NEURO-PHYSIOLOGICAL PROBLEMS AT HIGH ALTITUDES

By

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I have been asked to speak on the Neuro-physiological changes produced as a result of stay at high altitudes. We have not done any work on this and, unfortunately, there have not been many other studies reported on this. I will, therefore, present before you today whatever little is available in the published literature. Mostly, workers carrying out physiological studies at high altitudes have made certain general remarks about changes in the emotional behaviour and other neuropsychological changes due to involvement of the central nervous system.

Central nervous system is a highly evolved and specialised tissue, which depends for its activity on the utilization of glucose in the presence of a sufficient supply of oxygen. The metabolism of neurones is so sensitive that cutting off the oxygen supply even for very short periods can produce irreversible damage to the nervous structures. Here again, some of the neurones, specially those present in the brain-stem which have been assigned the vital role of adjustment of certain vital functions in the body, are more specifically affected earlier than the other neurones.

The effects of high altitude on the functioning of the central nervous system would, thus, mainly depend upon the decreased oxygen supply to it. To understand these in a better perspective it may be of some help to first refer to the effects of hypoxia on the central nervous system in experimental studies conducted on animals. One such important study has been carried out by Hugelin, Bonvallet and Dell (1959). They have beautifully demonstrated that with lower levels of hypoxia one observes an increased activity of certain higher nervous regions, and later on with more marked hypoxic effects this activity gets depressed. These workers have carried out these studies by recording the electroencephalographic and other changes produced in the animals when they were exposed to hypoxia. They have explained their results due to a prior selective involvement of the brain-stem reticular formation (activating system), before the setting in of depression of the cortical regions.

Let me first of all say some thing about the physiological mechanisms pertaining to the reticular formation. This important region of the brain-stem is responsible for producing 'alerting' or the 'arousal' response in the neocortex, in response to its activation through peripheral afferents. This arousal of the neocortex is achieved through the nonspecific projections from the ascending reticular formation to the neocortical regions (Fig. 1). Reticular formation also sends descending extra-pyramidal fibres which go to the motoneurones and thus influence the activity of the

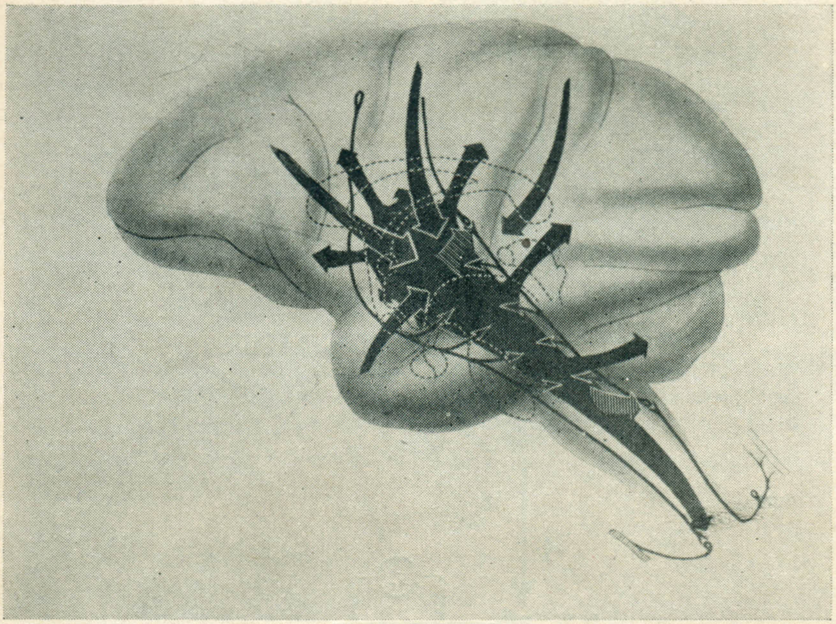

Fig. 1. Schematic presentation of the ascending and descending influences of the retiular formation and its reciprocal relationship with other systems. Arrows directed upward indicate the ascending influences of the reticular formation upon widespread areas of the cortex and cerebellum. The thin line arrows indicate collaterals from sensory and motor pathways influencing the reticular formation. Corticifugal influences are indicated by the downward directed arrows into the reticular formation. The arrow to motor mechanisms and the hatched arrow to central sensory relays indicate the descending influences of the reticular formation (From Worden, F. G. and Livingston, R. B. *Electrical Stimulation of the Brain* Ed. Sheer, D. E. University of Texas Press 1961).

