HUMAN BRAIN POTENTIALS DURING THE ONSET OF SLEEP

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WHEN A person goes to sleep, the pattern of his brain potentials alters systematically. Five clearly defined stages have already been described (Loomis, Harvey, and Hobart, 1937) as follows:

A—interrupted alpha: the normal waking 10-per-second rhythm dominates the pattern
B—low voltage: the alpha rhythm is lost
C—spindles: short groups ("spindles") of 14-per-second waves appear and also random "delta" waves 0.2 second or more in length
D—spindles plus random: both types of wave increase in voltage and the delta waves become longer
E—random: the 14-per-second waves become inconspicuous, but delta waves continue to increase in voltage and wavelength

We have now investigated the finer details of the A and B stages, and are able to relate alterations of the electrical pattern of the brain to signals given by the subject which are based upon changes in his state of consciousness. Such a correlation is of great interest from the point of view of psychophysiology, for it unites a subjective with an objective aspect of brain function.

METHOD

The experiments to be described were carried out in the Loomis Laboratory. We employed the amplifiers, the ink-writing oscillographs, the automatic recording drum and accessory apparatus, which have been in use in this laboratory for some time (Loomis, Harvey, and Hobart, 1936). In addition we employed the portable two-channel ink-writing electroencephalograph and associated amplifiers which are in routine use in the Department of Physiology of the Harvard Medical School. These were designed and constructed by Mr. A. M. Grass. The two sets of instruments on direct comparison proved to be almost identical in their characteristics. The only exception is the electrical filters. The Loomis filters are quite sharply tuned and select one frequency rather specifically from the medley of brain activity. The Harvard filters, on the other hand, are much more broadly tuned and can be legitimately compared to combinations of high-pass and low-pass filters, leaving a band of a third of an octave or more which is passed with relatively

* Following the suggestion by Walter (1936) we employ "delta" as a generic term to designate brain-potential waves whose wavelength is 0.2 second or longer. They may or may not be rhythmic in sequence.
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‡ The higher the frequency to which one of these filters is tuned, the sharper is the tuning. The sharpness may be expressed as the ratio of the frequency at which the amplitude of a sine wave is 1/2 what it is at the center of the band to the frequency of the center of the band. For 3 per second this ratio is 2.7; for 10 per second, 1.4; and for 14 per second, 1.3.
little distortion. Each type of filter has proved of particular value for particular purposes.

Two signal pens connected in parallel write upon the drum and the tape, respectively. They are connected to a push-button operated by the subject, or to a mercury contact switch driven pneumatically by a rubber bulb held by the subject. (The rubber bulb was introduced to eliminate a rather troublesome electrical artifact which emanated from the push-button and its grounded shield.)

Small metal electrodes were attached in standard positions on the heads of the subjects as follows: (1) Vertex; in the midline directly on the top of the head on a frontal plane through the two auditory meatuses. This point is over or near the sensorimotor area of the legs. (2) Occiput; in the midline about 2 cm. above the inion. This point is over the visual area of the brain. (3) and (4) The right and left mastoid processes or the right and left ear lobes. Points 3 and 4 were used either singly or connected in parallel, as reference electrodes common to all of the recording circuits. We shall speak of electrical activity at the vertex or occiput when we mean, strictly, the electrical potential appearing between vertex or occiput and these ear electrodes. The degree of unlikeness which appears between simultaneous occiput and vertex records shows that it is safe to assume that not more than 10 per cent of the electrical activity is due to potential changes of the ear electrodes, except perhaps in the stage of deep sleep.

Two types of electrode were used in different experiments—(1) a small flat coil of silver wire and (2) a flat drop of solder in which the end of a copper lead-off wire is imbedded. No systematic difference between the results obtained with these two types of electrode could be determined. Much more important than the type of electrode was the state of the subject's skin and the firmness of mechanical contact. Electrical contact was made with Sanborn Electrode Paste and the electrodes were held in place by collodion. It is not difficult to obtain satisfactory electrical and mechanical contact with the scalp without even cutting a hair.

