BRITISH MEDICAL JOURNAL

LONDON SATURDAY MARCH 1 1952

STUDIES ON THE PHYSIOLOGY OF AWARENESS: ANOXIA AND THE LEVELS OF SLEEP *

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It has recently been suggested (Lovett Doust, 1951a) that the varying strata of attention and awareness are intimately related to the levels of the arterial blood oxygen saturation as determined by the methods of continuous oximetry. It was shown that "attention peaks" of periods of increased concentration and awareness are associated with a rise in the oxygen saturation levels, whereas periods of boredom, decreased concentration, reverie, etc., are correspondingly accompanied by falls in the oximetric values.

Considerable work has already been done on the question of anoxia in various pathological and pharmacological analogues of natural sleep, and its importance in these states appears to be paramount. An impressive parallelism has also been found between many types of fatigue conditions and the clinical syndrome induced by experimental anoxic anoxia; indeed, Barcroft (1925) suggested many years ago that the symptomatology of chronic anoxia was that of mental and bodily fatigue.

These phenomena are closely associated with consciousness, and it was therefore thought desirable to follow such changes to their logical fulfilment—namely, that of natural sleep.

Experimental Procedure

Seven normal healthy human subjects were studied and 22 observations made over a period of three months. Six of the subjects were males and the seventh a female. Ages ranged from 22 to 36 years.

Arterial blood oxygen saturation levels were measured photo-electrically and continuously by means of a Millikan oximeter (Millikan, 1942), with the sensitive photo-cell attached to the pinna of the ear in the conventional manner. The instrument was previously standardized on each occasion by the inhalation of 100% oxygen from a cylinder through a modified B.L.B. mask for at least seven minutes until stationary readings were obtained on the galvanometer.

*This work was done during the tenure of a Nuffield Foundation Medical Fellowship (J. W. L. D.) and of a Commonwealth Fellowship (R. A. S.).

The experiments were conducted under conditions as natural as possible and, so far as circumstances permitted, for night-long periods. For the latter experiments the subject changed into night attire, performed the customary chores of brushing his teeth—reading if that were his wont preparatory to his retiring—and was provided with a comfortable bed in the darkened laboratory.

An observer was constantly present in the same room and a continuous record was made of the galvanometric deflections as they occurred. He also noted changes in the position of the subject, the type and rate of respirations, snoring, the influence of external stimuli, the apparent depth of sleep, etc. At the conclusion of each experiment an inquiry was made of the subject to ascertain details of the depth and quality of sleep, the ability to recall events of the night, and the nature of any fantasy or dreaming.

An attempt was made objectively to record respiratory pattern changes, but this was not found feasible under the otherwise "natural" conditions of the investigation. It was abandoned in view of the already large body of data in this regard (Best and Taylor, 1945).

Results: Sleep and Progressive Anoxaemia

A rather consistent pattern was seen to obtain in some seven observations of protracted, restful, satisfactory sleep. Five observations were made over a period of about three to six hours, from 1 a.m. to 7 a.m. Four observations were made earlier in the evening—for example, from 10 p.m. to 1 a.m.—and the remainder during a postprandial "nap" from 1 to 2 o'clock in the afternoon.

The accompanying Table lists the basic data, and oximetric charts are exemplified in Figs. 1, 2, and 3. Considerable variation was noted to occur, both between different subjects and in repeated observations on the same subject, but a similar overall picture was evident. Noteworthy points will be mentioned later concerning the differential progress of the march of sleep, but, in general, it may be said that the subject began on a base-

Table Showing the Basic Data on 22 Sleep Observations in 7 Subjects (A–G). All Save Subject A Were Males

Subject	Plane 1					Plane 2					Plane 3					Plane 4				
	T	O_2	M	N	R	T	O_2	M	N	R	T	O_2	M	N	R	T	O_2	M	N	R
A	28	94–97	16	7	0	140	90–94	14	17	1	120	89–91	9	7	4	44	86–90	5	1	6
B	34	90–93	10	4	0	46	90–92	4	5	0	40	85–91	2	0	9	39	87–88	2	3	2
B	10	93–95	0	0	0	15	90–92	0	0	3	0	—	—	—	—	0	—	—	—	—
C	1	95–97	0	0	0	13	89–96	1	0	5	18	87–92	2	0	4	31	87–89	1	1	2
C	74	93–96	13	3	23	14	92–96	5	1	11	8	88–93	0	0	3	0	—	—	—	—
C	11	93–95	0	0	0	13	90–92	0	0	0	25	89–90	5	0	14	0	—	—	—	—
C	12	93–94	2	0	0	42	89–93	4	0	5	0	—	—	—	—	0	—	—	—	—
C	3	94–96	3	0	0	10	90–92	0	0	1	21	88–90	8	3	15	0	—	—	—	—
C	5	94–95	0	0	0	11	90–93	0	0	0	0	—	—	—	—	0	—	—	—	—
D	10	95–96	0	0	0	30	92–96	6	1	4	55	89–92	3	5	4	0	—	—	—	—
D	9	92–95	10	0	0	15	90–93	2	3	3	8	89–91	0	1	2	0	—	—	—	—
D	13	92–94	0	0	0	10	91–92	3	1	0	0	—	—	—	—	0	—	—	—	—
E	7	92–94	3	0	0	1	90–92	1	0	0	4	86–90	2	1	2	0	—	—	—	—
F	15	95–97	0	0	0	11	90–92	2	0	1	23	89–91	0	0	2	32	87–88	0	0	0
F	9	92–93	3	2	0	13	91–92	1	1	3	3	88–91	1	1	1	22	86–88	0	4	0
F	6	92–93	3	0	0	10	90–92	6	0	0	12	89–91	5	0	0	0	—	—	—	—
F	13	92–95	0	0	0	10	90–92	0	0	3	0	—	—	—	—	0	—	—	—	—
F	5	93–95	0	0	0	4	91–93	0	0	2	0	—	—	—	—	0	—	—	—	—
F	2	92–93	0	0	0	14	90–91	5	0	2	8	89–91	2	3	0	0	—	—	—	—
G	53	91–96	0	2	0	27	90–93	6	5	0	48	88–91	3	6	2	26	87–88	2	7	3
G	48	93–95	6	0	0	30	90–92	2	0	0	62	88–91	3	0	0	28	86–89	0	2	0
G	3	94–97	0	0	0	40	90–92	4	5	0	0	—	—	—	—	0	—	—	—	—

