PHYSIOLOGICAL CONCEPTS OF CONSCIOUSNESS

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In the words of Russell Brain (1958), "there are no more complex problems in neurology than those which arise in connetion with consciousness, and few topics more plentifully breed confusion". Even to define the meaning of the word consciousness is not easy. William James (1892) said that everyone knows what consciousness is until he tries to define it. It is, therefore, no use here to try to define it. The definition given by Stanley Cobb (1948) that consciousness is "awareness of environment and of self" may be sufficient to convey the meaning of this word.

Various other words are also used by physiologists and other workers to describe the state of nervous system, which is synonymous with consciousness. These would be the states of wakefulness, attention, alertness or arousal of the brain. It will be observed later on that the activity of the brain and the mechanism producing it in all these states is similar. Opposite to this would be the states of sleep or unconsciousness. The brain mechanisms producing these states are again similar. The unconsciousness resulting in anaesthesia or in coma again are related phenomena, with the only difference that it is possible to wake up a sleeping person, while it is not so in the other conditions. The reason for this will be obvious when the mechanism producing sleep and wakefulness, or unconsciousness and consciousness are understood.

Two recent reviews have appeared on this subject, one by Magoun (1958-"The Waking Brain.") and the othor by Feldberg (1959—"A physiological approach to the problem of general anaesthesia and of loss of consciousness") which have very much clarified our concepts. These two reviews have mainly formed the basis of the present review.

I.—Cerebral cortex and consciousness

For a long time it was supposed that consciousness was exclusively a function of the cerebral cortex. The unconsciousness produced as a result of head injury or concussion, was attributed to cortical damage. Neurologists believed that the loss of consciousness from cerebral haemorrhage was caused by general cortical anaemia.

In animal experiments, on the other hand, it was observed as early as the end of last century (Goltz, 1892; Schafer, 1900), that removal of cerebral hemispheres does not cause loss of consciousness, and these animals can sleep

as well as awake. Cairns (1952) showed similar responses in human anencephalic and hydrocephalic monsters.

Jefferson (1938) pointed out that the neurologists were wrong in assuming that the cerebral cortex was the seat of consciousness. He and his colleagues (1950, 1958) published maps on the basis of clinical cases, showing that damage to the upper brain stem and diencephalon leads to depression of consciousness, hypersomnia or coma.

The real knowledge regarding the involvement of upper brain stem, and its relationship with the cerebral cortex, in the production of the states of "consciousness", on the other hand, has emerged as a result of a large number of experimental studies conducted by neurophysiologists. I will now pass on to describe some of them which have acted as real landmarks in the evolution of our knowledge regarding this mechanism.

II :—Classic contributions to the problem.

(I) EEG patterns in relation to consciousness and sleep.

Shortly after discovery of the electroencephalogram by Berger (1929), came his observation that in sleep its patterns tended to be composed of large, slow, wavelike fluctuations of potential (Gamma Waves), while a flattened record was characteristic of wakefulness. Thus the EEG pattern of sleep consists of high-voltage, slow-waves of synchronised discharges, while during wakefulness or alertness the record consists of low voltage, fast, desynchronised activity (Fig 1). This latter type of desynchronised record is now accepted to be synonymous with the 'arousal' of the animal. The high-voltage slow-wave record is obtained during sleep, as well as unconsciousness produced as a result of anything.

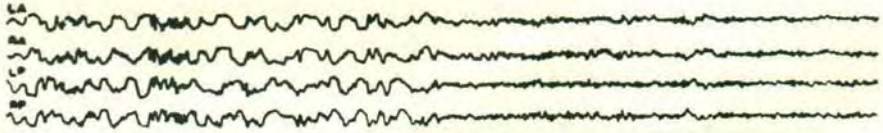

Fig. 1. EEG of a cat when asleep and when woken up. (From Lindsley et al., 1950).

Rheinberger and Jasper (1937) studied simultaneons EEG and behaviour of cats and observed that the low-voltage fast pattern of EEG occurs alongwith attentive wakefulness and is therefore termed EEG 'activation' or 'arousal'. This can be evoked equivalently by stimulations of several afferent modalities (Fig. 2). However elicited, this is distributed generally over the whole hemisphere and not restricted only to the brain area which receives

the afferent sensation. Also, once aroused, this 'arousal or activation pattern' tends to persist for a long period, as long as the behavioural 'arousal' (attentive wakefulness) lasts. These very important observations indicated the importance of afferent stimulation in initiating both EEG and behavioural wakefulness.