The subject lay comfortably on a bed in a darkened room. A steady noise from an electric fan provided a constant auditory background and masked accidental noises from other parts of the laboratory. The subject was instructed to settle down for an afternoon nap or for the night's sleep, as the case might be, but to signal by squeezing the bulb once whenever he realized that he had just “drifted or floated off” for a moment. The subjective aspect of this “drifting” or “floating” on the borderline of sleep varies with different individuals and will be described in detail below. The subject was also instructed to signal twice if he felt that he had just awakened from “real sleep.” Most of our subjects drew a definite distinction between these two experiences. If the subject was still awake after he had given ten or fifteen signals, the experimenter entered the room and obtained from him a description of the subjective experiences indicated by the signals. If he fell asleep as deeply as the C stage, it was sometimes necessary to awaken him deliberately.
We have carried out twenty-eight experiments on fourteen different subjects. Three experiments were inconclusive as to any psychophysiological correlation, as the subjects gave no signals. In one case the subject fell immediately asleep without "drifting," and in the other two the subjects were unable to relax sufficiently to reach the "drifting" stage. Five other experiments were qualitatively positive, but are not considered in detail because of technical differences or inadequacies which make it impossible to compare them in detail with the main series. In the remaining twenty experiments satisfactory records and signals from eleven subjects were obtained. For purposes of exposition, we shall disregard for the moment the signals from the subject and first describe the typical onset of sleep in terms of electrical activity of the brain.

The onset of sleep. We can distinguish several fairly well-defined steps in the approach and onset of sleep. These steps are not to be confused with the stages A, B, C, etc., of Loomis, Harvey, and Hobart, but represent a more refined analysis of stages A and B.

As a subject "settles down" his alpha waves may first increase slightly in voltage and regularity, but in subjects who have a steady alpha rhythm, a modulation of the alpha waves soon appears, i.e., the alpha waves systematically increase and decrease in voltage. The period of this modulation is several seconds and is sometimes quite rhythmical. The maximal amplitude of the alpha waves also tends to be reduced. Many individuals show a similar modulation of the alpha waves even when fully awake, and in such an individual the trains of alpha waves become shorter and the voltage lower as he becomes drowsy.

The second step is complete interruption of the alpha rhythm for periods of 1 to 5 seconds. Sometimes the alpha activity does not disappear entirely during these gaps, but the waves become small and irregular both in shape and frequency (Fig. 1B and C). A sharply tuned filter fails to respond to them.

The third step is that the interruptions of alpha activity become longer, although at the end of each gap the alpha waves return quite suddenly, usually with their normal maximal amplitude. At this stage an increase in voltage of the longer, random, delta waves can first be clearly identified. The delta waves appear during the gaps in alpha activity. Most individuals show some slow waves of low voltage at all times as a slight irregularity of the baseline, but in the stage in question slow waves appear singly or in groups of three or four, sometimes quite rhythmically at a frequency of 4 or 5 a second, with a voltage of approximately 50 microvolts (Fig. 1D). The delta waves tend to be larger and more easily identified at the vertex than at the occiput. The changes in alpha activity, on the other hand, are most clearly discerned in the occipital record.

Some individuals have little or no alpha activity in the waking state, but have instead many shorter, sharper waves of 50 to 60 msec. in wavelength which appear irregularly or in brief trains. When they are regular enough to
constitute a definite frequency it is usually 17 to 20 per second (Fig. 2B). These waves are clearly quicker than alpha waves and they do not disappear when the eyes are opened, yet they are slower than the waves which generally have been designated as "beta" waves, namely, those with frequencies above 20 per second (Berger, 1929, 1930, 1934). In their general characteristics they seem more nearly akin to beta than to alpha waves. They are more prominent at the vertex than at the occiput. A generic term for these waves would be convenient, but it seems wiser to defer assigning a Greek letter or other specific designation to them until more is learned of their significance and relationships. In this paper we shall refer to them as "quick" waves, and reserve "beta" for frequencies above 20 per second and wavelengths of 50 msec. and shorter.