Subject	Plane 5					Plane 6					Plane 7					Remarks
	T	O_2	M	N	R	T	O_2	M	N	R	T	O_2	M	N	R	
A	16	89–91	0	0	0	4	90–92	0	0	0	14	92–95	0	0	0	Good restful sleep
B	20	87–91	1	2	2	3	91–92	0	0	0	4	92–93	0	0	0	,, ,, ,,
B	0	—	—	—	—	6	91–93	0	0	0	12	92–93	0	0	0	Sleepy
C	20	86–91	7	1	2	16	88–92	2	3	2	5	90–93	0	0	0	Good restful sleep
C	3	90–92	0	0	1	5	91–92	0	0	0	5	92–93	0	0	0	Short period of light sleep
C	0	—	—	—	—	2	89–92	3	0	2	2	92–94	0	0	0	Light sleep
C	0	—	—	—	—	6	89–92	4	0	5	6	93–94	0	0	0	Reverie. Day-dreaming
C	0	—	—	—	—	2	89–92	5	2	2	9	94–97	0	0	0	Light sleep
C	0	—	—	—	—	3	90–93	1	1	3	7	94–95	0	0	0	Reverie
D	36	90–93	7	2	2	6	89–93	3	0	3	8	92–93	0	0	0	Light sleep
D	0	—	—	—	—	2	90–92	0	1	5	3	92–94	0	0	0	Light sleep. Anxious
D	0	—	—	—	—	1	91–92	0	0	0	4	92–94	0	0	0	Reverie
E	0	—	—	—	—	3	90–92	0	2	3	8	92–94	0	0	3	Dozing
F	3	89–91	0	0	0	7	87–93	5	0	3	6	92–93	0	0	5	Dozing into deep sleep
F	26	89–90	0	0	0	7	91–92	4	2	3	4	92–94	0	0	2	,, ,, ,, ,,
F	0	—	—	—	—	5	90–92	10	0	2	7	92–93	0	0	0	Light sleep
F	0	—	—	—	—	3	90–93	0	0	2	14	91–94	0	0	0	Reverie
F	0	—	—	—	—	2	91–95	0	0	0	11	94–95	0	0	0	,,
F	0	—	—	—	—	32	89–92	15	36	5	4	92–93	0	0	0	Light sleep
G	12	89–92	5	5	3	4	91–94	0	0	0	3	92–94	0	0	0	Good restful sleep
G	7	89–90	0	0	0	5	91–92	3	0	2	15	91–94	0	0	0	,, ,, ,,
G	0	—	—	—	—	2	90–92	3	2	1	5	92–93	0	0	0	Reverie

"T" is time in minutes spent in any one plane of sleep; "O_2" is the % range of arterial blood oxygen saturation as determined by continuous oximetry; "M" is the number of observed gross movements made by the subject; "N" is the number of possibly disturbing noise stimuli; "R" the number of gross changes in respiratory response patterns.

line level of arterial oxygen saturation which was always within the critical limits of normality—that is, between 92 and 98% oxygen—and that this base-line tended to be at its lowest when fatigue was at its maximum.

From the point at which the light was quenched and the subject composed himself for sleep, oxygen levels fell progressively in a step-like fashion, with fluctuations of 1 to 3%, to reach their consistent and now unvarying minimum of about 87% oxygen at the period of deepest sleep. This was maintained for about 30 minutes, after which the oxygen level would increase, again slowly step by step, until awakening occurred. Furthermore, it was found repeatedly that the period between 4 and 5 a.m. was the time at which anoxaemia was at its greatest and "life was at its lowest ebb."

The Levels of Sleep

Most investigators have divided the varying depths of the sleep pattern into a series of arbitrary levels—reminiscent of the planes of anaesthesia. For our purpose it seemed practicable to distinguish seven such planes of sleep: (1) A period of wakefulness in which conversation is possible and the subject, although at physical rest, still responds to external stimuli by conscious attention. (2) A period of pre-sleep in which muscular relaxation is greater than in plane 1, fantasy life is enriched, drowsiness is obvious, and periods of dozing and transitory lack of awareness are common. The subject often feels some sensations of floating and depersonalization; subjective warmth permeates his body. (3) A period of light sleep in which objective response to stimuli occurs but is relatively unconscious, considerable muscular activity being present as further progressive relaxation of the many muscle groups is sought. (4) A period of heavy deep sleep in which little muscular movement is apparent, no response to external stimuli takes place and the subject is "dead to the world." Wakefulness, in like fashion, is a reversal of the process of sleep and its passage contains a similar number of stages starting with deep sleep, although the time intervals are somewhat displaced. Plane 5 is the period of light sleep following deep sleep; plane 6 the period of pre-wakefulness; and plane 7 the actual awakening to the new world of to-morrow.