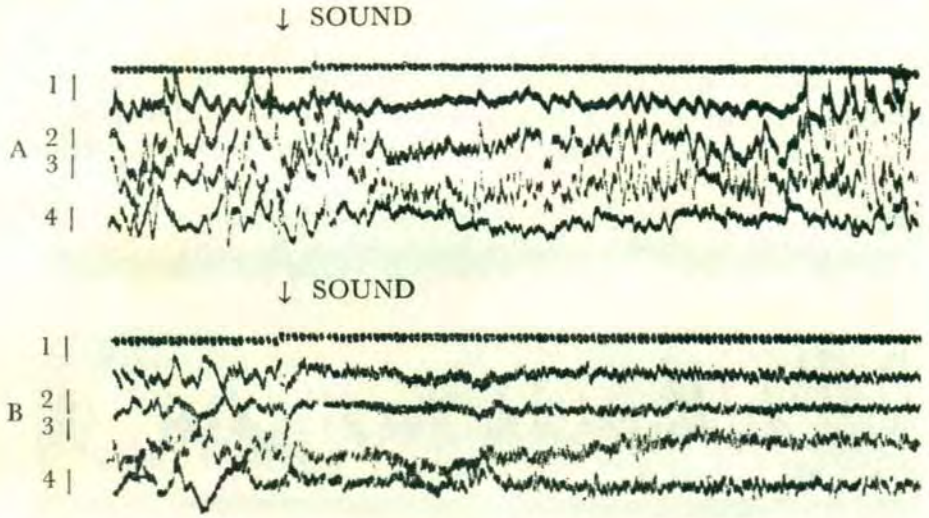

Fig. 2. EEG from several regions of the cerebral hemisphere of an inattentive (drowsy) cat, showing generalised activation pattern evoked by auditory stimulation. (From Rheinberger and Jasper, 1937).

These EEG studies then formed the basis of most of the important studies which have been carried out to elucidate the mechanism of production of consciousness and sleep. In some experiments wakefulness has been studied as a behaviour change and this is termed as 'behavioural arousal or wakefulness'. But such studies can be conducted only in unanaesthetised animals. Therefore majority of the studies have utilised 'EEG arousal' and EEG sleep' to interpret these states in lightly anaesthetised animals, in whom behavioural arousal can not be produced. High-voltage slow synchronised waves are interpreted as synonymous of the state of sleep or unconsciousness, while low-voltage fast desynchronised waves are interpreted as synonymous of the state of arousal, wakefulness, consciousness, alertness etc. Thus the pioneer studies with EEG cannot be underestimated in terms of their importance for these studies.

(2) *Brain stem mechanisms in relation to cousciousness and sleep.*

a) Studies by Bremer:—

Bremer (1935, 1936, 1937) made two types of cats with transverse cuts through the brain stem preserving the blood supply to the cortex and studied their behaviour and EEG. He observed that when sections are made between

the superior and inferior colliculi (B of Fig. 3), the head of such a cat behaves as in constant sleep and the EEG record shows typical high-voltage slow-wave sleep-pattern. This preparation was called "*Cerveau Isole*". On the other hand, if the sections are made below the medulla oblongata (A of Fig. 3) leaving the brain in contact with the brain stem, such a preparation exhibits mainly periods of wakefulness which alternate with periods of sleep. During wakefulness the EEG shows low-voltage fast desynchronised waves, while during sleep the EEG record is typical of sleep. This preparation was named "*Encephale Isole*". Bremer, therefore, concluded that