Three individuals in our series, whose waking records are dominated by these quick waves, show the usual increase in delta waves with the onset of sleep. As drowsiness increases, there is a general reduction in voltage and usually also in the average frequency of the quick waves. The quick waves do not cease entirely, and, inasmuch as they are often quite irregular even in

![Fig. 1. Six sections from the record of a subject going to sleep and signaling "floating." The upper line of each record shows potential changes at the vertex (V), the lower, at the occiput (O), with reference to the ears. Upward deflection means O or V negative to ears. Time scale and amplification are constant throughout as shown in the figure. A: Normal record of the subject awake. B, C, D, E: "Floating" with signals from the subject on rousing. Drowsiness is increasing throughout this series. Note in B that the alpha waves disappear at the occiput before they disappear at the vertex. Note that in C the subject's signal precedes the return of alpha waves. F: Real sleep; entering the C stage, with waves at 14-per-second and 12-per-second in addition to large delta waves. The largest delta waves appear square-topped because the limit of the linear range of the recording system has been reached. The actual voltage of these waves is at least 150 microvolts.](http://jn.physiology.org/DownloadedFrom/10.22033.1)
the waking state, there is no abrupt loss of regularity such as we find in the
typical alpha waves.

The fourth step in the onset of sleep shows an increase in the wavelength
of the delta waves which appear during the gaps of alpha activity. Alpha
waves, when they appear at all, show a slower frequency than the individual's
normal waking rate (Fig. 2C). The slowing usually amounts to 10 per cent,
and may be as much as 20 per cent. The slowing is not uniform, however, for
immediately following a gap, when the waves first return, they are accelerated
by as much as 10 per cent above the waking frequency and then progressively
slow down to 9 or 8\(\frac{1}{2}\) per second before the next interruption. The temporary
acceleration is particularly evident if the subject has given a signal and it is
very similar to the acceleration which often occurs when the subject opens his
eyes for a few seconds and then closes them again. The slowing of the alpha
rhythm below its normal frequency is a characteristic phenomenon associated
with the approach of real sleep, although it may not be very evident if an in-
dividual goes directly into deep sleep without lingering in the intermediate
"floating" stage.

The fifth step is characterized by the complete loss of alpha waves and by
the appearance of delta waves of 150 microvolts or more (Fig. 1F). If the delta
waves are rhythmic, as is frequently the case, the most characteristic fre-
quency is 4 per second or a little slower. We shall see later from the subjective
reports of the subjects that this stage should be regarded as probably real
sleep.

The next stage, which is certainly sleep, corresponds to the C stage of the
original classification (Loomis, Harvey, and Hobart, 1937) and is identified
by the appearance of characteristic brief trains ("spindles") of waves at 14
per second and 50 microvolts or more in voltage (Figs. 1F, 2F and 2G).
In this stage there is a still further increase in the average voltage of the delta
waves and also an increase in their average wavelength.

If we compare the preceding description of the alpha waves with the
original classification of the A, B, and C stages of sleep, it appears that the
A and B stages alternate with one another for a time as the subject goes to
sleep. This description is incomplete, however, for, although there is a fluctua-
tion between alpha activity and absence of alpha activity (which we shall
find is correlated with temporary subjective changes in the state of conscious-
ness of the subject), there can nevertheless be traced a general trend under-
lying these briefer fluctuations. This trend appears as a lengthening of the
periods of absence of alpha activity, as a progressive slowing of the alpha
rhythm, and also as an increase in voltage and average wavelength of the
delta waves when they appear. The general trend is associated with increasing
drowsiness of the subject. On this general trend is superimposed a series of
fluctuations of some other factor, which is expressed by the intermittent out-
bursts of alpha activity.

As a rule, alpha activity and delta activity are inversely related, that is,
delta activity tends to appear only when alpha activity is suppressed. This is
true in general, but it is important to note that the rule is not invariable. Particularly in the very early stages, before the alpha rhythm is significantly slowed, the alpha waves may disappear for a few seconds without any measurable increase in delta activity. Furthermore, the alpha waves may disappear

