

CYCLIC VARIATIONS IN EEG DURING SLEEP AND THEIR RELATION TO EYE MOVEMENTS, BODY MOTILITY, AND DREAMING

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INTRODUCTION

The EEG patterns accompanying dreaming have never been adequately characterized. In the course of the early descriptive studies of sleep patterns, incidental observations were made by several different groups of investigators and their combined results seemed to indicate that dreaming could occur in all stages of sleep. Davis *et al.* (1938) got reports of dreaming from subjects who were awakened shortly after the onset of sleep when the EEG had not progressed beyond the "B" stage, a low voltage, irregular pattern, and also after awakening from a "C" stage, spindling with a low voltage background. Blake, Gerard, and Kleitman (1939) concluded that "dreaming is present most of the time" mainly on the basis of one subject who reported dreams nearly every time she was awakened during the night. They felt that dreams were less likely to occur in the presence of high voltage, delta activity. Knott, Henry, and Hadley (1939), on the other hand, obtained several reports of dreaming when subjects awakened spontaneously during periods of high voltage delta activity, and also during spindle activity. Henry (1941) described dreams reported after awakening from low voltage, spindle, and spindle plus delta stages. In a study specifically concerning the relation between EEG patterns and dreaming, Teplitz (1943) concluded that dreams could occur in association with any sleep potential pattern, but found the highest incidence of dream recall after awakenings during the "B" and "C" stages.

The above results, frequently cited in the literature, suggest a lack of relation between EEG stages during sleep and functional levels of central nervous activity. However, dreaming, with its complex visual imagery and at least a certain degree of organization and purposefulness, is closely akin to waking mental activity, and the supposition that it can occur at any level of sleep as indicated by brain waves is difficult to accept. To be sure, with the exception of Teplitz, the dream reports in the studies cited above were very small in number.

A new method for the detection of dreaming was recently described by Aserinsky and Kleitman (1955a) who reported the occurrence of periods of rapid conjugate eye movements during sleep and found a high incidence of recall of dream content in subjects awakened during these periods and a low incidence after awakenings at other times. The occurrence of these eye movements and their relation to dreaming was confirmed in both normal subjects and schizophrenics (Dement 1955), and a recently completed study appears to have conclusively established this relationship (Dement and Kleitman 1957). In this study, an 80 per cent incidence of vivid detailed dream recall was elicited from subjects after nearly 200 awakening during periods of rapid eye movements over many nights of sleep. Adequate control was maintained throughout the experiments of such distorting factors as the subjects' desire to please the experimenter with dream reports and unintentional cuing by the experimenter. Only 7 per cent recall was obtained after a comparable number of awakenings, randomly interspersed, when the eyes were quiescent. It was noted that the largest share of these dream reports during quiescent periods re-

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sulted from awakenings following very soon after the end of a rapid eye movement episode which suggested that they resulted from the persisting memory of earlier dream material rather than dreaming during the quiescent periods. In addition, it was demonstrated that the subjective estimation of dream-duration and the amount of dream narrative correlated highly with the length of the rapid eye movement period before awakening, and that the eye movements themselves seemed to be meaningfully related to the visual imagery of the dream. Brain waves were recorded, and it appeared that the eye movement periods were associated with a low voltage pattern while the interspersed periods of ocular quiescence were associated with spindle and delta stages.

In the investigation to be described, the EEG during *undisturbed* all night sleep was carefully examined using the periods of rapid eye movement as an objective criterion of dream activity. In this way it was hoped to establish conclusively that the rapid eye movements (dreaming) were associated with a characteristic EEG stage and to determine the frequency of occurrence and quantity of rapid eye movement and related EEG variations throughout an entire night of sleep. Body movement was also observed because of its possible relation to dreaming and its close association with EEG changes during sleep.

Some of the data have already been described in a brief preliminary report (Dement and Kleitman 1955).

SUBJECTS AND METHOD

The subjects for the experiments were 26 men and 7 women. Their ages ranged from 16 to 61 with the majority between 20 and 30. All gave negative medical histories and none reported having insomnia or other sleep difficulties.

All night recordings of eye movements, brain waves and body motility were made on each subject for one or more nights of sleep. In a typical experiment, a subject reported to the laboratory a little before his accustomed bedtime. He had been previously requested to abstain from coffee, alcohol, excessive food intake, and unusually strenuous exercise dur-

ing the day. Silver disc electrodes were affixed to the scalp with collodion and to the ear lobes and around the eyes with elastoplast. Great care was taken in attaching the electrodes so that they would remain in place without drying throughout the entire night. The lead wires were gathered together and further fastened to the top of the head with collodion. The subject then went to bed in a quiet dark room. The leads were taped together and ran as a single cord to the lead box at the head of the bed. This arrangement allowed a free range of movement without entanglement and minimized any annoyance to the subject. The experimenter then retired to an adjacent room where the recording equipment was located and did not again enter the experimental room or disturb the subject in any way until he awoke spontaneously in the morning or until his sleep was terminated artificially after an adequately long period.

The EEG and eye movement potentials were amplified and recorded by a four channel Grass Model III Electroencephalograph. All pens were set at the same gain and the EEG time constant was used throughout. Monopolar recording, either from scalp or eyes, was with reference to both ear lobes. In the first few experiments, one channel recorded the EEG monopolarly usually from a parietal electrode and three channels were used for eye movement potentials. One pen gave a bipolar record from a supra-orbital electrode above one eye to an infra-orbital electrode. The other two pens recorded monopolarly from the same two orbital leads referred to the ear lobes. Changes in the resting potential field, with reference to the electrodes, as the eyeball rotated were assumed to generate the observed electrical impulses (Fenn and Hursh 1937). In this way it was felt that eye movement potentials could be accurately differentiated even in the extreme case of a very small movement against a high voltage EEG background. Brain waves, with the same gain on all pens, were of smaller amplitude with the bipolar arrangement (supra-orbital to infra-orbital) than with the monopolar, and were also in phase on the monopolar pens. Consequently, only eye

movements gave the characteristic criteria of larger deflections on the bipolar pen and simultaneously out of phase smaller deflections on the monopolar pens. Vertical eye movements gave the largest potentials and movements in other directions varied approximately as the cosine of the angle of displacement from vertical.

It soon became apparent that such careful recording of eye movements was not necessary and subsequently they were recorded with either two pens monopolarly or one pen bipolarly allowing more pens to be used for EEG tracings. Also horizontal eye movement leads were frequently used, one on each outer canthus, because of the ease of their attachment. These gave the same differentiation criteria as the vertical leads. The usual technique was to definitely ascertain the presence of eye movements and then quickly switch so that three pens recorded the EEG from frontal, parietal, and occipital leads referred to the ears and one pen recorded from the eye bipolarly.

Electrode resistances were checked before the subject retired and any electrode giving a reading above 10,000 ohms was re-applied. The resistances were then checked at the Grass machine irregularly throughout the night and it was found that they invariably remained less than 10,000 ohms.

Body motility was recorded by means of an attachment to the bed spring which registered a deviation on a moving tape when the subject stirred. Note was also made of body movement artifacts in the EEG record and the two sources were combined to give the final motility record.