Thus we have a series of seven planes of sleep, from wakefulness to wakefulness once more. An average of our observations suggests that anoxaemia is differentially distributed in each of these planes in the following manner:

Plane 1:	Wakefulness ..	Artl. oxygen satn.	=96%
,, 2:	Pre-sleep ..	,, ,, ,,	=90–92%
,, 3:	Light sleep ..	,, ,, ,,	=89–91%
,, 4:	Deep sleep ..	,, ,, ,,	=87–88%
,, 5:	Light sleep following deep sleep	,, ,, ,,	=89–91%
,, 6:	Pre-wakefulness	,, ,, ,,	=90–92%
,, 7:	Awakening ..	,, ,, ,,	=92–98%

These seven planes of the sleep cycle were selected arbitrarily in accordance with the judgment of the observer and the subsequent inquiry of the subject. The oxygen levels, it should be noted, are means and tend to be relative to the initial base-line of the subject. One in whom high initial levels are recorded may drop by similar amounts to one in whom an initially relatively low base-line is seen. But it is by no means uncommon, on the other hand, for a precipitous fall to take place from an initial high base-line to the same anoxaemic level of 87%.

Significance of Muscular Movements in Sleep

A study of our protocols reveals some interesting information regarding the twists and turns, shifts in position, limb movements, and certain quasi-purposive hand movements noted during these sleep observations. These are briefly considered.

(A) *Influence of Posture, etc.*—Because of the necessity that the oximeter earpiece should not come in contact with the pillow, the subjects were instructed that they could lie prone, supine, or on one side or the other, but that the decision regarding which side must be made before the standardization of the oximeter. Their motivation was apparently excellently maintained even during unconsciousness, for none attempted to turn to the side on which the oximeter had been fixed; indeed, most stated that they customarily lay on the one side or the other, but rarely on either.

It was noted that after some turning, usually from the side to the supine position and back again during plane 2, the subject would settle on his side and fall asleep in plane 3 in that position. By the time plane 4 had been reached, however, the subject was usually on his back, and would commonly complete his period of deep sleep thus.

Interestingly enough, exact temporal correlation with the oximeter record showed that each change in position was meaningful in terms of the blood oxygen saturation levels. Not only were twists and turns and changes of position associated with considerable oximetric fluctuations, but also such fluctuations preceded the muscular movement. The saturation levels, for example, would begin to fall from 92 to 91%, and such a fall would be immediately followed, in planes 2 or 3, by muscular movement; if the fall were a major one—for example, to 90%—then often it would immediately be followed by a change in position from side to back, or vice versa. In like fashion such a change in position, apparently occasioned by an incipient anoxaemia, would be followed by a rise in the oxygen saturation levels—for example, from 90 up to 92–93%.

If the subject was not disturbed by this and hence brought into a lighter plane of wakefulness, a third happening would then occur—that is, the oxygen saturation would again fall, not merely to its previous low level, but well beyond it, such a sequence often presaging an imminent change from a lighter to a deeper plane of sleep. Indeed, it was often found to be possible not only to estimate the exact plane of sleep by the saturation value recorded on the oximeter, but also to predict the ensuing pattern of sleep from the combination of the changing oximetric values and the concomitant muscular movements.

(B) *"Pruritic" Phenomena.*—A rather constant observation during the passage of the subject from plane 2 to plane 3 was his tendency to scratch or rub his face or body. Usually this manipulation was confined to the face, nose, and neck; not uncommonly, however, it would spread and include the genital area or, indeed, anywhere else on the body surface. The activity proved on inquiry to be at a very low level of conscious awareness, but sometimes it might of itself induce a slight increase in awareness, and the subject would then be conscious of what he was doing. It formed a useful landmark of the depth of sleep and the immediate progress which might be anticipated. The meaning of the phenomenon is discussed later.

Respiratory Responses During Sleep

Plane 1 is characterized by irregular activities such as yawning, coughing, and sighing. These are fully conscious but involuntary. They accompany subjective feelings of tiredness, lethargy, and fatigue, and help to condition the subject for the sleep awaiting him. Oximetrically, each activity is invariably preceded by anoxaemia and usually succeeds in temporarily overcoming this. Apart from these activities little of significance was noted during the observation of planes 1 and 2 and 6 and 7 in this respect. Subjectively, however, it was not uncommon to be told by an introspective sleeper that he was aware of certain other