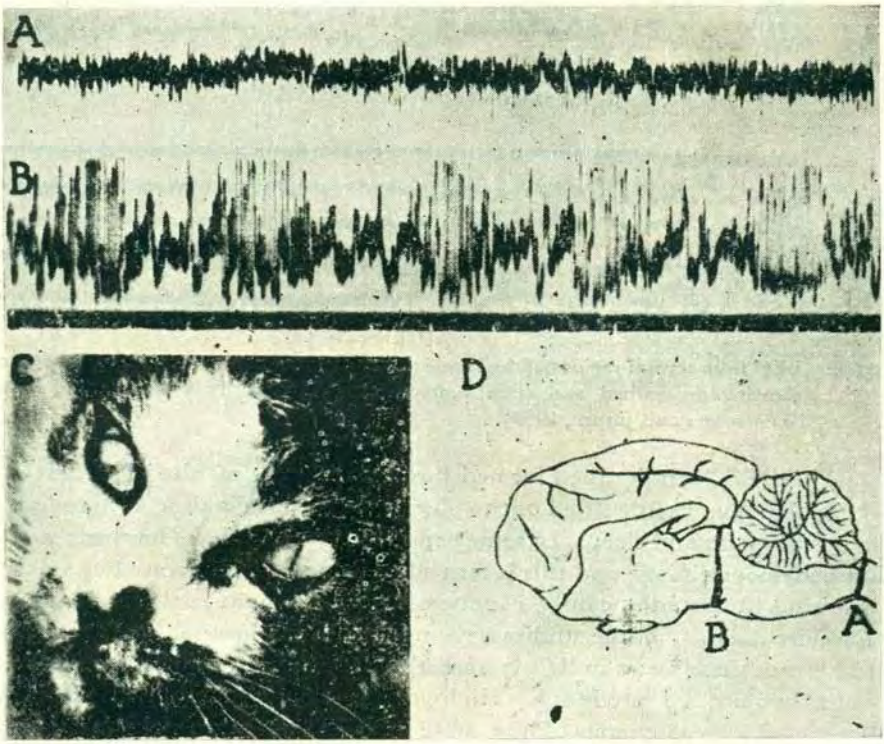

Fig. 3. EEG of cat showing waking record (A) of *encephale isole* following section at bulbospinal, juncture (D-A) and sleeping record (B) of *cerveau isole* following mid-collicular section (D-B). The sleeping appearance of the latter is seen in (C). (From Bremer 1937).

sleep was the consequence of deafferentation (cutting out of sensations) of the cerebral hemisphere. Later studies mostly supported the general features of Bremer's conclusions, with this difference that it was shown that the sleep pattern is not due to cutting out of the direct sensory routes to cerebral cortex, but due to cutting out of the projections from the central reticular formation of the brain stem.

(b) *Studies by Magoun's group* :—

We owe our present concepts about the mechanism of consciousness mainly due to extensive studies which have been carried out by Magoun (1958) and his group. Moruzzi and Magoun (1949) found that direct stimulation of the central reticular formation of the brain stem reproduced all the electrocortical features observed in the EEG arousal reaction associated with wakefulness. Such studies have been often repeated since then and have helped to elucidate a number of facts regarding the mechanism of wakefulness. Segundo *et al.* (1855), with the help of chronically implanted electrodes in the reticular formation, showed that reticular stimulation evokes the same pattern of EEG arousal as is induced by peripheral sensory stimulation and this coincides with behavioural awakening (Fig. 4).

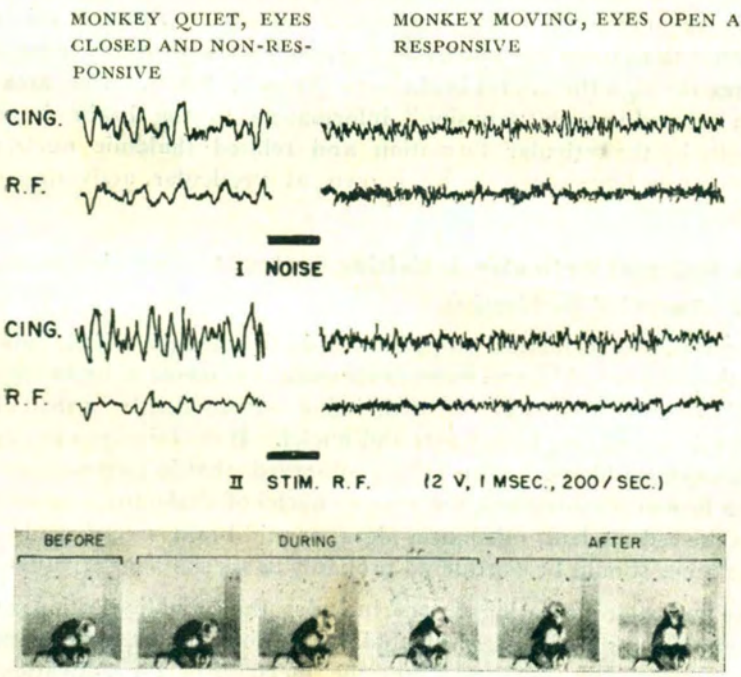

Fig. 4. EEG and motion picture frames from a monkey who was aroused with peripheral afferent stimulation (I - Noise) and by stimulation of reticular formation. The arousal in both cases is identical. (From Segundo et al., 1944). (II STM R.F.)