![Fig. 2. Brain potentials from vertex (V) or occiput (O) referred to the ears. Upward deflection = scalp negative. Broadly tuned filters used in all except A and upper line of B. Frequency of filters shown by numerals at extreme right. Voltage calibrations at left, 50 µV in all cases. When tuned filter is used calibration refers to peak-to-peak voltage of a sine wave of frequency matching the tuning of the filter. A: Unfiltered, showing unusually prompt appearance of delta waves in a brief "float" (or nap?). B: End of a "float," with subject's signal at arrow showing return of "quick" 18-second waves in a subject with very few alpha waves. Lower line shows the same potentials taken simultaneously through a 14-second filter. The frequency of the waves is approximately 18 per second. C: Return of alpha waves after a "float," showing variability and slowing of alpha rhythm in the very drowsy state. Alpha frequency indicated on record. The next "float" begins just after the sequence of 7.5-per-second alpha waves. Both records from the vertex. Upper line filtered for alpha; lower line for delta. D and E: Ends of two "floats" from the record of the same subject. D: The usual return of alpha waves shown in lower line, which is occipital record filtered for alphas. E: Shows unusual delta activity appearing at the vertex. Alpha waves at the occiput continue unaffected by it. This delta episode continued more than 30 seconds. The subject signaled during the delta activity as shown, and believed himself to be fully conscious throughout. F and G: Records from the vertex of a single subject during sleep. Upper line filtered for deltas; lower line for 14 per second and 10 per second. F: Typical 14-cycle "spindles." G: Irregular slowing of 14-cycle waves, giving rapid shifts of frequency between 14 per second and 10 per second. Frequency count shown on the record. Note reduced amplification of G as compared with F. Also in both cases lower line is taken at twice the sensitivity of the upper line.]
in one region—the occiput, for example—while they continue for a few seconds at the vertex, and vice versa. Still more important is the occasional appearance of fairly high delta waves running as a continuous background on which the alpha waves are superimposed, or a transient episode of great delta activity at the vertex while the alpha activity continues smoothly at the occiput. We may note immediately that, in the three such episodes of which we have clear records, the subject did not report sleep but believed himself to be conscious. In the case illustrated in Fig. 2E the subject reported unusual kinesthetic and somasthetic sensations, as if he were slightly dizzy and starting downward in a fast elevator. Whatever the significance of this report may be, it is clear that various parts of the brain do not always show simultaneous changes in the alpha and the delta waves.

**Correlation of Changes in the Electroencephalogram with the Signals from the Subject.** The subjects in these experiments signaled whenever they felt they had momentarily "floated" or "drifted" off or experienced any other clearly defined change in the state of consciousness. These signals correlated to a surprising degree with the alterations in the brain potentials (Figs. 1 and 2). The relation was clearest and most precise in those subjects whose standard waking record was largely occupied with alpha waves. Six of our subjects had such "high alpha" records, showing the alpha rhythm 70 per cent or more of the time. In 9 experiments these 6 subjects signaled "have floated" or "have slept" 165 times. All but 6 of these signals were preceded by definite depressions of the alpha waves which lasted from 1.5 to 30 or 40 seconds. The records showed only 39 equally clear depressions of alpha waves which were not signaled. One subject signaled correctly 20 consecutive depressions, and two others had consecutive runs of 10 or more. The minimal duration of a depression which was necessary for a subject to give his signal varied somewhat from one individual to another. One subject consistently signaled gaps as brief as 1.5 second, others required gaps of 4 or 5 seconds, but for each the minimal duration was quite consistent. The data of Table 1, based on two subjects, are broadly typical of the whole group, and also illustrate the characteristic prolongation of the "floats" as sleep approached.

The signal was usually given immediately after the return of alpha waves (Figs. 1B, D; 2C, D, E). The latency of the signal following the first reappearance of alpha waves varied from zero to as much as 5 seconds, and is more or less characteristic of the particular subject. Occasionally the signal was given just before the alpha waves returned (Fig. 1C). This is a point of considerable theoretical interest, as it suggests that a subject may be able to realize that he has "floated" even when his alpha waves are still absent and that the waves may return because the subject rouses himself further by the act of signaling. In order to test this point it will be necessary to carry out similar experiments while obtaining records simultaneously from many parts of the brain, for the reappearance of alpha waves, like their disappearance, is not necessarily simultaneous at all points on the cortex. The latencies in Table 1 are all calculated on the basis of the return of alpha waves at the occiput, where these waves are usually most prominent.
In those cases in which the delta waves reached 150 microvolts and persisted for half a minute or more, the subject frequently signaled "real sleep" when he next awoke. Two subjects did not identify any intermediate stage between waking and real sleep, and almost all of the changes which occurred in their records involved the appearance of large delta waves for half a minute or more. Sometimes a subject who showed this type of change in the record would neglect to signal "real sleep" on waking, but state subsequently that he realized later that he had made a mistake and should have signaled "real sleep" rather than mere "floating." The situation suggests that the ability to discriminate between "floating" and sleep becomes relatively depressed when sleep actually occurs. Occasionally a period of one or two minutes of unquestionable sleep passed entirely unsignaled. This agrees with our experience in other experiments in which such changes have appeared in the records and in which the subjects have denied having fallen asleep. Akin to this is the situation toward the end of an experiment when the subject is asleep most of the time and often fails to signal when alpha waves appear for a few seconds on the record. In this state the subject apparently does not arouse himself sufficiently to signal, and we have not included this part of the experiment in reckoning our scores. If we consider that even in the early "floating" stage the subject is in an extremely drowsy state, perhaps only semiconscious, it is surprising that our subjects actually attained an overall score of 75-per-cent accuracy of signaling depressions of alpha activity.