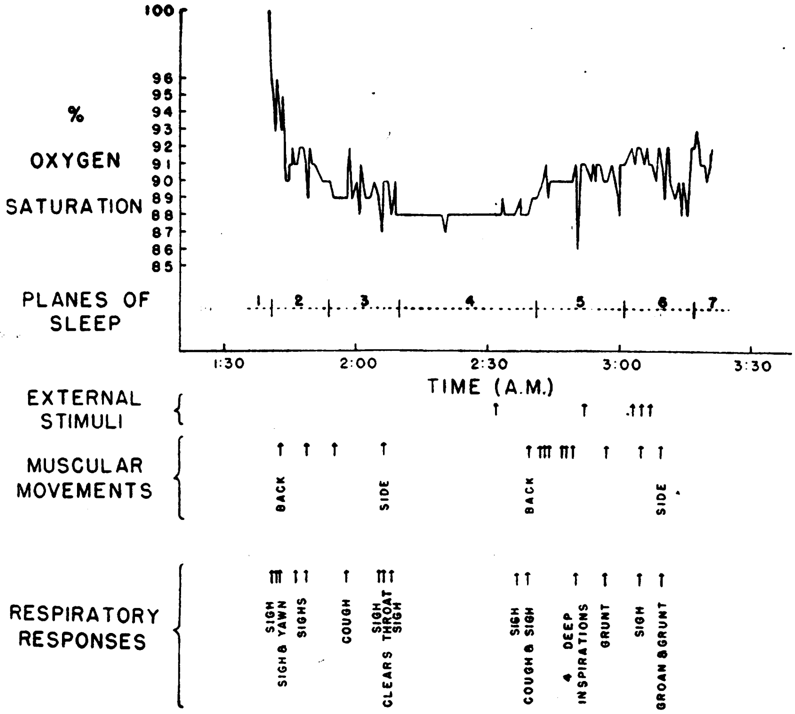

FIG. 1.—Male subject "C." Composite chart showing results of clinical observation and those of continuous photoelectric oximetry during 1¾ hours of sleep. See text for description of the seven levels or "planes" of sleep. In this and in subsequent charts the initial reading of 100% oxygen followed the preparatory inhalation of pure oxygen by facemask for standardization of the oximeter.

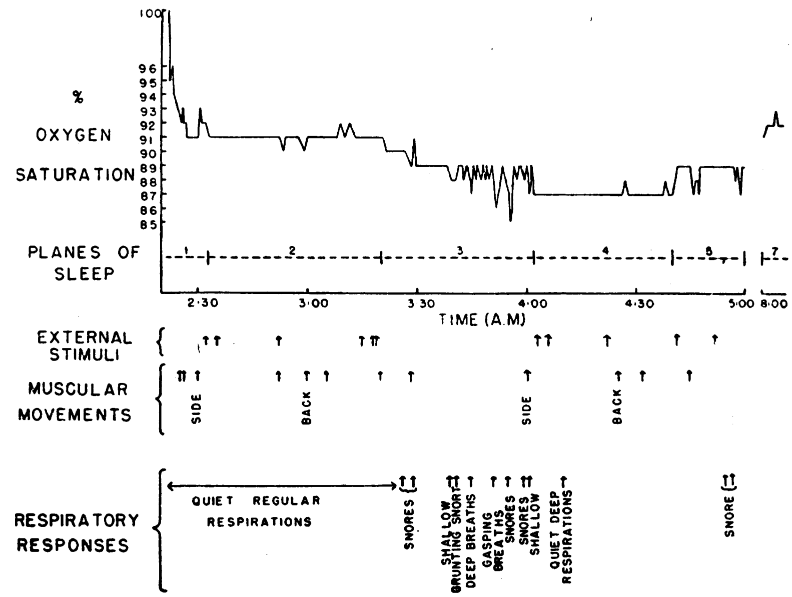

FIG. 2.—Female subject "A." Restful sleep during a six-hour period of observation.

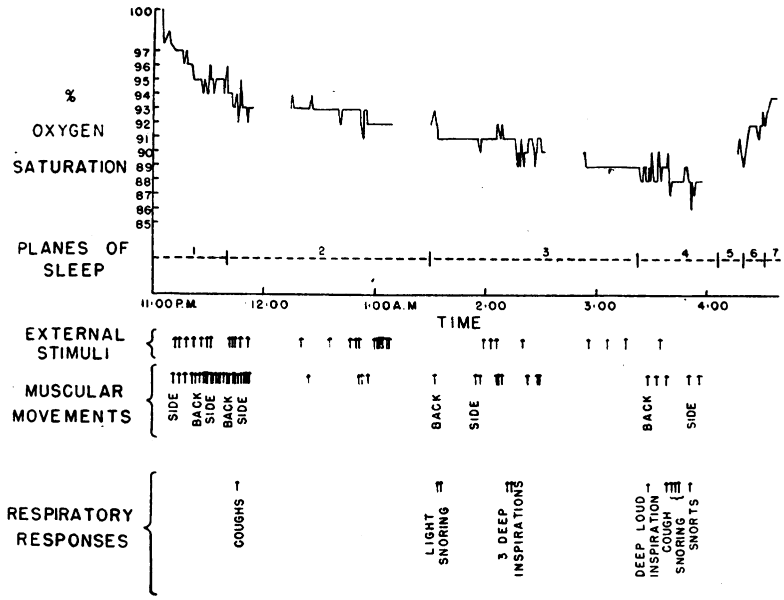

FIG. 3.—Male subject " B." Restful sleep. Illustrates differences of temporal relationships for times spent in the various planes of sleep—compare Figs. 1 and 2. Interruptions in the oximeter tracing indicate periods during which the instrument was switched off to prevent burning of the subject's ear.

changes, especially during plane 2. These consisted of periods of shallow breathing alternating with periods of apnoea and deep breathing. They seemed to be relatively automatic, the subject being conscious that they were occurring though exercising no conscious voluntary control over them. Indeed, when such control is established these patterns tend to disappear and the passage to deeper sequences of sleep is interrupted.

