Emmons, W. H., Responses to material presented during various levels of sleep. The RAND Corp., Santa Monica, Calif., 1955, RM-1222.