The EEG machine was run continuously throughout the night. This was important because the EEG changes and eye movement periods frequently lasted only a few minutes and might have been missed entirely by intermittent sampling. A constant paper speed of the standard 3 cm. per sec. was impossible because of the prohibitive quantity of paper that would have been consumed in the 6-8 hours of recording. Therefore, whenever possible, the paper speed was slowed to 0.6 or 0.3 cm. per sec. The reliability of doing this was greatly enhanced by the fact of the

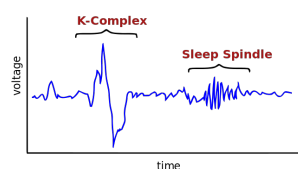
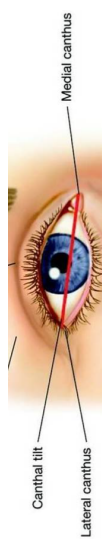
experimenter's constant attendance, because the paper speed could be immediately increased when any change occurred or any question arose. Also, frequent confirmatory standard speed samples could be taken.

High voltage delta waves were easily identified at the slower speeds due to their wide amplitude band. Low voltage faster waves required a standard speed most of the time, but spindles with a moderate amount of delta activity could be identified at the slower speeds because of the wider band and because the experimenter could actually see and hear the characteristic movement and scratch of the pens while reproducing a spindle and could confirm this impression with frequent standard speed samples. The records were all carefully measured and judged at a later date in addition to the original on-the-scene judgments.

In order to facilitate the organization and analysis of the large amount of data from many experiments running continuously for hours, the categorization of the EEG patterns during sleep was somewhat simplified. Four categories or stages were used:

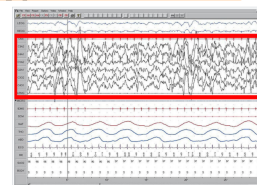
Stage 1. The essential characteristic was an *absolute lack of spindle activity*. In general, a low voltage, relatively fast pattern corresponding to the "B" stage of Loomis *et al.* (1937) and the "drowsy" stage of Gibbs (Gibbs and Gibbs 1950), and including what the Loomis group called the "A" or interrupted alpha stage. Thus, any EEG pattern between full wakefulness and the appearance of spindles was included in stage 1.

Stage 2. Characterized by the presence of spindle activity with a low voltage background. A certain amount of slower activity was included in this stage in the 3-6 per sec. range. Gibbs' biparietal hump phase was also included although recognition of the humps was hindered by the unilateral recording. However, since this wave form is less prominent in the adult age group (Gibbs and Gibbs 1950) and in most cases was followed almost immediately by the appearance of spindles, its inclusion was felt justifiable. Careful distinction had to be made between spontaneous "K" complexes occurring in this stage and delta waves appearing in deeper



I complessi K sono forme d'onda di alto voltaggio rilevabili in un elettroencefalogramma (EEG) e si verificano durante la fase 2 del sonno non-REM. Sono stati definiti il "più grande evento nell'elettroencefalogramma di un uomo sano". [1] Questi complessi sono più frequenti nei primi cicli di sonno. Sia i complessi K che l'attività delle onde delta nella fase 2 del sonno creano oscillazioni a onde lente (0,8 Hz) e delta (1,6-4,0 Hz). Tuttavia, la loro distribuzione topografica è diversa, e la potenza dei complessi K è maggiore.

Delta waves are high amplitude neural oscillations with a frequency between 0.5 and 4 hertz. Delta waves, like other brain waves, can be recorded with electroencephalography (EEG) and are usually associated with the deep stage 3 of NREM sleep, also known as slow-wave sleep (SWS), and aid in characterizing the depth of sleep.



This is a screen shot of a patient during Slow Wave Sleep (stage 3). The high amplitude EEG is highlighted in red. This screen shot represents a 30-second epoch (30 seconds of data).

stages. In general, the "K" complex or arousal response could be easily identified by its wave form and its widely spaced occurrence which caused it to stand out sharply against the low voltage, spindle background.

Stage 3. An intermediate stage characterized by the appearance of high voltage slow waves with some spindling superimposed. In borderline cases, records with an average of less than two waves over 100 μ V. and 1-2 c/sec. or slower in 10 sec. were assigned to stage 2 and records with more than half over 100 μ V. and 1-2 c/sec. or slower were assigned to stage 4.

Stage 4. At least half or more of the record dominated by waves of 100 μ V. or greater in the 1-2 c/sec. range or slower.

It should be emphasized that judgment was based on a fairly long stretch of record. Thus, if classifications were made of every few seconds of record, for example during a spindle stage, a spindle wave form might not occur in this brief period and the low voltage background would have to be assigned to stage 1. This would give the misleading impression of excessively frequent alternation between stages. Also, there was some tendency for delta waves to wax and wane and a few seconds of record during a waning phase would then have to be assigned to a different stage. In general, the judging of the record was a continuous, on-the-scene process.

RESULTS

1. The occurrence and interrelations of rapid eye movements, brain wave patterns, and body motility during a night's sleep.

In the first series of experiments, a total of 71 nights of sleep recordings was taken from 26 men and 7 women. The number of nights slept by each subject ranged from 1 to 7 with the majority being studied for 2 nights. The length of the sleep period averaged 6.5 hours and ranged from 2 to 9. In general, sleep was continuous except for occasional brief awakenings indicated by the appearance of a waking EEG pattern which usually followed gross body movements. These brief awakenings, as a rule, were not recalled by the subjects on the following morning. For purposes of analysis, if the

awakening was prolonged more than a few minutes, the sleep period was considered terminated. Awakenings lasting more than a few seconds were easily identified by, in addition to the waking EEG, persistent muscle potential and movement artifacts, blink artifacts, and often the subject's calling out. The occasional brief bursts of waking EEG following body movements did not show these artifacts.

A. Eye Movements. Discrete periods during which their eyes exhibited rapid movements were seen in all 33 subjects every night they slept. The recorded eye movement potentials varied from just discernible up to several hundred microvolts. From controls it was seen that a 100 μ V. deflection corresponded roughly to a movement through a 20 degree arc in the plane of the electrodes. A single movement was executed in about 0.1-0.2 sec. and was followed by a fixational pause of varying duration. Several experiments with electrodes around both eyes confirmed that the movements were binocularly synchronous and that they occurred in all directions. The size, direction, and amount of the movements varied widely and irregularly from moment to moment and period to period. In general, the movements tended to occur in clusters which were grouped together into a rapid eye movement period. However, the movement was sometimes virtually continuous throughout such a period and at other times exceedingly sparse. As a rule, the relative quiescent intervals between clusters of movement varied from several seconds to several minutes. Quiescence of more than 5 min. almost invariably signaled the end of a rapid eye movement period, and then no movements were seen until the onset of the next period. Figure 1, A-C, presents examples of eye movement potentials recorded at a slow speed from the outer canthi of one subject on the same night to illustrate variations in quality and quantity. Figure 1, D, is the occipital EEG band during an eye movement period from the same subject to show relative voltages. The eye movement potentials in figure 1, E, were recorded from the subject the next morning while he was sitting erect watching the experimenter. He was told not to move

his head but did not know his eye movements were being recorded. This record indicates that the potentials of purposeful waking movements are comparable to those seen during sleep.