Planes 3 and 4 are characteristically noisy periods of sleep; groaning, mumbling, grunting, gasping, snoring, sighing, and sometimes coughing being individually representative responses for any given subject. Each of these activities is closely correlated with oximetric changes, in a similar fashion to that observed with muscular movements; a trumpeting snore, for example, often occurs at a time when exceptionally low oxygen levels have been reached (for example, down to 85%) and seems to be an effective mechanism for returning the saturation values to their previous levels. Sometimes, as we have all observed, such snoring awakens the sleeper, the mechanism of which is readily understandable in terms of these findings.

Response to External Stimuli

Observations were recorded of all external noises occurring during the sleep experiments. Such external noise was discontinuous in pattern but continued throughout the periods of observation. It consisted of traffic noises, the sirens of tugboats on the river, the beating of storms against the window-panes, the whine of aircraft passing overhead, the occasional clatter of dishes from another floor, the cries of sick children from the department of paediatrics across the courtyard, and finally the sometimes inadvertent, sometimes consciously produced noises of the observer at his night's vigil.

Despite the irregular discontinuity of all these stimuli the subject responded differentially to them according to the depth of his sleep. During planes 1 and 2 and 6 and 7 little change was noted oximetrically or clinically to such stimuli, the subject accepting them consciously and incorporating them into his awareness as part of the field of his environment. In planes 3 and 5, however, dramatic responses were noted. The subject at these times was not consciously aware of these discontinuous stimuli, but each time they occurred he would show a prompt if ill-sustained "attention peak," bringing his oxygen levels up by 1–2%. The significance of this in terms of the tendency for noise to bring about wakefulness is obvious. In plane 4, however, no response to noise took place, the subject remaining oblivious to the stimulus and the oximetric values maintaining their unswerving degree of anoxaemia.

Fatigue, Wakefulness, and the Inability to Sleep

It is not always easy to fall asleep to order. Out of 22 observations, seven represented unsuccessful attempts to sleep in that no progress was made beyond plane 2 despite their being continued under apparently optimal conditions and for a period of some hours.

It would appear that more than mere physical fatigue is necessary to ensure the sleep state. According to the Pavlovian theory a "set" is required incorporating all the usual preliminaries to sleep; but it would appear that this is inadequate of itself, since sleep was sometimes impossible even given every apparent requirement for it, including its urgent desire on the part of the subject and very considerable physical fatigue.

A typical example of this is shown in Fig. 4. The subject could get from plane 1 to plane 2 but not beyond this point. Each time his oxygen saturation level fell to 91–93% it was brought back again by such mechanisms as muscular movement, respiratory patterns of yawning, sighing, grunting, etc., and abandonment to sleep proved impossible. Interrogation of the reasons for this in all four instances proved fruitless, the subject remarking that he just could not understand his inability to fall asleep.

Some factor of emotional or mental fatigue must, it would seem, be added to purely physical factors. It is common knowledge that deep sleep is often impossible for the neurotic or the individual who cannot relax emotionally.

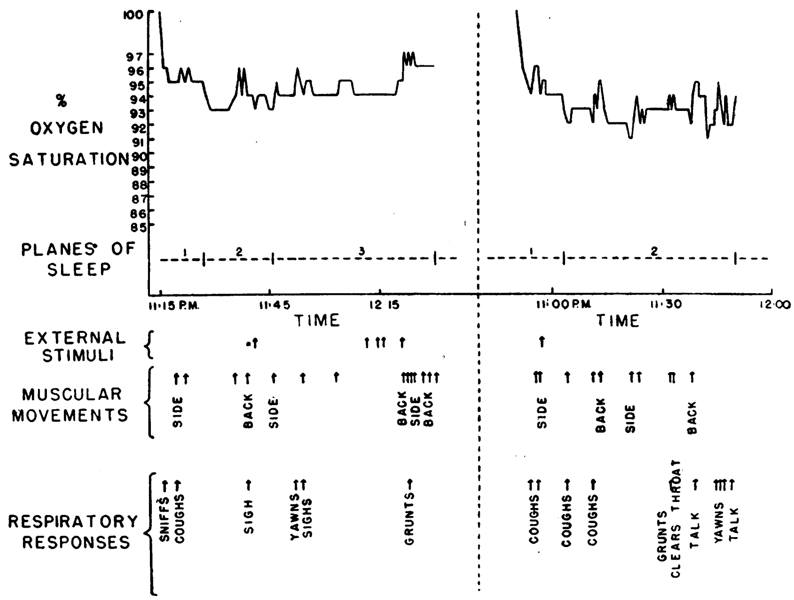

FIG. 4.—Two examples of inability to sink into deep sleep, despite subjective feelings of tiredness and fatigue.

Perseveration of ideas, repeated inability to forgo interest in the environment or in personal problems, persistent introspection, or anxiety is sufficient to maintain relative wakefulness, and it is possible that such factors as these, operating at the peak of their intensity in the fantasy-full planes 1 and 2, produce those patterns of relative awareness which prohibit further progress to a deeper plane.

Dozing

The "nap," "forty winks," "resting one's eyes" are expressions by which are usually indicated temporary cessations of conscious awareness occurring at times not usually associated with sleep—for example, after a heavy meal, during a monotonous conversation, on a hot afternoon, or with a relative cessation of attention-provoking external stimuli. On introspection, however, it would appear that these states are indistinguishable from natural sleep, the deficit of consciousness often appearing to telescope the subjective appreciation of the passage of time, and, furthermore, fantasy is usually enriched to a marked degree.