Failures to signal the changes perfectly occurred for several reasons besides extreme drowsiness. One reason was that on the first trial the subjects did not always sink deeply enough toward sleep. They did not attain the necessary condition for "floating," but, being anxious to cooperate, began signaling too soon, not waiting for the correct end-point. The failure was essentially the selection of the wrong subjective end-point. It is significant, however, that among all of the subjects who gave any signals at all only one failed to reach the proper end-point at one of his later trials; and even the one whose experiment we class as a failure was not entirely negative in his correlations toward the end of his second trial. According to his own statements, however, he was still shifting his end-point from time to time in an endeavor to find what we call the "floating" stage.

### TABLE 1

<table>
<thead>
<tr>
<th>Subject</th>
<th>Signals</th>
<th>Average time between signals</th>
<th>Average duration of depression of alpha waves before signals</th>
<th>Average time from return of alpha waves to signal</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>1-5</td>
<td>16.9 sec.</td>
<td>2.9 sec.</td>
<td>0.2 sec.</td>
</tr>
<tr>
<td></td>
<td>6-10</td>
<td>12.1 sec.</td>
<td>4.1 sec.</td>
<td>0.2 sec.</td>
</tr>
<tr>
<td></td>
<td>11-15</td>
<td>17.8 sec.</td>
<td>7.8 sec.</td>
<td>0.4 sec.</td>
</tr>
<tr>
<td></td>
<td>16-20 (sleep)</td>
<td>20.5 sec.</td>
<td>13.5 sec.</td>
<td>0.3 sec.</td>
</tr>
<tr>
<td>B</td>
<td>1-3</td>
<td>39.2 sec.</td>
<td>6.2 sec.</td>
<td>2.4 sec.</td>
</tr>
<tr>
<td></td>
<td>4-6</td>
<td>37.8 sec.</td>
<td>10.4 sec.</td>
<td>2.6 sec.</td>
</tr>
<tr>
<td></td>
<td>7-9 (sleep)</td>
<td>36.2 sec.</td>
<td>22.7 sec.</td>
<td>1.1 sec.</td>
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</tbody>
</table>
Occasionally the subject fluctuated very rapidly, according to his record, between a state of waking and a state of "floating," and under such conditions he frequently failed to signal all of the fluctuations. The period of such fluctuations was often as short as 5 seconds. Furthermore when the fluctuations are very rapid, the contrast between the sections of the record is often not great. The subjects expressed the greatest uncertainty concerning the subjective transitions on those very occasions when the record itself showed no sharp contrasts. Sometimes also there were very slow gradual transitions from one state to the other which apparently escaped the notice of the subject. It is significant that the very conditions which make judgment of end-points difficult on the record seemed to be correlated with a similar lack of clear definition and clear transition in the subject's own experience.

The Subjective Experiences. Two of the ten subjects in the successful experiments reported only "real sleep," and these two actually showed characteristic sleep patterns in 7 out of 12 alterations of pattern which were signaled. The first two alterations in each record were less clear than those which followed, but delta waves of at least 70 microvolts were visible in every case. The shortest period of delta activity was 10 seconds. These are more profound changes than our other subjects showed in their early "floats."

Our two youngest subjects (21 and 13 yrs.) gave no adequate description of their experiences. Their records passed quite rapidly into the characteristic sleeping pattern with only two and four intermediate "floats" (or naps?), respectively, but signals were given immediately after the alterations in every case.