No rapid eye movements were seen during the onset of sleep in the subjects studied. Table I summarizes the data concerning successive eye movement periods throughout the night for this group of experiments. It should be noted from the mean durations that the eye movement periods tended to be longer the later in the night they appeared. In

first 6 hours of sleep, the average total time taken up by eye movement periods was 64 min. or 17.7 per cent. The percentage would, of course, be larger for sleep durations of 8 hours or more, since the longer eye movement periods generally occurred during the later portions of the night. For reasons to be discussed later, if sleep showed a persistent lightening at about 1 hour after the initial onset without the appearance of eye movements and then deepened again, the first eye movement period was tabulated with the group of second eye movement periods. This

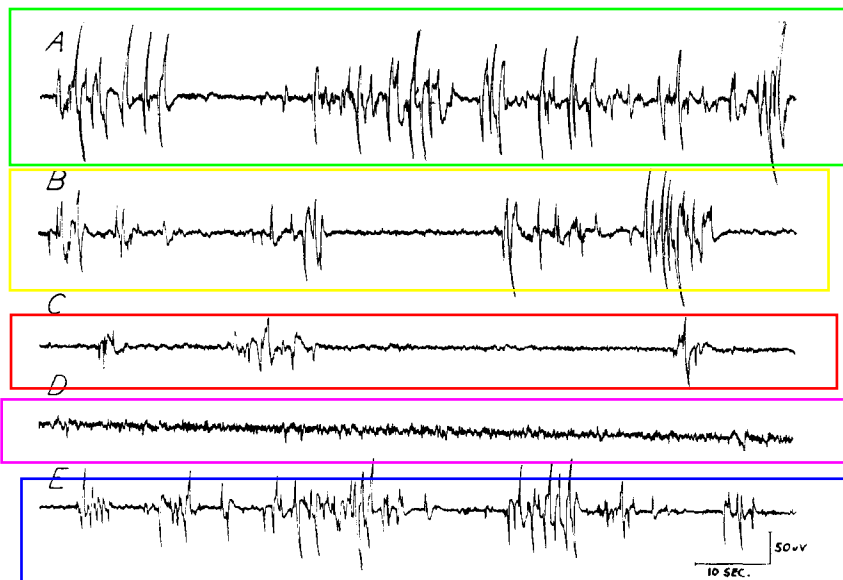


Fig. 1

Sample tracings of eye movement potentials. A-C are bipolar records from the outer canthi of one subject on a single night. D is the monopolar occipital EEG coincident with B illustrating the low voltage EEG. E is a sample of eye movement potentials from the same subject after awakening in the morning.

general, 4 eye movement periods were seen in 6 hours of sleep. Because of the small number of nights where sleep lasted longer than 6-7 hours only a few fifth periods were seen and in just one night's sleep lasting 9 hours was a sixth eye movement period observed. The shortest quiescent interval between eye movement periods was 36 min. The range of duration of eye movement periods was quite large, 1 to 72 minutes. The range of time of appearance after the initial sleep onset increased for each successive period due to temporal dispersion. Calculated on the basis of the

occurred in 15 of the 71 nights in records from 11 subjects.

A small series of control experiments was done to test the possibility that the lack of eye movement potentials at certain times was due to marked decrease of the resting potential of the eye. Subjects were awakened by a buzzer during these periods and according to previous instruction immediately began moving their eyes back and forth between two dim lights above the bed. In all cases, the eye movement potentials that appeared within 3 to 10 sec. after the onset of the noise were

comparable in amplitude to those seen during both sleep and wakefulness.

B. *Electroencephalographic findings.* The EEG showed a strikingly consistent relationship to the rapid eye movement periods. The only pattern seen while the eyes were moving was stage 1, a low voltage, non-spindling EEG. This stage invariably persisted throughout the entire eye movement period, including the intervals of relative ocular quiescence between clusters of movement, and also throughout the

TABLE I

TIME OF FIRST APPEARANCE AND DURATION OF SUCCESSIVE EYE MOVEMENT PERIODS

Eye Movement Period	Minutes after Sleep Onset		Duration	
	Range	Mean	Range	Mean
1st	45-118	67	1-36	9
2nd	107-222	156	2-54	19
3rd	180-340	253	4-72	24
4th	257-412	338	4-66	28
5th	300-420	404	30-39	34

entirety of periods with very sparse amounts of movement. Rare exceptions to this occurred when the EEG changed briefly to stage 2 in the middle of an eye movement period. No actual eye movements ever coincided with the stage 2 EEG, however, and the reappearance of eye movements was always accompanied by a reversion to stage 1. This "slipping" down to stage 2, when seen, usually happened during the first eye movement period and almost never occurred later in the night.

The stage 1 EEG persisting throughout the eye movement periods showed considerable variation within this classification. Generally a low voltage, irregular pattern, there were also many bursts or trains of regular 7-10 per sec. waves in the occipital leads, and 18-25 or 5-7 per sec. waves in the frontals. Although all these variations were usually seen in every subject, the occipital regular waves were more common in subjects with a prominent waking alpha rhythm and were characteristically 1-2 c/sec. slower than the waking frequency. The frontal "beta" waves were more common in non-alpha subjects. These synchronous patterns were somewhat

more prominent in the intervals between clusters of eye movements and often seemed to be disrupted or "blocked" by the eye activity. As far as could be seen, the EEG patterns accompanying an eye movement period 1 hour after the onset of sleep were no different from those accompanying eye movements 6 or 8 hours after the onset of sleep. Figure 2 contains sample EEG recordings taken on single nights from two subjects. It illustrates the stage classifications used in this study and particularly shows some of the various stage 1 patterns that occurred during the eye movement periods.

All the stage 1 EEG variations accompanying eye movements were also seen during the stage 1 EEG at the initial onset of sleep. The only distinction was that at the sleep onset the different patterns of the stage 1 classification appeared in a fairly orderly sequence as part of a steady progression from a waking EEG to deeper stages, whereas, during eye movement periods the stage 1 level was maintained for lengthy intervals, and variations within the stage occurred more or less at random.

The eye movement periods and sleep onset accounted for nearly all the stage 1 patterns. The only other times that they appeared in the records were: (a) following the cessation of eye movement periods but progressing quickly to stage 2; (b) often following large body movements for a few seconds; and (c) during the return to sleep after occasional brief spontaneous awakening. Of course, when the body movement or brief awakening occurred at a time when an eye movement period was about due, the stage 1 EEG could persist if rapid eye movements actually appeared. With the above exceptions, the interspersed periods of ocular quiescence were always associated with the "deeper" stages, 2, 3, and 4.

As the rapid eye movement periods occurred at regular intervals, so the EEG during the night showed a regular and concomitant variation. These regular sequences of variation were termed cycles. The definition of the first cycle was from the onset of sleep to the end of the first eye movement period. The second cycle was from the end of the first

eye movement period to the end of the second and so on throughout the night.

The usual sequence was that after the onset of sleep, the EEG progressed fairly rapidly to stage 4 which persisted for varying amounts of time, generally about 30 min., and then a "lightening" took place. While the progression from wakefulness to stage 4 at the be-

period ended, the EEG again progressed through a continuum of change to stage 3 or 4 which persisted for a time and then lightened often abruptly with body movement to stage 2 which again gave way to stage 1 and the second rapid eye movement period. This cyclic variation in the EEG recurred repeatedly throughout the night. The slowest,