somatic musculature (Fig. 2.). On the other hand, in the reticular formation of the brain-stem, there are also various autonomic centres which are connected by descending fibres to the autonomic outflows-both sympathetic and parasympathetic and thus changed activity of this region would also influence the autonomic outflows.

Hugelin, Bonvallet and Dell (1959) have demonstrated that as a result of partial hypoxia in the earlier stages, the reticular activating system is reflexly stimulated through the chemo-receptors (Bonvallent, Dell and Hiebel, 1954) present in

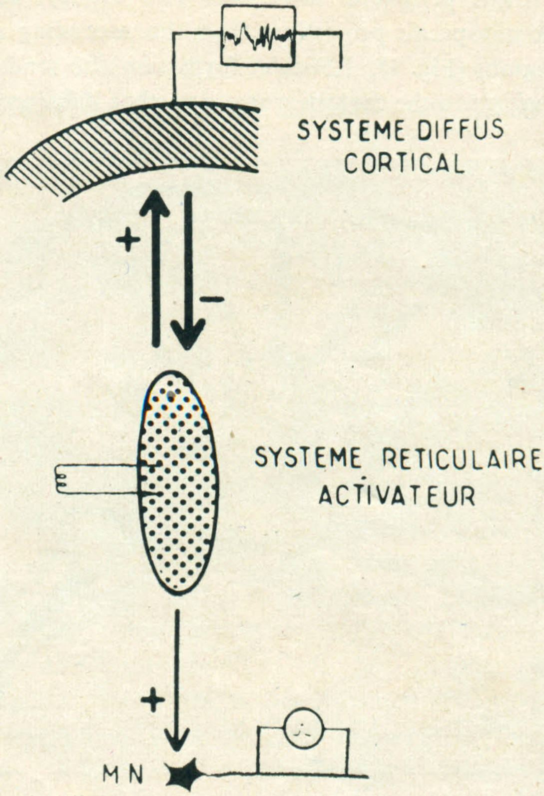

Fig. 2. Schedule for the comparative study of the effects of a known reticular stimulation on reticular ascending and descending discharges (From Hugelin, A. et Bonvallet, M., *J. Physiol.*, Paris 49 : 1957).

the carotid and aortic bodies (Fig. 3). This reflex activation of the reticular system then leads to the production of 'alerting' or 'arousal' responses in the cortex with its various concomitant results (Fig. 4). This 'arousal' is due to afferents coming from chemo-receptors, as shown by its disappearance after vagotomy (Fig. 5.) It would also be expected to facilitate the autonomic as well as somatic motor outflows. Although the autonomic system is facilitated by this, increased somatic activity is not produced during this stage. This has been explained by these workers due to direct inhibitory influences flowing from the neocortex to the motoneurones (see Fig. 2), as a result of the 'alerting' of the cortex. Thus, from these experiments one would expect that as a result of partial hypoxia there would be facilitation of neocortical functions and the autonomic outflows, and a certain amount of inhibition of the somatic activity. Later on more marked hypoxia leads to a direct depression of the cortical activity (Fig. 4). This would release the lower