These studies were further extended by observing the consequences of experimental destructions involving the brain stem and diencephalic regions (Lindsley *et al.*, 1950, French *et al.* 1952). Animals with large lesions of the central cephalic brain stem remain as though deeply asleep. Their EEG records show sleep or coma waves. Neither behaviour, nor EEG arousal can be produced in them by any peripheral sensory stimulation. Even if the long

sensory and motor paths to the cerebral cortex passing through the brain stem are spared and only the central core of reticular formation is destroyed, such animals show no signs of awareness of their environment, and cannot show either behavioural or EEG arousal. On the other hand. if only the long sensory paths to the cortex rae destroyed and the central core of reticular formation is intact, the animals are capable of both behavioural as well as EEG arousal. It was seen in our laboratory (Anand, 1955) that small destructive lesions in the mammilary region of the hypothalamus produce typical comatose picture and it was therefore concluded that the mammillary region may form a very important component of this reticular activating system.

These studies demonstrated that the afferent influx transported centrally through the brain stem is implicated in the arousal mechanism. The coma of *cerveau isole* animals, therefore, depends upon exclusion from higher cortical structures of 'activating' stimuli conducted selectively through this median zone rather than upon the blockade of primary sensory signals transported to the cortex through the lateral brain stem (French, 1960). The area implicated in conveying such "arousing" information to the brain is occupied principally by the reticular formation and related thalamic nuclei; hence these structures have come to be known as "reticular activating system" or RAS.

III. Relation of Reticular Activiting System to Consciousness.

(1) *Anatomical considerations.*

The reticular formation proper begins in the medulla a little above the decussation of pyramids, and extends through the whole of brain stem to the base of brain. It is centrally located, being surrounded by a shell of neural tissue consisting of long fibre tracts and nuclei. It contains groups of neurons with interspersed fibres. Allen (1932) observed that in its development, the reticular formation surrounds the sensory nuclei of thalamus, and such structures as the red nucleus, substantia nigra, or mid brain nuclei and parts of hypothalamus should be considered probably as specialised derivatives of it.

The 'reticular activating system' includes the cephalic portions of reticular formation, as well parts of thalamus, subthalamus, epithalamus and hypothalamus. This unit constitutes the mechanism for activation of the cerebral cortex.

(2) *Ascending connections.*

This diffuse system ia the middle of brain stem (RAS) receives sensory signals from collaterals of all kinds of ascending fibres. As the classical afferent paths ascend towards the cortex collaterals pass widely from these into the central region. These collaterals are received from the somatosensory fibres in the medial lemnisci, from the other cranial nerves, and from visceral afferent fibres. The reticular formation in turn sends impulses

to practically the whole cortex. These impulses desynchronise the high-voltage slow-wave activity of the cortex thus activating it. This arrangement is illustrated diagramatically in Figs. 5 and 6.