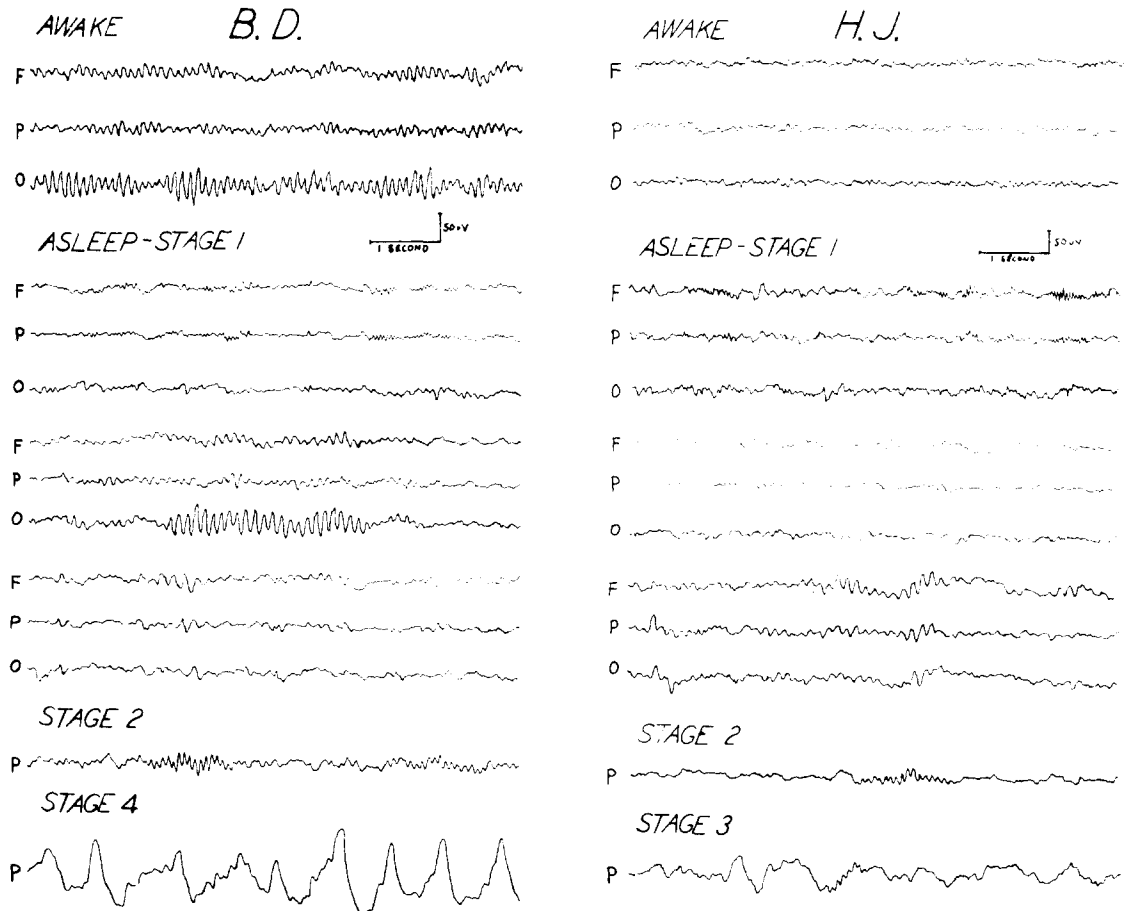


Fig. 2

EEG samples from two subjects to illustrate the classification of patterns and some of the variations in the stage 1 category associated with rapid eye movements. In the waking and stage 1 samples, each group of three tracings, F — frontal, P — parietal, O — occipital, is simultaneous. All samples were taken from one night's recordings.

ginning of the cycle was almost invariably through a continuum of change, the "lightening" was usually quite abrupt and coincident with a body movement or series of body movements. After the termination of stage 4, there was generally a short period of stage 2 or 3 which gave way to stage 1 and rapid eye movements. When the first eye movement

highest voltage waves were usually seen in the first cycle and stages 3 and 4 were only occasionally reached during cycles following the second. As a rule, cycles after the second were characterized by a progression only to stage 2 which persisted until the next eye movement period and stage 1. However, this was partly an artifact of the EEG categoriza-

tion since even in these cases there was obviously a progression to a "deeper" stage 2 and then a change to a "lighter" stage 2 before the onset of stage 1. There were, of course, many irregularities in the smooth sequence of events just described. Upward changes in the EEG often occurred in the middle of the cycles concomitant with body

the interpretation that the mechanism usually inducing the upward change to stage 1 was not active enough to get beyond stage 2. This occurred about 20 per cent of the time in this series of experiments. Eye movements never failed to appear, however, toward the end of the second cycle. Figure 3 shows examples of the EEG plotted continuously in several

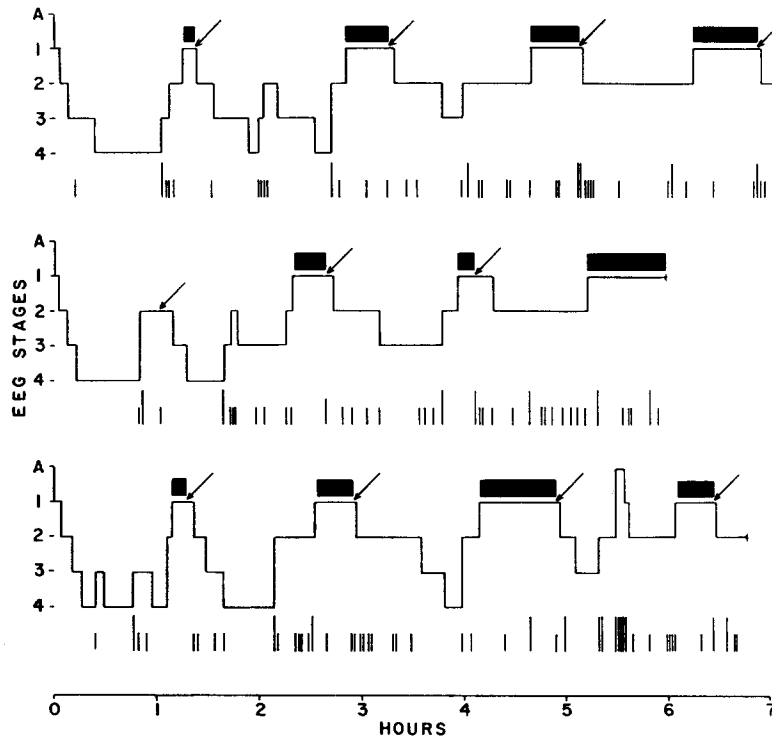


Fig. 3

Continuous plotting of the EEG patterns for three representative nights. The thick bars immediately above the EEG lines indicate periods during which rapid eye movements were seen. The vertical lines below stand for body movements. The longer vertical lines indicate major movements, changes in position of the whole body, and the shorter lines represent minor movements. The arrows indicate both the end of one EEG cycle and the beginning of the next.

movement only to settle back to the previous level.

Occasionally, when the upward change of the first cycle occurred, it reached a very light stage 2 which persisted for many minutes *without* giving way to stage 1 and rapid eye movements and then deepened again to stage 3 or 4. When this happened, the middle of the period of the stage 2 EEG was considered to be the end of the first cycle with

subjects for a night's sleep. Successive beginnings of what have been designated cycles are indicated by arrows. Eye movements are represented by thick bars and body movements by vertical lines. In this type of plotting gradual change through a continuum cannot be shown. When the EEG was judged to have reached a different stage an abrupt change was made on the graph.

The distribution of the occurrence of

spontaneous "K" complexes showed interesting peculiarities. As has been observed by others (Davis *et al.* 1939), this wave form appeared most frequently during periods of a low voltage spindling EEG. However, it was generally of greater amplitude and more frequent during the stage 2 EEG preceding an eye movement period than following. In fact, the stage 2 EEG following eye movement periods was often devoid of "K" complexes.

C. Body Movement. Body movements occurring during sleep were grouped into two categories, major movements and minor movements. The former were any movement resulting in a change in position of the whole body and the latter included any other detectable movement, usually stirrings and limb movements. In general, each type of movement simultaneously gave characteristic deflections on the motility recorder and artifacts on the EEG. However, small limb movements often appeared only on the motility recorder and chewing, sucking, and small head movements appeared only as EEG artifact.