Oximetrically, it was found (see Table) that these states corresponded to planes 2 and 3 and 5 and 6 of sleep, and on clinical observation could be termed states of impaired awareness. Sometimes they could be shown to proceed to the deep sleep of plane 4, but more often some degree of consciousness was present and circumstances prohibited this from happening. Sometimes, again, it seemed that the unpleasant feeling accompanying drowsiness or dozing might be due to the guilt that sleep should not have been taking place at that time at all. On such occasions retrospective analysis revealed that unpleasant affect had coloured the fantasies, the dreams, or the reverie, and had done so with all the force of the anoxia present at that time.

Discussion

The Physiological Epiphenomena of Sleep

A large body of consistent evidence testifies to a certain cycle of changes which occur during the process of natural sleep. Briefly these include the following: a decline in the blood pressure of from 10 to 30 mm. Hg systolic, with the lowest level about the fourth hour of sleep; bradycardia; reduction in the basal metabolic rate by 10–15%; hypothermia; slowing and intermittent irregularity of respiration, together with a tendency for it to be costal in character; possible disappearance of the knee-jerk, and presence of a positive Babinski sign though lowered thresholds for vasomotor reflexes are typical; oliguria; a variable effect on gastric secretion and some increase in gastric motility; finally, depression of most glandular secretions has been noted to occur.

Among the neurophysiological observations, some interesting electro-encephalographic studies have been made during the various phases of the sleep process. Lindsley (1944) has abstracted the evidence and quotes the relevant literature from Berger's (1932) original observations, showing how five stages of sleep have been delineated from this point of view. Summarizing the E.E.G. evidence, it would seem that the alpha rhythm gradually disappears in the passage from wakefulness to pre-sleep and is extinguished and replaced by 4–5 cycles a second activity in light sleep. These slow waves are complicated by spindles of 14 cycles a second activity in deep sleep, the spindles tending to disappear and the slow waves beginning to decrease in frequency and regularity as the depth of sleep progresses. Brazier (1949) has further shown that a shift occurs with sleep in the origins of maximal voltage activity from the parieto-occipital area to the prefrontal and precentral regions of areas nine and six respectively.

Now, disappearance of alpha rhythm and the production of slow activity is also characteristic of experimentally induced anoxic anoxia when this is pushed to the point of obvious impairment of consciousness (Berger, 1934; Davis *et al.*, 1938; Gibbs and Davis, 1935), and provides us with some interesting circumstantial confirmation of our findings of anoxia in sleep.

In similar fashion all the physiological disturbances occurring during sleep noted initially in this section have also been shown to be associated with states of anoxia. As with the analogy of the E.E.G. findings so with these other disturbances, and we list this evidence for the epiphenomena of anoxia in the order in which we have mentioned them in our discussion on sleep.

Hypotension.—Anderson *et al.* (1946) found that experimental acute anoxia is often accompanied by hypotension and sometimes faintness.

Bradycardia.—The response of the heart rate to anoxia is inconsistent, but Haldane *et al.* (1919) showed that continued anoxic anoxia sometimes leads to slowing after an initial tachycardia.

Basal Metabolism.—Killick (1940) showed that in animals subjected to slow carbon monoxide intoxication the basal metabolic rate decreased, and Beck (1936) confirmed this for human subjects similarly poisoned. At high altitudes, however, such a depression of the basal metabolic rate was not found to occur in human subjects, the rate actually undergoing no change (Monge, 1937), although Hamon *et al.* (1935) showed a decreased oxygen consumption in animals under diminished barometric pressure.

Body Temperature.—Hamon *et al.* (1935) noted that the body temperature falls as the atmospheric pressure decreases. Armstrong (1939), studying human subjects taken to a simulated altitude of 12,000 ft. (3,658 m.), found consistent falls in body temperature lasting up to some 24 hours. Gellhorn (1943) also states that the body temperature falls with anoxia.

Respiration.—The depth of respiration is increased more by anoxia than is the rate (van Liere, 1942). Mosso (1898) first demonstrated the periodicity changes of the respiratory pattern at high altitudes and mentioned the tendency for mountaineers to show a Cheyne–Stokes type of breathing. "This irregularity most frequently occurs during sleep at night. It is caused by oxygen-want, as shown by the fact that the administration of oxygen abolishes it" (van Liere, 1942, p. 113). Barcroft *et al.* (1923) produced radiological evidence for the increased costality of the manner of breathing seen in natives living in the high Peruvian Andes.

Reflexes.—Jokl (1939) showed that a depression of the deep reflexes begins when ascent by man reaches an altitude of 6,600 ft. (2,012 m.) This would represent a blood oxygen saturation level of about 92%. King *et al.* (1932) showed specifically that anoxia inhibits the knee-jerk. Vasomotor reflexes are stimulated (Bouckaert *et al.*, 1941). A Babinski-type plantar response is common in the coma of hypoglycaemic shock (Lups and Kramer, 1940), and, as Gellhorn (1943) has shown, the clinical and other findings associated with hypoglycaemia parallel those of anoxia.

Urine.—Adolph (1934) found a complete anuria in frogs subjected to anoxia, the suppression being associated with total constriction of the glomerular arterioles. Van Liere *et al.* (1935) noted a diminished urine excretion in dogs subjected to anoxic anoxia. These findings have not, however, been confirmed in man.

Gastric Motility.—Anaemic anoxia in dogs greatly increased the tonus of the stomach wall and also the intensity of the hunger contractions (Carlson, 1916). Curtis and Hamilton (1938) showed that these findings are also true for patients with pernicious anaemia.

From these considerations it seems evident that the relationship between the physiological changes occurring in association with the sleep process and those of anoxia is an intimate one. We shall not press their possible functional identity further, however, for a reason which becomes evident later on.