The remaining six subjects who gave signals related to the changes in their potential patterns all agreed on two points—(1) that they would not call the early episodes "real sleep" but an intermediate stage, and (2) that during the episodes which they signaled there had been a depression of awareness or consciousness. The depression involved the awareness of immediate external stimuli (e.g., sounds, contact of the bed-clothes, etc.), or of self-consciousness, awareness of the experimental situation, etc. One of them compared the state to that of "nodding" or "dozing" during a lecture or sermon, and others agreed to the aptness of the comparison. Beyond these common points they gave the greatest variety of descriptions, such as:

(1) "These things are practically dreams, but I am awake enough to catch them." (99)*

(2) "No dreams or visual fantasies. Mind a blank. Noises no longer noticed." (12)

(3) "Unexpected visual fantasies are my end-point." (98)

(4) "My thoughts wandered or floated unexpectedly." (15)

(5) "Drifting of thoughts. Definite kinesthetic sensation of being suddenly brought upright at the end." (95)

* The figures in the parentheses following these descriptions are the "alpha indices" of the respective subjects, i.e., the percentage of the time occupied by alpha waves in his waking record under standard conditions (Davis and Davis, 1936; Saul, Davis, and Davis, in press.)
(6) "Pleasant sense of numbness, of dizziness, of being nothing at all." (72)

These six spontaneous characterizations cover the senses of hearing, touch, equilibrium, and kinesthesia; and include thought, visual fantasy and dreams. They also include emphatic denials of dreams and visual fantasies.

We have no evidence relating dreams to specific changes in the record. The fantasies of the "floating" stage merge imperceptibly into dreams, and we have many unequivocal reports of dreams which must have occurred during the B stage, for the subjects never went beyond the B stage in those particular naps. One subject was awakened abruptly from the C stage by a knock on the door. He reported that he had just been dreaming and had awakened spontaneously, but had forgotten the content of the dream. Only 3 seconds elapsed from his last large "spindle" of 14-per-second waves (which preceded the knock) to his own signal indicating that he was awake, so that it seems quite safe to refer the dream to the C stage. Dreaming can therefore occur in both B and C stages. Concerning D and E we have as yet no evidence.

DISCUSSION AND INCIDENTAL OBSERVATIONS

In the reports of our subjects as to their subjective experience during the times when alpha waves were depressed in their records, no single sense modality is uniquely involved. We therefore cannot assume that the alpha waves are depressed in the "floating" stage because of visual activity in the form of fantasy, analogous to opening the eyes. In fact, "floating" seems rather to involve a depression of cortical activity, while opening the eyes and also those emotional states such as startle, "puzzlement," apprehension, etc., which suppress the alpha waves, are clearly forms of stimulation.

Inspection of the records leads to the conclusion that alpha activity may be reduced in two distinct ways. In one situation, as in "floating," the waves cease, simply diminishing in voltage to zero. They return again abruptly, then fade out once more, but, as they come and go, there is also, with the approach of real sleep, a general slowing of the alpha rhythm to 8 or even to 7 (cf. Durup and Fessard, 1936; Jasper, 1936). The slowing is most noticeable when the subject goes to sleep slowly with many "floats" in and out. Whenever the frequency falls to 7 or 6.5 per second the waves become irregular and disorganized and the subject passes off into another "float" or into real sleep. The behavior of the alpha waves resembles the slowing and disorganization of alpha waves in hypoglycemia described by Hoagland, Rubin, and Cameron (1936).

The 14-per-second waves which are so characteristic of sleep appear at about the stage when the last few recognizable alpha waves have been depressed to a frequency of approximately 7 per second. In a few instances in our records it appears that 7-per-second waves which are presumably slowed alpha waves have broken up into two groups which beat alternately with one another, thus generating a rather irregular 14-per-second frequency. The possibility of such an apparent doubling of frequency has been suggested in another connection by Rheinberger and Jasper (1937). This mechanism,
however, will not account for the genesis of the 14-per-second "spindles" in general, for the latter appear quite characteristically in the records of individuals who have no clearly marked alpha waves at any time. Also the 14-per-second waves are higher in voltage than the alpha waves at this stage of sleep.

The alpha waves are not the only ones which are progressively slowed with the onset of sleep. The quick (20-per-second) waves are similarly affected; in the individuals in whom the quick waves are prominent enough to be studied easily the groups of 14-per-second waves appear strongly when the average frequency of the quick waves has fallen to approximately 14 per second. This observation, although pointing to a genetic connection between the quick waves and the 14-per-second waves (cf. Jasper, 1937), offers no clue as to why the 14-per-second waves should reach a voltage higher than that exhibited by the quick waves at other frequencies. The frequency does not remain stable at 14 per second, but may oscillate between 14 and 10 per second or thereabouts (Fig. 2G). The "spindles" of 14-per-second waves have been identified because here seems to be a maximum of voltage and perhaps a somewhat greater stability of frequency in each train of waves.