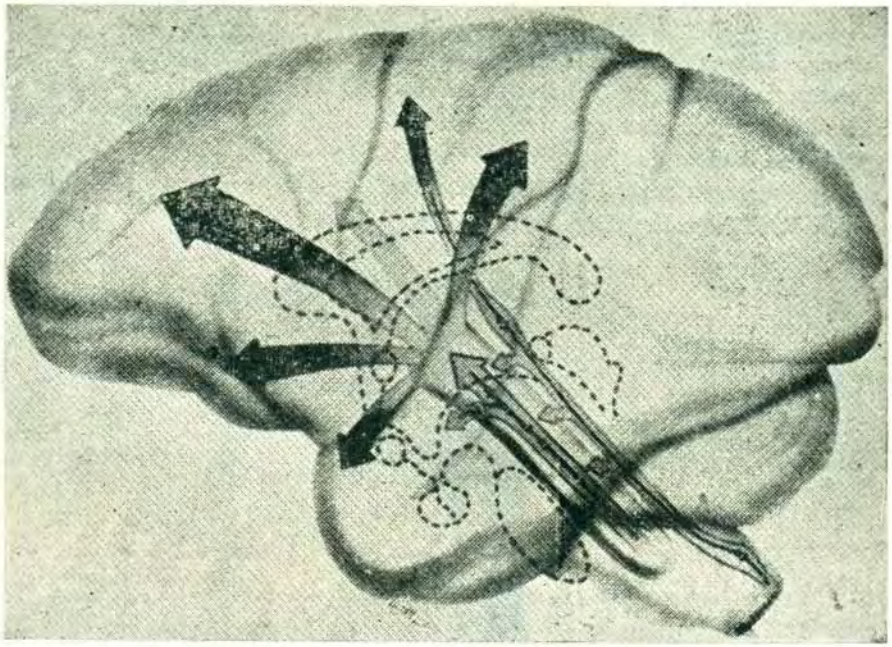

Fig. 5. Lateral view of monkey's brain showing classical somatic afferent pathway projected to the sensory cortex, and the reticular activating system in the central brain stem receiving collaterals from the classical afferent pathway and then projecting diffusely to the cortex. (From Magoun, 1954).

(3) Mechanism of arousal.

It is thus evident that arousal of the brain is a function of the RAS. When the RAS is not activated, the rhythm of the brain is synchronised slow high-voltage. During this stage any afferents which may go up to the cortex are not well received as the cortex has not been alerted to receive them. On the other hand, when the stimulation of peripheral afferents activates the RAS through the collaterals going to it, the activated RAS arouses the brain through its diffuse projections. During desynchronised fast low-voltage activity, the cortex has been altered and is ready to receive and interpret any peripheral afferents which will project to the cortex. Thus it will be seen that the stimulation of the peripheral afferents themselves will arouse the brain through collaterals going to RAS and thns alert the brain for their own reception and interpretation. It may be noted here that the arousal mechanism is mediated through multiple relays (synapses) in the RAS and thus

exposed to the effect of certain factors (anaesthetics for example) at this level.

(4) *Types of affarent stimuli capable of arousal.*

The RAS is capable, probably of some spontaneous or autochthonous discharge, although the bulk of its tonic potency is derived from its several inputs. However, some receptor systems exert a more powerful excitatory influence upon the RAS than do others. Stimulation of the visual nerves has been found to be least effective (Arduini *et al*, 1953), while somatic sensory excitation is most potent in this regard (French *et al*, 1952). It has been shown that even in *encephale isote* the wakefulness depends upon sensory inputs to the RAS from the trigeminal nerves.

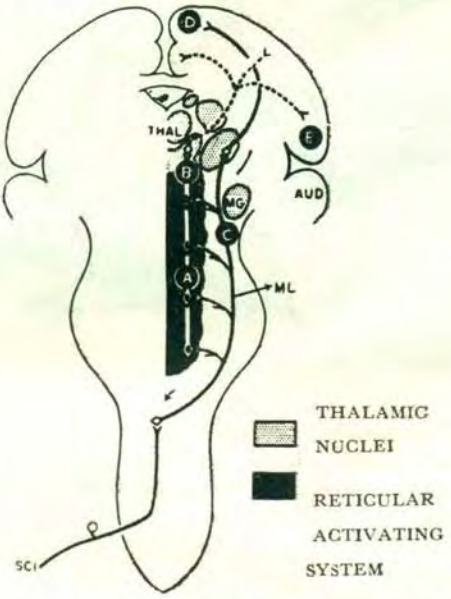

Fig. 6. Diagram of brain showing classical somatic afferent pathway projecting to sensory cortex (solid line), and reticular activating system (black) receiving colltaerals and with diffuse cortical projections. (From French, Verzeano and Magoun 1953).

(5) *Part played by cerebral cortex in arousal.*

Although arousal is produced through the RAS, the activity generated there must be exerted upon the cortex, in order for the alert state to be displayed. The cortical regions contribute to the process of arousal by functioning in the maintenance of prolongation of sensory—induced awakening (French 1952). Decorticate animals and man exhibit only transient brief periods of apparent wakefulness, but during such temporary arousal, alertness or appropriate reaction to environment is impossible. It appears, therefore,

that crude arousal is possible without cortical contribution, but the intact cortex is essential for prolonged sustained alert wakefulness characteristic of the normal adult subject.

(6) *Phylogenetic development of consciousness.*

If one studies the phplogenetic development and evolution, one comes across the same phenomena which have been elucidated above. In the early evolution, with the development of nervous system analagous to spinal cord and brain stem, the animal develops a general "awareness" of its environment. On top of these developed the older parts of brain (Rhinencephalon —Limbic System), which now are considered very important for regulation of visceral activities. This also regulates the affective behaviour and so here we have the "feeling" in response to the enviromental stimuli. Then developed the neocortex, and with this came the "knowledge" of the environmental stimuli. This is what we understand by the term consciousness. It will be apparent from this also that the basis of this "knowledge" or consciousness could be the activity at brain stem level, producing general awareness.