The Biological Significance of Sleep

Philosophers from the earliest times have speculated upon the meaning and necessity of sleep, and their theories have ranged from those suggesting that the soul leaves the body and wanders freely through the world to the concept that man dies at the end of each day and is reborn with the coming of the following dawn. These theories of primitive men are echoed in the findings of contemporary dynamic psychologists who conceive of sleep and dreams as regressive patterns to an earlier plane of existence. Dreaming, says Jung for example, "is a psychosis brought about by free choice"; and Freud writes, "Dreaming is a fragment of the superseded psychic life of the child."

Physiologically, sleep has been perhaps the least well investigated aspect of the functions of man, such theories as have been advanced to account for it being crude and often purely hypothetical extrapolations reflecting the stage of medical progress at the time. The so-called "neuronal theory," postulating a retraction of dendritic processes which leads to a suspension of cortical activity, is an example of this. Various chemical theories have also been proposed, indicating lactic acid accumulation acting as a cerebral depressant, "hypnotoxin," acetylcholine, and "bromhormone," with little supporting evidence for their role in natural sleep. The Pavlovian theory, based largely on animal experimentation, suggests that sleep is a spread of conditioned internal inhibition and seems to account for one aspect of the problem, though its connexion with such hypothalamic centres as have been shown to be involved in various pathological disturbances of the sleep rhythm appears to be remote.

Kleitman (1939) has stressed the importance of afferent impulse bombardment in relation to sleep, and has published some important work which suggests that a lessening in the number of such impulses from the muscles of the periphery is a necessary prelude to sleep. This has been further elaborated by Max (1935) into what he terms the "motor theory of consciousness."

As long ago as 1897 Howell suggested that vasomotor fatigue could explain the necessity for sleep and showed that the fall in blood pressure and peripheral vasodilatation accompanying sleep could logically accompany a relative cerebral anaemia. This theory has been criticized, but it still remains a practical possibility, for differential anoxia on a vascular basis could exist with no overall change in cerebral blood flow.

Ontogenetically, the diurnal rhythm of sleep seems to develop from an irregular polyphasic cycle in infancy, and it has often been suggested that wakefulness is a modality which depends upon maturation, that it is a state to which the organism must *ascend* at intervals and in a pattern which in unique to the individual at any one time in his development. If this is so, then it might be expected that all the forces which contribute to make up the uniqueness of individual personality also assist in the formation of the individual pattern of the sleep–wakefulness cycle.

In a review of the literature concerned with fatigue Bartley and Chute (1947) conclude that fatigue is a part of the picture of frustration and conflict, and any assessment of fatigue states—including its dimension of sleep—must take these important factors into account. They stress the ever-present nature of conflicts and point to the part these play in the constant homoeostatic adjustments which the individual is called upon to make. Sleep would seem to be a release from these conflicts and a time for the "realignment" of the personality in terms of homoeostatic demands. Inability to express emotional needs leads to tension development, and if this tension is abnormally great sleep becomes impossible. The tendency for emotional tension to "spread" and become "somatized" is representative of the organism's inability to withstand the impact of such self-generated forces, and is also the pattern and a means for their—usually inadequate—discharge in dreams. Mature personality development is normally sufficient to permit of the organism's abandonment to sleep, since the force of such deviated "neurotic" tensions is not relatively great. In psychiatrically disturbed individuals, and particularly in psychoneurotics, this is not so; for them conflicts, in the face of poorly differentiated personality development, are very considerable, and sleep, because it entails relaxation, is either impossible or greatly upset.

These considerations help in understanding the often otherwise incomprehensible inability of the normal subject to get to sleep. We have seen already how physical tiredness may be urgently present, the subject apparently desirous of sleep, and all the reflex conditioning stimuli at hand, yet sleep may prove impossible. From the concepts we have just considered it would appear conceivable that these subjects were not emotionally ready for sleep; they were not in a condition to accept its psychodynamic demands. Furthermore, the inability to sleep, it would seem, postulates as well the continuance of a degree of skeletal muscular tonus inhibitory to progress in the sleep cycle. Just as, therefore, inability to sleep may entail persistently increased muscle tone, keeping up an afferent bombardment of the cortex, so also may an actual fear of sleep prevent its onset from a fear of the fantasies accompanying it.

As an example of the interactionism between our findings of anoxia and these psychodynamic considerations of the sleep process, it is interesting to reflect back to our observations of skin-scratching noted to occur in many of our subjects during their passage through plane 2 of the sleep cycle. One of the accompaniments of anoxia produced by lowered barometric pressure is a lowered threshold of irritability of the skin. This may be the result of an altered body-water distribution, as Smith (1928) suggested, and he has postulated it as one of the causes of restlessness in anoxic subjects—a concept which fits in nicely with our findings of the increase in muscular movements at this stage of sleep. It also might be expected psychodynamically in view of the considerable weight of evidence pointing to the function of the skin as an erogenous zone from which pleasure may be obtained through stimulation. The unconscious preference shown by the subjects for those areas of the skin especially sensitive in this respect—for example, the naso-oral mucous membrane, the cheeks, neck, and genitalia—lends support to these considerations.