Waves at approximately 10 per second may appear during sleep (cf. Blake and Gerard, 1937), but their frequency is seldom as regular as the waking alpha rhythm. Also a subject who has fallen asleep and lost his alpha waves for a time may show them again for a few seconds without signaling that he is awake, and they may be elicited regularly by stimuli which fail to arouse the sleeper. The pattern of brain potentials may change, and the subject may shift his position in bed, but when awakened may have no memory of the stimulus. The function of memory is certainly depressed. If the subject does give a signal in this state, its latency, with respect either to the stimulus or to the appearance of alpha waves, is unusually long—often many seconds, and giving the signal often involves great subjective effort. Whether or not we regard the subject as "asleep" under these conditions (when the alpha waves appear) is a question of definition which we shall leave open for the present.

One of our subjects always gave strong regular 10-per-second waves from vertex, occiput, and forehead nearly continuously while deeply asleep. There is no doubt as to the depth of sleep in this case. The 10-per-second waves appeared only in the C stage of 14-per-second waves. Frequencies of 10 and 14 per second often appeared simultaneously in the record. This subject gives such "alpha" waves only when soundly asleep. Her waking record is dominated by quick 20-per-second waves, and relatively few sharp irregular alpha waves appear. (The alpha index of this subject is 15.) It is a question whether or not her regular well-rounded 10-per-second waves in sleep represent the same cell-groups and mechanisms as the ordinary waking alpha rhythm. Her sleeping 10-per-second waves are strongest at the vertex instead of at the occiput, but this is also true for the waking alpha rhythm in about 2 per cent of our normal subjects. Obviously the test of opening the eyes could not be
tried in sleep! We believe that the sleeping 10-per-second waves in general are more closely akin to the 14-per-second waves of the spindles and to the "quick" 18- or 20-per-second waking waves than they are to the waking alpha rhythm. In sleep the 14-per-second and 10-per-second frequencies are not sharply differentiated. Many trains at 12 per second can be identified (See Fig. 2G). It is at 14 per second, however, that the highest voltages and greatest regularity are usually attained. In all subjects the sleeping 10-per-second waves, like the 14-per-second waves, are more prominent at vertex than at occiput, and they are equally strong in individuals with many and with few waking alpha waves.

Is "falling asleep" a unitary function or event? Our observations suggest that it is not. Different functions, such as sensory awareness, memory, self-consciousness, continuity of logical thought, latency of response to a stimulus and alterations in the pattern of brain potentials all go in parallel in a general way, but there are exceptions to every rule. Different functions may be depressed in different sequence and to different degrees in different subjects and on different occasions. Only the general progress of depression remains constant. We have pointed out that the changes in the pattern of brain potentials need not occur simultaneously in different parts of the brain. Only if we choose to define sleep in terms of response to a particular stimulus or of a particular change in the potential record from a particular area of the cortex—only then can a "moment of falling asleep" be precisely defined. Otherwise the problem is just as vague and difficult as that of determining the exact moment of death.

In terms of potential patterns the index which seems most nearly to reflect the "depth of sleep" is the frequency and voltage of the slow, random "delta" waves. Blake and Gerard (1937) have pointed out this general parallelism and it is implicit in the classification of stages of sleep cited in the opening paragraph of this paper. Our present observations show that the delta activity begins to increase both in voltage and in average wavelength at the stage of the earliest subjective "floating" or transition into sleep. The increase in voltage and wavelength appears to continue progressively as the physiological depression of the nervous system which we call sleep becomes deeper. It is probably no accident that most forms of mental disorder except the convulsive varieties have been reported as showing "slow waves" of one kind or another in those cases in which any difference from the normal could be detected (Berger, 1932, 1933; Gibbs, 1937; Walter, 1937; Jasper, 1937). We have confirmed this general relationship in a series of observations which will be reported in detail elsewhere.