During EEG stages 3 and 4, major movements were invariably accompanied by an upward EEG change which persisted for at least a minute or two and, as has been stated, often represented the upward swing of a cycle. Minor movements were frequently, but not always, accompanied by upward EEG changes. During stage 2, major movements usually resulted in a fleeting appearance of stage 1 or waking EEG while minor movements caused little apparent change and were usually followed by an immediate reappearance of spindling.

Figure 4A illustrates the cyclic variations in EEG, incidence of rapid eye movements, and incidence of body motility and their interrelations. The EEG stages, incidence of rapid eye movements and body motility during each successive 6 min. period after the onset of sleep were added and averaged for all 71 nights. Even without complete control over certain factors that might have disturbed the sleep pattern, such as the chance occurrence of excessive noise outside the building, and environmental temperature and humidity changes, a clearcut, regular, cyclic

variation in EEG and eye movements was seen for the group with the peaks of eye movement related to the peaks of the EEG cycle. A concomitant variation in body motility is suggested.

Since the cycle lengths tended to vary with the subject, the lining up of all the nights in terms of the sleep onset resulted in a considerable amount of phase interference between individual cycles especially in the latter portions of the composite histogram. This effect is eliminated in figure 4B which brings the interrelationships into clearer focus by breaking up the graph into

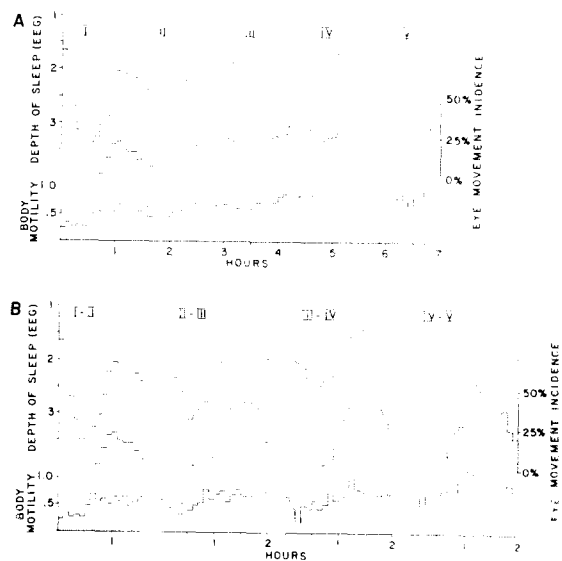


Fig. 4

(A) Composite histogram of mean EEG, eye movement incidence, and body motility incidence including 71 nights of sleep data from 33 subjects. The top curve was obtained by adding up the numerical values in terms of the EEG stages 1 through 4 for each successive 6 min. interval after the onset of sleep and dividing by 71. In the middle curve, the numbers of minutes of eye movement in each successive 6 min. interval were added for the 71 nights. If every night had showed 6 full minutes of eye movement in the same interval, a 100 per cent incidence would have been attained. The third curve is average incidence of body movement in arbitrary units. A major movement equalled 2 units and a minor movement, 1.

(B) This graph is the same as A except that the 6 min. intervals are oriented in terms of the beginnings of successive cycles instead of the initial sleep onset. This reduces the effect of temporal dispersion and further shows that there are no eye movements for a considerable time after the beginning of a new cycle.

individual cycles, that is, placing the beginnings of all subsequent cycles at the same place so that the start of the graph of the 2nd cycle contains the beginnings of all the individual 2nd cycles regardless of where they occurred in relation to the initial onset of sleep and likewise for the 3rd and 4th cycles. In addition to a more sharply defined EEG-eye movement relationship, it now can be clearly seen that the incidence of gross body motility also undergoes a cyclic variation.

The fact that the mean incidence of gross body movement seems to rise to a peak concomitant with the EEG peak in figure 4B is somewhat misleading. During the actual experiments it was seen that rapid eye movement periods often started immediately after a series of body movements and that a body movement often coincided with their termination while the sleeper seemed relatively quiet during the eye movement period itself. A graph of the incidence of body motility with reference to the onset and termination of eye movement periods was made (figure 5) and it was seen that the incidence rose to a peak,

dropped sharply at the onset of eye movements, and rebounded abruptly as the ocular activity ceased.

On seven nights, the experimenter sat near the bed and watched the subjects throughout the entire night with the aid of a dim light, making notations of the occurrence and quality of the body movements and their duration. These observations confirmed what has been stated, but in addition, it was noticed that during rapid eye movement periods numerous very small distal limb and digital movements occurred which did not register on either the EEG as artifacts or the motility recorder as deflections. Thus, although gross body and limb movements were decreased during rapid eye movement periods, there seemed to be a unique increase in very fine movements which were almost entirely absent during the interspersed periods of ocular quiescence.

II. Stage 1 EEG without eye movements.

It was mentioned previously that no rapid eye movements were seen during the onset of sleep when the EEG passed through stage 1 in going from the patterns of full wakefulness to the spindle and delta stages, although this stage 1 EEG seemed to be identical with those occurring later in the night concomitant with actual eye movements. Since the later stage 1 patterns are apparently associated with dreaming (Dement and Kleitman 1957), it seemed desirable to investigate the stage 1 EEG at the sleep onset with regard to dream activity in spite of the lack of rapid eye movements.

Ten subjects were awakened a total of 50 times by a buzzer while the EEG showed patterns within the range encompassed by the category, stage 1, during the initial onset of sleep and in addition, were occasionally awakened during rapid eye movement periods later in the night. They were asked to give their impressions of what had been in their minds before the awakenings and, if possible, to differentiate between the state of mind preceding the early versus the later awakenings.

In all cases, the subjects felt that, although the mental content during the onset of sleep

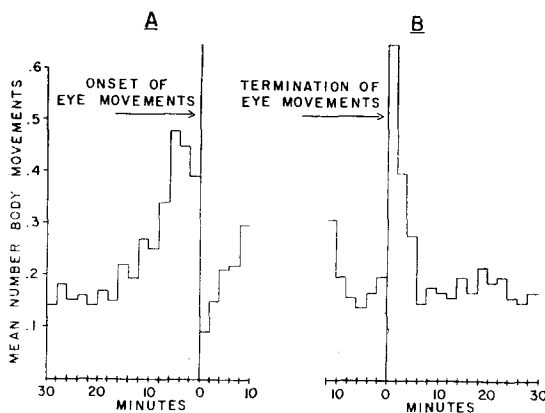


Fig. 5

A composite histogram of the incidence of body movement in terms of the onset and termination of rapid eye movement periods. It brings into clear focus the tendency of body movement to increase up to the beginning of eye movements at which point it decreases sharply and rebounds at the end of the period of eye activity. Since the eye movement periods were of widely varying lengths, two separate histograms were necessary. Data from 198 eye movement periods is included. Remembering that eye movements and stage 1 EEG were concomitant, the graph also indicates that more body movements occurred while a stage 2 EEG was present than a stage 1.

was often "dream-like", it was distinctly different from an actual dream. They invariably stated that they were not asleep and that the mental imagery was not as organized or "real" as that occurring in dreams. A variety of images and sensations were described that might be called hypnagogic, such as "floating", "drifting", "flashing lights", etc. The later eye movement, stage 1, awaken-

tained, the intensity was raised slightly and the stimulus was repeated after one minute had elapsed. This procedure was continued until the subject responded. Intensity was calibrated in terms of voltage across the loudspeaker.