The psychodynamics of the process of perception and awareness are intimately bound up with those of sleep. Fenichel (1945) has pointed out that the primitive modes of perception employed by psychotics, with their relatively vague and poorly differentiated experience of environment-reality, are identical with those of infants. There is a poverty of sharp distinction both between perceived objects and between the relationship of the sensory experience and the experiencing self. But such awareness patterns, poorly knit and without their normal relationship to such interpreting and normally acting mechanisms as the faculty of associative recall, are also typical of the diminished intensity of consciousness in sleep. It is with the essential identity of these three patterns of awareness—in infancy, in schizophreniform states, and in sleep—that we finally concern ourselves here.

Conclusions: Sleep and the Problem of Anoxia and Awareness

Hughlings Jackson has observed, "Find out all about dreams and you will have found out all about insanity." It is comparatively recently that physiologists have begun to interpret the findings of dynamic psychology in their schema. Yet, intimately associated as sleep is with awareness, it is impossible to neglect the interrelationships of such concepts with the somatic functional disturbances associated with these states.

We have shown (Lovett Doust, 1951a) how conscious awareness is a fluctuating variable, ever in this condition, and with extremes of the complete lack of awareness of deep coma states on the one hand and, on the other, those states of heightened awareness in normal individuals which we have designated by the term "attention peaks." And accompanying such variations in the pattern and continuum of awareness, with its subjectively experienced panorama of consciousness, we have shown a like picture of oximetric variation. An attention peak in consciousness is accompanied by an oxaemic peak in the arterial blood oxygen saturation levels; a state of reverie or inattention is accompanied, in temporal identity, by anoxaemia. A correlate of awareness variation is oxaemic variation; the appearance of the one postulates the appearance of the other, and vice versa; the one would seem the mirror image of the other—two different ways of viewing a single phenomenon and its ever-changing patterns. It is as easy to follow the progressive diminution in awareness to the levels of sleep, or the intense and overwhelming desire for it accompanying periods of forced wakefulness, or the incarceration of a subject in a low oxygen-pressure chamber equipped with a mechanism allowing for a progressive increase in the simulated altitude to 12,000 ft. (3,658 m.), as it is to follow the progressive anoxaemia occurring in natural sleep as awareness is gradually shut off, in step-like fashion as has been shown, down to the deepest levels of plane 4, and the dramatic anoxia represented by an arterial oxygen saturation level of 87%.

A final point must now be considered. Time and time again it was noticed (Figs. 1, 2, and 4) that the sleeper woke with his blood oxygen saturation levels still low. They climbed back only slowly to their former base-line values. The sleeper was awakening; although no longer asleep he was, however, far from completely conscious. The slurred speech, confused ideation, the weary passage of his hand across his brow, and the frequent yawning were all important evidence of a diminished state of awareness. It would not seem legitimate, therefore, to correlate the diminished oxygen levels completely with sleep, but rather to identify them with the levels of relative unawareness which are so much the necessary components of sleep.

And just as dreams subjectively portray the enrichment of the fantasy life of sleep, so this same enriched fantasy and these same dreams are seen in the phenomenology of anoxia, infancy, and schizophrenia. The qualities of the "real" change their values in anoxia and in dreams—that is, in these states of altered consciousness the schizophrenic-like mutisms, perseverations, autisms, and illusion-delusions merge with hallucinations of every modality of sensation; the dream world is one of bizarre yet essentially personal and meaningful reality, but on a plane and in a sequence ill understood enough by the dreamer—and how much less by the observer.

To be awake under such conditions and in such a nightmare is, in a word, to be a schizophrenic—Jung's "a dreamer in a world awake"—but to be asleep is the experience of us all. And when the homoeostatic realignments which serve, perhaps, the purposes of sleep are accomplished we are recalled to the state of conscious awareness once again.

The oxygen saturation levels of the constitutional schizophrenic, as determined oximetrically (Lovett Doust, 1952), are those of the dreamer. When the attention peaks which have maintained him by conscious empathic effort give, he sinks back into a state of "wakened dreams." His levels of awareness are those of *unawareness* of all modalities save those of his unconscious; his oxygen saturation is that of the sleeper, and fluctuates uneasily as the sleeper, dreaming, twists and turns, mutters and sighs, groans, and snores his way through sleep.

Summary

The sleeping habits and levels of sleep of seven normal healthy subjects were studied.

Photoelectric oximetry in a series of 22 observations suggested seven planes of sleep. These planes were: (1) wakefulness (arterial oxygen saturation 96%); (2) pre-sleep (90–92%); (3) light sleep (89–91%); (4) deep sleep (87–88%); (5) light sleep following deep sleep (89–91%); (6) pre-wakefulness (90–92%); (7) awakening (92–98%).

Muscular movements, posture, scratching, respiratory adjustments, and responses to external stimuli were found to correlate differentially with all these separate planes.

It was seen that the various physiological concomitants of sleep closely resembled those accompanying states of anoxaemia.

The theories of sleep are reviewed, and it is suggested that the concepts of homoeostasis and dynamic psychology, psychiatry, and maturation bear an important relationship to the phenomena of fluctuating awareness, anoxia, and sleep.

It is a pleasure to express our gratitude to Professor Harold G. Wolff and Dr. Stewart Wolf for their constant encouragement and for the provision of facilities enabling this work to be carried out.

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More medical students should be admitted to Oxford University, according to the report for the year ending July 31, 1951, of the Regius Professor of Medicine (*Oxford University Gazette*, February 9, p. 499). At present 55 men and 10 women are admitted to preclinical studies each year, and divided among the 30 colleges, which makes teaching arrangements very difficult. The restriction to 32 clinical students annually is satisfactory, however, since many of these students come from other universities, while Oxford students are encouraged to pass on to London.