(7) *Centrencephalic System of Penfield.*

By definition this refers to neurone systems which connect both hemispheres and which are located in the central core of the upper brain stem. According to Penfield (1952) this centre in the upper brain stem is the seat of all consciousness, and through which all activities of the two cortices are integrated. Although differing in certain important respects, the basic concept of this that the seat of consciousness is in the brain stem, fits in with the hypothesis elaborated above.

(8) *Relationship to pain conduction.*

Collins *et al* (1954) and Livingston (1954) have shown that stimulation of peripheral afferents subserving pain, evoke potentials in the mid brain tegmentum. These studies suggest that, from the bulbar level forward, the ascending pain pathways may be made up very largely of relays through the RAS. They would thus be sensitive to central anaesthetics here (see below). It also seems appropriate that a central neural mechanism, concerned with alerting and arousal, should be supplied abundantly with connections from the afferent pathway for pain.

IV. **Wakefulness and Sleep.**

(1) *Wakefulness.*

One can now summaries wakefulness as a condition of the brain which has been aroused or alerted by the RAS, which in turn has been activated by projection of afferent stimuli—mostly somatic into it. Such an alerted brain will receive and interpret the afferent stimuli direct by projecting to

the cortex and in such a state we will, therefore, be aware of our environments. When this arousal of the cortex is lacking, the afferent stimuli projecting directly to the cortex will not be aware of our environments i. e. we will be unconscious.

(2) *Sleep.*

This condition is produced when the cortex is not aroused by the RAS. It will, therefore, occur when no peripheral afferents are activating the RAS. In this condition the mechanism of RAS is still intact, only it is not being activated. If any peripheral stimulus is applied and the afferents are strong enough to activate the RAS, the condition of sleep will change into wakefulness.

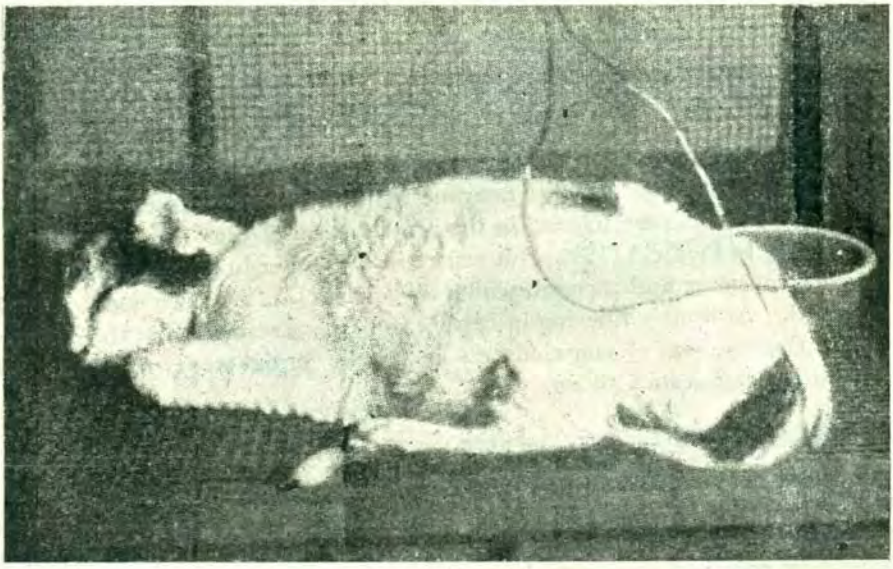

Fig. 7. Stimulation of anteromedial amygdala through implanted electrodes produces sleep in cat. (From Anand and Dua, 1956).

Previously many other hypotheses had been put forward to explain the mechanism of sleep, but it is no use referring to these here. There are certain stimulation studies, however, which at first sight do not seem to conform with this general concept regarding sleep and wakefulness. Sleep according to this is due to blockage of impulses going up to cortex from RAS. Hess (1944), on the other hand, showed that cats, in whom medial diencephalic regions were stimulated through implanted electrodes, went into normal sleep during the period of stimulation and so he had suggested a sleep centre in the diencephalon. It has now been argued that this sleep is produced by stimu-

lation at slow rates of medial thalamic nuclei, which produces delta sleep waves in the cortex. In our laboratory also it has been observed that stimulation of amygdaloid nuclei sometimes induces sleep in cats (Anand and Dua 1956, Fig. 7). It is suggested that there may be other nervous mechanisms also which could block the RAS projection to cortex and thus produce sleep.