A total of 32 responses was obtained from the 10 subjects during the stage 1 EEG at the onset of sleep and 26 responses were elicited

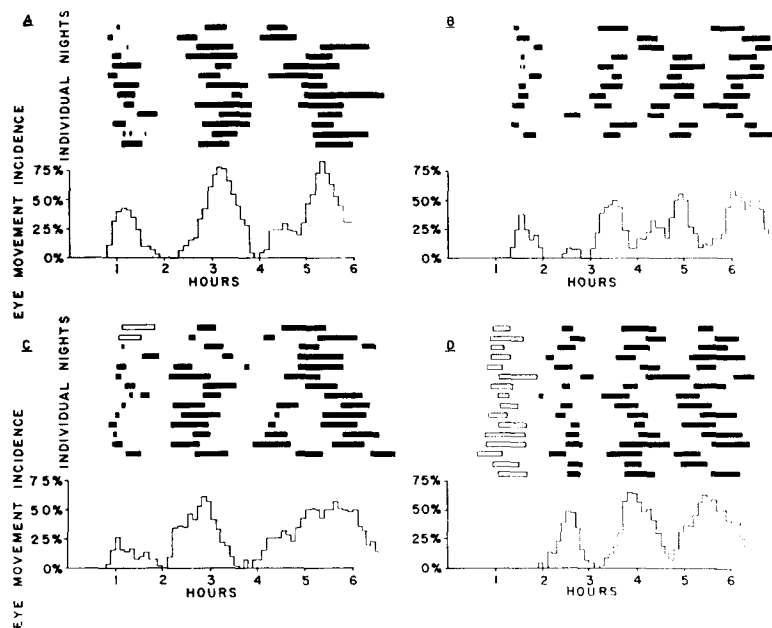


Fig. 6

The regularity of rapid eye movement periods over a number of nights in 4 individual subjects (A-D). Each bar represents a single eye movement period and each horizontal line of bars, a single night. The open bars in C and D stand for periods of stage 2 EEG which represent the peak of the first sleep cycle. Composite histograms of eye movement incidence for each individual are placed below the group of nights to which they refer. In general, these histograms show the cyclic variation more clearly than figure 4 A, i.e. individuals seem to be more regular than the group as a whole.

ings generally elicited dream recall and the impression of having been "really asleep".

A further test of the difference between the two phases was done by examining the auditory thresholds necessary to elicit a response from the subjects. The stimulus was a 1000 cycle tone sounded for 10 sec. and the response was clenching the jaw 3 times which gave easily identified muscle potentials in the EEG record. If no response was ob-

during the stage 1 EEG periods accompanying eye movements later in the night. The threshold ranged from 0.1-0.4 V. at the sleep onset and 1.0-1.8 for the later awakenings. The difference of the means was significant at the $p < .001$ level. Further attesting to the significance of this difference was the fact that the stage 1 EEG at the sleep onset was always allowed to progress to a complete disappearance of alpha rhythm while the

EEG at the time of the stimulus during rapid eye movement periods often contained considerable amounts of alpha activity.

III. Individual differences in normal sleep.

Four subjects were further studied for from 12 to 16 nights per subject in a third group of experiments to obtain some information regarding individual differences.

Figure 6, A-D, shows the durations and patterns of occurrence of eye movement periods for each night in the 4 subjects, together with a composite histogram of overall incidence of eye movement for each individual. The bars which indicate eye movement periods also, of course, represent periods of stage 1 EEG.

Certain individual characteristics and differences were apparent. Two subjects (6A and 6D) showed a striking regularity in the pattern of occurrence from night to night, while the other two were less consistent, especially 6C. Apparently the actual time at which they went to sleep was not important since for the former two it ranged irregularly over about 3 hours and oddly enough, for the latter two it was at nearly the same time every night. One subject (6D) was unique in that rapid eye movements never appeared during the first "lightening" or upswing of the EEG cycle. The persisting periods of stage 2 representing the first peak in this subject are indicated by open bars. The average cycle lengths varied somewhat, being longest in 6A and shortest in 6D. The subject illustrated in 6C seemed to have short cycles in the first half of the night and long ones in the second half, but this may have been at least partially an artifact of his irregularity. The average duration of eye movement periods was greatest in 6A and least in 6B. In general, it appeared that individual subjects were somewhat more regular than the group as a whole.

DISCUSSION

Regularly occurring periods of rapid, conjugate eye movements were recorded without exception during each of 126 nights of undisturbed sleep. The periods of eye movements were invariably concomitant with a char-

acteristic EEG pattern, stage 1, while the interspersed periods of ocular quiescence always showed "deeper" patterns, stages 2, 3, and 4. The same results were obtained in an additional 20 nights during which sleep was interrupted for the determination of auditory threshold and the presence of dream recall. The composite EEG for 71 nights from 33 subjects showed a regular cyclic variation with a period of about 90-100 min. and the regularity was even more striking when studied in terms of individual subjects.

This cyclic variation was reported in a preliminary communication (Dement and Kleitman 1955) after the accumulation of 43 nights of recording from 16 subjects. It should be mentioned that the composite histograms of EEG and incidence of eye movements for 43 nights were quite similar to those shown in figure 4 for 71 nights. The inclusion of 28 nights' data from 17 additional subjects did not significantly alter the curves and it is likely that a further accumulation of recordings would add little to the results.

The basic mechanism of such a regular occurrence of eye movements (dreaming) and associated EEG variation is unknown. However, its prototype may exist in infants (Aserinsky and Kleitman 1955) as an observed rest-activity cycle during sleep with a period of approximately 60 min. The greater cycle length seen in adults resembles the lengthening of other physiological cycles, i.e. cardiac and respiratory, and may be related to their lower basal metabolic rate. In any case, the regularity and apparent universality of this sleep cycle in adults indicate that it is an intrinsic part of the sleep pattern rather than a result of external disturbance.

A close perusal of the all-night EEG graphs published by Loomis *et al.* (1937), Knott *et al.* (1939), and Díaz-Guerrero *et al.* (1946) reveals a tendency toward this type of cyclic variation. Henry (1941) found that 20 per cent of the EEG during a night's sleep was occupied by a low voltage pattern which is almost identical with the percentage of stage 1 found in this study. It seems possible that sampling techniques rather than continuous recording, miscategorization of the

EEG due to eye movement potentials appearing in brain wave leads, and disturbances of the subjects may have been responsible for these authors not noting the marked regularity described here. Long periods of low voltage EEG called "null" by Blake and Gerard (1937) and "early morning sleep" by Gibbs (1950) probably represent the lengthy rapid eye movement periods often occurring toward the end of the sleep period. It is also gratifying to note that Brooks *et al.* (1956) have recently published graphs of the mean EEG showing cyclic variations in depth of sleep that are similar to the results previously reported by us (Dement and Kleitman 1955) and further extended in this paper.

In the study of rapid eye movements and dreaming (Dement and Kleitman 1957) it was suggested that eye movements should be the criterion of the presence or absence of dreaming and they were used as such in this study. However, it should be pointed out that the EEG is actually a better criterion. Thus, *with the exception of the initial onset of sleep*, a persisting stage 1, non-spindling EEG seems to be invariably concomitant with dreaming while the amount of eye movement may be large or small depending on the actual imagery of the dream.

As stated, the only significant occurrence of stage 1 EEG patterns not accompanied by rapid eye movements was found at the onset of sleep. However, the auditory thresholds were still quite low at these times, and awakenings elicited descriptions of what may be called hypnagogic reveries and the feeling of being still awake. On the other hand, the stage 1 periods later in the night were invariably associated with eye movements, raised auditory thresholds, dream recall, and the feeling of having been "really asleep". The difference probably has to do in part with a persisting awareness of being awake in the former case, whereas the dream periods generally followed an interval of deeper sleep and thus the sleepers had no such cue to tell them the dream hallucinations were not real. They therefore behaved as though they were real, at least to the extent of executing appropriate eye movements. The raised auditory thresholds may have meant either that

the subjects were too engrossed in the dream content to notice outside stimuli, or an actual difference in auditory excitability.