The abruptness with which a subject’s record can change from a high-alpha waking pattern to a "light sleep" record with clear delta waves (cf. Fig. 2A) raises an important practical point for clinical electroencephalography. Before we conclude that a low-alpha or a high-delta pattern is due to mental disorder, brain tumor, or other lesion of the brain, we must be certain that the patient was awake when the record was obtained and that he did not
momentarily "float off" in light sleep. Records must be carefully evaluated in terms of the state of the patient. Measurements of the amount of alpha activity are particularly subject to error from drowsiness, which may partially depress the alpha waves long before actual sleep occurs. Absence of drowsiness must be rigorously enforced as one of the necessary standard conditions for such measurements.

### POTENTIALS OF THE MOTOR AREA DURING SLEEP

<table>
<thead>
<tr>
<th>State of Sleep</th>
<th>Awake</th>
<th>Asleep</th>
</tr>
</thead>
<tbody>
<tr>
<td>Drowsy</td>
<td>&quot;float off&quot;</td>
<td>light sleep</td>
</tr>
<tr>
<td>Deep sleep</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Class of Waves</th>
<th>Voltage</th>
<th>Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Delta</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Alpha</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Quick</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Beta</td>
<td></td>
<td></td>
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</tbody>
</table>

**Fig. 3.** In the upper line the stages of sleep are characterized by the subject's reports; in the next line, according to the classification of Loomis, Harvey, and Hobart (1937).

The classes of waves are defined by the values given for their frequencies. The delta waves sometimes have no clear frequency but appear as isolated waves, and strictly should be defined by wavelength rather than frequency. In sleep they tend to be fairly rhythmical.

The height of each curve above its own base-line indicates the most characteristic maximal voltage for that class of wave at the corresponding stage. Note that the voltage scale for delta is half that of the other classes.

Broken lines indicate that at the corresponding stage of sleep the frequency of the waves in question becomes irregular or that its appearance is very intermittent, or its identification uncertain.

The frequency of the alpha waves is the most definite and constant. The others vary from moment to moment by as much as 25 per cent. This may or may not indicate corresponding shifts in the "depth of sleep."

The chart describes the potentials from the motor area referred to the ears. The corresponding chart for the visual area is similar except for lower voltage of the delta and the "quick" classes of waves. Some individuals show very little alpha voltage, even when awake, particularly in the motor area.

The following chart (Fig. 3) summarizes graphically the typical behavior in sleep of the various components of the brain-potential pattern. It is to be regarded as tentative and highly schematic, since the various components are not necessarily as closely correlated with one another as this graphic representation implies, i.e., the dominant frequency of quick waves need not be exactly double the alpha frequency, although this is often the case. Broken lines signify variability of behavior or intermittent appearance of the corre-
sponding class of wave. It is important to note that the horizontal dimension does not represent time. A subject frequently shifts back and forth from one stage of sleep to another, sometimes quite rapidly and erratically.

**SUMMARY**

Brain potentials were recorded from subjects while they were going to sleep. Alterations in the pattern were related to the state of consciousness of the subject by means of signals given spontaneously by the subjects (Fig. 1).

Subjects who have a well-developed alpha (10-per-second) rhythm when awake often showed repeated depressions or loss of alpha waves while going to sleep. Just after such a depression the subject typically signaled that he had "floated" or "drifted off" for a moment. Slow "delta" waves, 0.2 to 0.3 second in duration, usually appeared during the depression of alpha waves. Subjects who have few or no alpha waves showed a corresponding but less clearly marked depression of their "quick" (15- to 20-per-second) waves, and the same appearance of "delta" waves.

Nine of our ten subjects gave signals which correlated clearly with alterations in their brain-potential records. The "floating" state of consciousness always involves a loss of awareness for immediate external stimuli. Some subjects, but not all, also describe visual fantasies, kinesthetic sensations, interruptions of logical thought, etc.

"Real sleep" was regularly acknowledged when slow waves (recorded from the vertex) had reached 150 µv and persisted for half a minute. The appearance of "spindles" of 14-per-second waves is a sure sign of real sleep.

Dreams may occur in the low-voltage, B stage and also in the 14-per-second, C stage.

Alterations in the alpha and delta waves are not always simultaneous in different parts of the brain. We cannot define exactly the moment of going to sleep or the moment of awakening.

In the clinical study of brain potentials the drowsy state must be strictly avoided because of the similarity of the patterns of very early sleep to those described for many abnormal conditions.

**REFERENCES**


SAUL, I. J., DAVIS, H., and DAVIS, P. A. Correlations between the electroencephalogram and the psychological organization of the individual. (In preparation.)