3. *Unconsciousness and Coma.*

This would be a sleep like condition produced again by blockage of impulses projecting from RAS to cortex. This would be produced by any condition which damages the reticular formation in the brain stem or diencephalon. This differs from sleep in the essential feature that such an individual cannot be aroused with the help of peripheral sensory stimulation. This is obvious, as in this case the RAS has been damaged and so cannot arouse or alert the cortex; which, therefore, stays in a continuous state of sleep and unconsciousness.

4. *Damage to Cerebral Cortex.*

As has been explained above, in such a case although the RAS which is responsible for wakefulness is intact, the cortex which displays the alert state is not functioning. Such individuals can exhibit only transient brief periods of apparent wakefulness, but alertness or appropriate reaction to environment is not possible.

V. **Effect of Anaesthesia.**

The loss of wakefulness in central anaesthesia has been attributed to a depression of activity within the RAS. Under light anaesthesia it has been convincingly shown that anaesthetics block impulses propagated over the medial pathways (RAS), but the laterally conducted impulses remain unimpaired and reach the cortex (French *et al* 1953). This selective susceptibility of RAS to anaesthetics is due to the path through this being multisynaptic (see above). It is only with larger doses that some depressant action over thalamic relay nuclei is observed.

Feldberg (1959) and his colleagues (1953) have shown that sleep-like conditions can be produced by injecting small doses of drugs into the III ventricle and aqueduct (Fig. 8.) Such effects can be produced with adrenaline, noradrenaline, Ca cl_2, as well as with anaesthetics like Mg Cl_2, urethane, chloral, and chloralose. The amounts injected are far too small to produce such effects on intravenous injection. These effects must therefore be produced due to the effect on structures lying just outside the III ventricle and aqueduct (RAS).

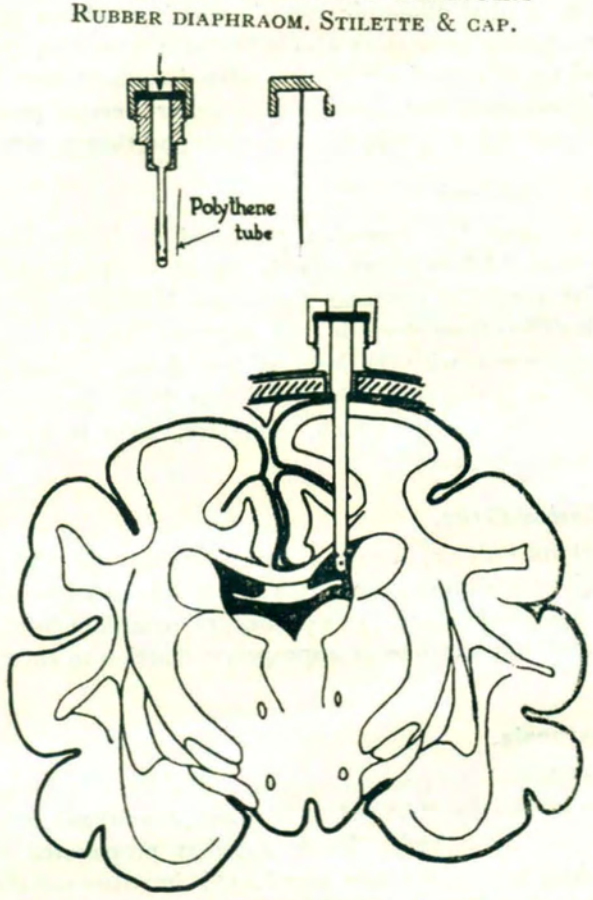

Fig. 8. Diagram illustrates the method of injection into the lateral ventricle. Cannula is screwed into the skull. (From Feldberg and Sherwood, 1953).

In the end it must be admitted that inspite of all this extensive work, the various aspects about the mechanism of consciousness are by no means completely understood. Much has been left unsaid and many questions left unanswered. Only further developments will tell us whether the concepts developed in this review will stand the test of future work.

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