The incidence of stage 1 EEG patterns and rapid eye movements during undisturbed all night sleep and the quantity of dream recall obtained by awakening subjects during these periods (Dement and Kleitman 1957) suggests the normal occurrence of a much greater amount of dreaming than was heretofore realized, both in the invariability of its presence from night to night and in its frequency and duration in a single night. Previous estimates of incidence of dreaming, which were generally based on recall obtained after morning awakenings, have varied from once a night to almost never (Ramsey 1953). In contrast, as many as 5 or 6 lengthy dreams have been frequently described after awakenings during eye movement periods even by subjects who previously stated that they "never dreamed".

It is apparent then that most of the dream experience in normal sleep is never recalled. That which is recalled can probably be accounted for by the fortuitous interruption of dreaming, as for instance when the alarm clock goes off in the morning. It should be noted from the incidence of rapid eye movements later in the night (fig. 4) that the chances of the alarm clock interrupting a dream are very good. The level of consciousness represented by dreaming would thus seem to be associated with a very short memory span, perhaps in some way analogous to that seen in very young children and in old people, who often have difficulty in recalling recent events. In some instances, even when the dream content was reported clearly and coherently after an awakening during an eye movement period, a re-description in the morning was fragmentary and distorted.

Several points of interest are seen when the results of the earlier study where subjects were awakened to elicit dream recall (Dement and Kleitman 1957) are compared to the results of this study on uninterrupted sleep. In the earlier study, subjects were awakened an average of 6 times a night or about once an hour. The main effect of these

awakenings was a more frequent occurrence of eye movement periods. This was clearly seen in one subject who served in both the earlier study and this one. As illustrated in figure 6A, he showed an average of about one eye movement period every 110 min. When his sleep was interrupted, he averaged one eye movement period every 70 min. over 11 nights. This reduction in cycle length seemed to be due to the artificial termination of the eye movement periods by an awakening when their duration was much less than their average in undisturbed sleep.

As a rule, eye movements did not immediately recur upon the return to sleep. In 191 awakenings during eye movement periods in the earlier study, there were only 16 instances of recurrence. Interestingly enough, 12 of the 16 were preceded by 1-5 min. of stage 2 sleep without eye movements, and 9 of the 16 were occasions when the subjects were unable to remember dreams and thus only had to say, "I don't remember", before going back to sleep. Furthermore, it was noted in the part of this study concerning auditory thresholds, where the subjects had only to clench their jaws three times, that eye movements recurred much more often, about 50 per cent of the time. It seemed that when the subjects had to awaken fully and describe a dream, the return to sleep generally was more like the initial sleep onset and a new cycle was initiated, whereas a brief or "partial" awakening often allowed the eye movements to continue. Awakenings during the interspersed periods of ocular quiescence seemed to have little effect, in that eye movements neither started on the return to sleep nor was the time of onset of the next eye movement period markedly changed from what would have been expected in the absence of an awakening. One explanation for this minimal effect could be that ocular quiescence was concomitant with deeper sleep (EEG stages 2, 3, and 4) and since the inability to recall dreams meant a relatively short period of wakefulness, the subjects were able to return to the deeper levels of sleep without disturbing the cycle pattern.

The deepest sleep in terms of EEG patterns was usually seen in the first hour and

nearly all the high voltage delta activity occurred in the first three hours. This parallels depth of sleep curves in terms of eye movement incidence, auditory arousal threshold (Blake and Gerard 1937), and in a general way, body motility, but not curves in terms of heart rate, skin resistance, and body temperature (Kleitman 1939). Also, body motility incidence did not consistently parallel the brain wave patterns in this study. Although it was lowest during stage 4, more movements were actually initiated in the presence of stage 2 patterns than during stage 1. Depth of sleep would seem to be a rather elusive characteristic which differs according to the specific variable used to describe it.

EEG and Consciousness. One of the most intriguing properties of the electroencephalogram has been the close correlation of some of its characteristic patterns with certain functional states of the organism. It has always been hoped that clarification of the mechanisms producing these patterns would yield insight into the neural basis of the functional states with which they are associated. An example in which these hopes have been at least partially realized can be seen in recent work on the brain stem activating system. Since stimulation of the reticular formation was found to elicit an EEG pattern associated with the waking state, while its ablation gave patterns generally associated with somnolence, the system was said to function in maintaining wakefulness. Without the correlation of EEG pattern and functional state, such a conclusion could not have been made.

One would like to use the EEG in a similar way to aid in defining the neural basis of consciousness. Of course, this immediately presents the very difficult problem of formulating an adequate definition of "consciousness". In the past, this obstacle has often been side-stepped by equating consciousness with wakefulness and unconsciousness with sleep. In addition to avoiding semantic entanglement, this device would seem to afford the advantage of conveniently relating levels of consciousness at least grossly to brain wave patterns. However, such a definition is in reality of little value because it tends to result in mere repetitious dis-

cussion of what is known about the neural basis of wakefulness, substituting for it the word "consciousness".

It should be noted that sleep and wakefulness, as states, can be objectively observed and to some extent measured. They can be compared and contrasted, and they can usually be distinguished from each other by simple inspection. In consciousness, on the other hand, the sleep-wakefulness dichotomy is absent. There is only one state whose criteria are mainly subjective, though partly objective, as the observer is able to make some inferences. One may omit the use of the term unconsciousness and merely refer to levels of consciousness varying from zero to a high level, depending upon the communications and performance of the individual.

Even with a very simple description of consciousness, i.e. the ability to analyze, integrate, and subsequently recall experience, it is obvious that a high level of consciousness is not always limited to wakefulness, nor does sleep always imply a very low or zero level of consciousness.

New-born infants, anencephalous children, and decorticate dogs or cats may exhibit wakefulness, but their level of consciousness is close to, if not at, zero. In delirium, fugues, ieteral or post-icteral automatism of psychomotor epilepsy, a person may be judged to be behaviorally awake, but his level of consciousness is very low.

Of course, the above examples are special cases, but the converse, consciousness during frank sleep as represented by the level of analysis, integration, visual imagery, and subsequent recall seen during dreaming, is virtually universal and quite normal. Since dreaming in the past was said to occur during all the EEG levels of sleep, one had to conclude that at least in sleep there was no particular relation between brain wave patterns and consciousness, and that the neural functioning, whatever it might be, underlying the production of spindles and high voltage slow waves, as well as low voltage patterns, was compatible with this degree of mental activity.

That this lack of relation between brain waves and consciousness, as represented by dreaming, is not the true picture seems clearly

indicated by this study. It was seen that the rapid eye movements during sleep, which almost certainly are concomitant with dreaming, occurred when, and only when, the EEG was "above" the spindling stage — that they were uniquely associated with a stage 1 EEG. Consequently, whatever its level during dreaming, consciousness ceases or at least falls below this level, in the normal course of events, when spindling appears in the EEG.

The hypnagogic reveries in falling asleep also apparently cease when the EEG reaches the spindling stage. Davis *et al.* (1938), in several hundred awakenings, elicited all sorts of reports of images and sensations from subjects whose EEG patterns had not progressed beyond their "B" stage, but when the "C" stage (spindling) appeared, awakenings no longer elicited hypnagogic recall and subjects said they were "really asleep". These findings were confirmed in this study.

With dreaming and hypnagogic reverie assigned to a definite EEG stage, there exists at least a fairly consistent relation between the EEG and levels of consciousness and it becomes possible to undertake the second step of considering the neural origin of these patterns as representing the basis of consciousness itself.

An examination of the mechanism of spindling would seem to be the most fruitful point of departure. In the first place, the appearance of sleep spindles represents a rather sharp, all-or-nothing type of brain wave change. They are either present with a wide distribution and a characteristic frequency and wave form (although there are topographical differences in frequency) or they are not seen at all. Secondly, their appearance or disappearance appears to be associated with a sharp change in the level of consciousness.

Although no completely satisfactory explanation has been extended for the mechanism of sleep spindles, it seems to be generally agreed that the integrity of certain subcortical structures is necessary. Spindling was found to be suppressed in humans after subcortical vascular accidents (Cress and Gibbs 1948) and prefrontal lobotomy

(Lennox and Coolidge 1949, Krueger and Wayne 1952), and in a patient with thalamic syndrome (Henriksen, Grossman and Merlis 1949). Subcortical lesions in cats (Knott and Ingram 1951) also seem to disrupt the appearance of spindle patterns. If barbiturate bursts and recruiting responses are considered analogous to normal sleep spindles rather than alpha rhythm, as is suggested by Ralston and Ajmone-Marsan (1956), then the role of the thalamus becomes very compelling.

It should be pointed out that even though the spindles may represent the synchronous activity and influence on the cortex of a diffuse thalamo-cortical system, disturbance of the pattern does not necessarily imply that the system has been totally destroyed nor that it is completely functionally incapacitated. That several similar systems exist together, in humans at least, was indicated by Lennox and Coolidge (1949) who found that pre-frontal lobotomy with probable subsequent degeneration of nucleus centralis medialis of the thalamus only affected the frontal 12/sec. spindles and left 14/sec. spindles unimpaired in both parietal and frontal regions. Thus, although the spindle patterns might be disturbed, it would probably take far larger lesions to totally destroy the systems that produce them, and such lesions would probably be incompatible with consciousness.

Some sort of diffuse diencephalic-cortical integrating system has been hypothesized by Penfield (1938, 1952) as a necessary component of conscious activity. If the synchronous patterns of spindling may be said to represent functional inactivity in such a system, assuming that during mental processes neural activity is essentially random, then the relation of the spindle patterns to consciousness becomes neurologically meaningful. That the waking EEG lacks spindles and is usually correlated with a high level of consciousness is well established. The results in this paper indicate that all periods of non-spindling EEG during sleep are also correlated with consciousness either as dreaming or hypnagogic reveries. The appearance of spindling signals a drop in the level of consciousness and is concomitant with functional inactivity

(i.e. synchronicity) of a diffuse subcortical-cortical integrating system.

The mere appearance of synchronous waves in the cortex by itself, however, certainly does not necessarily mean functional inactivity. A synchronous, persistent alpha rhythm may be present during very complex mental activities. The waves at the cortex more probably represent variations in membrane potentials, possibly in the dendritic layers, rather than synchronicity of actual nerve impulses. However, if the waves are due to subcortical influences, then there is almost certainly a synchronicity in nerve impulses ascending to the cortex. Thus, the presence of regular variations in cortical potential, as in alpha rhythm, may influence but not necessarily hamper the random flow of nerve impulses during thinking, whereas synchronous barrages of nerve impulses in diffuse projection systems might mean that the neural elements are unavailable for the essentially random firing of high level integration. It might be added that since there is no evidence of any consciousness during the deepest stages of sleep characterized by predominance of 1-2 sec., high voltage waves, the relative lack of spindling at this time is more likely a further depression of these systems rather than their activation.

The brain stem activating system is also very probably involved in producing the periods of rapid eye movement. Certainly the stage 1, low voltage EEG seen during these periods is at least partially "activated". The regions of the brain stem that produce activation of the EEG in animals apparently include both the bulbar ventromedial inhibitory (Moruzzi and Magoun 1949) and facilitatory (French, von Amerongen and Magoun 1952) reticular areas of Rhines and Magoun (1946) and Magoun and Rhines (1946). In this study, it was seen that the incidence of gross body movement was decreased during rapid eye movement periods. This may mean that mainly the inhibitory area was active at these times. A teleological basis might be that the dreamer is fixed or arrested by his preoccupation in the dream picture, analogous to the way one is held in motionless fascination by an exciting movie. Of course, it does

not account for the objective stillness of the dreamer when he is executing some violent movement in the dream, such as running, fighting, etc.

It appears to be possible in certain cases to produce a dissociation between the EEG and objective behavior. Wikler (1952) found after injection of atropine in dogs that the animals "were definitely 'excited' and had to be restrained to permit recording, at a time when the 'sleep patterns' were evident in the EEG tracing", and Rinaldi and Himwich (1955) saw stable sleep patterns in curarized, atropinized rabbits even during apparent behavioral arousal. There is also one report in the literature (Hamoen 1954) of sleep patterns including spindles occurring in 6 behaviorally awake humans suffering from narcolepsy, epilepsy, trauma, and schizophrenia.

On the other hand, patterns very nearly resembling those generally associated with full wakefulness, called "drowsy" patterns by Gibbs (1950), "transitional" by Simon and Emmons (1956), and "stage 1" in this paper, are seen at the onset of sleep, and also during the frank behavioral sleep with raised auditory threshold associated with dreaming. In addition, EEG patterns virtually indistinguishable from waking patterns have been observed to occur periodically in tracings taken in this laboratory from cats during a lengthy interval of normal, unsedated sleep.

Thus, as has been pointed out, consciousness may vary independently of sleep-wakefulness behavior, and likewise, EEG patterns may be in some cases dissociated from behavioral sleep and wakefulness. A consistent parallelism between levels of consciousness and EEG patterns is difficult to establish but may exist. In at least three qualitatively similar mental states, the EEG appears to be identical. One, dreaming, is seen during frank behavioral sleep. Another is represented by the hypnagogic reveries occurring in the transition between sleep and wakefulness. The third is from the very interesting McGill "boredom" studies (Heron 1957) where subjects showed the appearance of minimal slow wave activity and a slight decrease in the frequency spectrum of alpha

rhythm while awake but mentally disorganized and actively hallucinating. These EEG changes would seem to resemble those described in this paper as characteristically associated with dreaming. An even lower level of consciousness probably existed in the wakeful, atropinized animals showing sleep EEG patterns. In view of these considerations, it would appear that behavioral criteria should take precedence in determining the presence of sleep or wakefulness, whereas the electroencephalogram may be more closely related to levels of consciousness.

SUMMARY

In 33 adults, discrete periods of rapid eye movement potentials were recorded without exception during each of 126 nights of undisturbed sleep. These periods were invariably concomitant with a characteristic EEG pattern, stage 1.

Composite histograms revealed that the mean EEG, eye movement incidence, and body movement incidence underwent regular cyclic variations throughout the night with the peaks of eye and body movement coinciding with the lightest phase of the EEG cycles. A further analysis indicated that body movement, after rising to a peak, dropped sharply at the onset of rapid eye movements and rebounded abruptly as the eye movements ceased.

Records from a large number of nights in single individuals indicated that some could maintain a very striking regularity in their sleep pattern from night to night.

The stage 1 EEG at the onset of sleep was never associated with rapid eye movements and was also characterized by a lower auditory threshold than the later periods of stage 1. No dreams were recalled after awakenings during the sleep onset stage 1, only hypnagogic reveries.

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