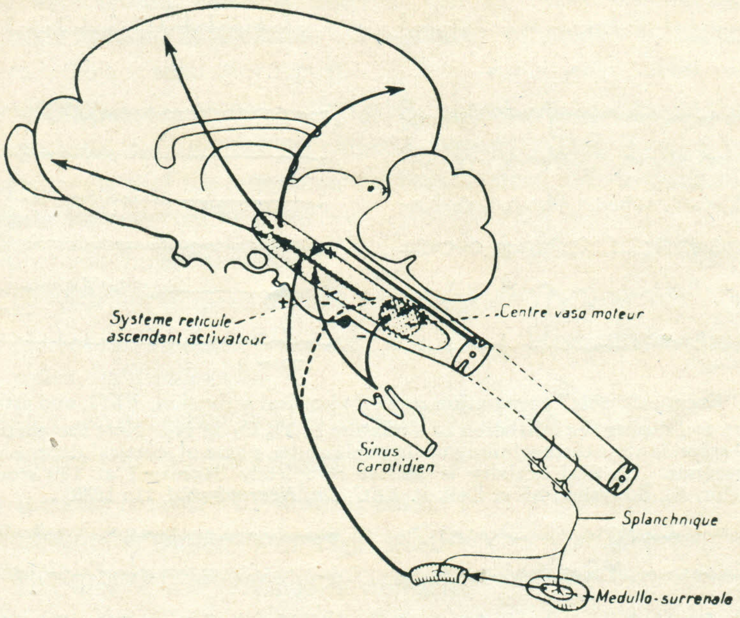

Fig. 3. Diagram showing three possible means by which cortical electrical activity and sympathetic tone are adjusted and inter-related :

(1) Activation of bulbar vasomotor and adreno-secretary centres and ascending reticular system by collaterals from sensory paths.

(2) Direct activation of ponto-mesencephalic reticular formation by circulating adreneline (see inset for levels of transection),

(3) Damping effects produced by carotid sinus afferents (From Bonvallet, M. Dell, P., et Hiebal, G.: *EEG clin. Neurophysiol.*, 6 : 1954).

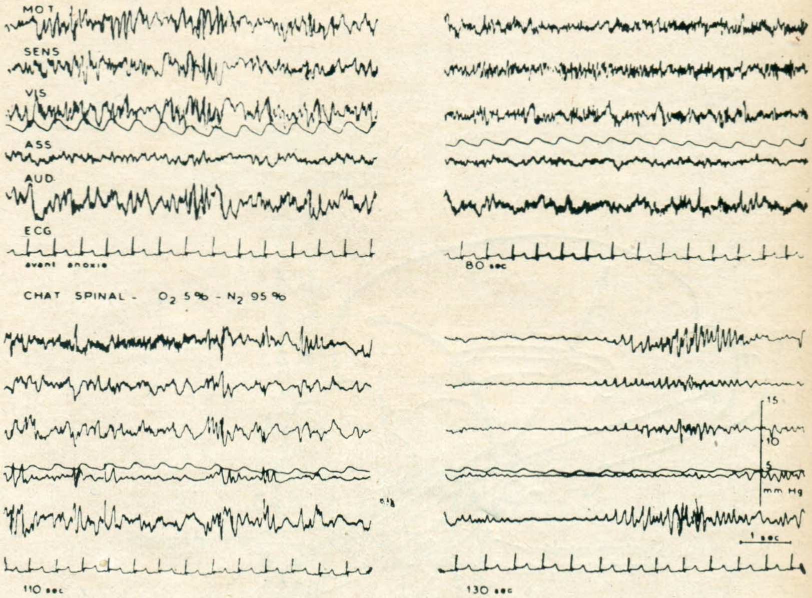

Fig. 4. Cat "Encephale isole" preparation cortical electrical activation, EKG, and arterial pressure before and during the inhalation of a mixture of 5% O_2 in N_2. Note the cortical activation at 80 seconds after the beginning of hypoxia and a phase of cortical depression starting at 110 seconds. Cortical activity is almost completely depressed at 130 seconds. (From Hugelin, A., Bonvallet, M. et Dell, P. ***EEG clin. Neurophysiol.*** 11 : 1959)

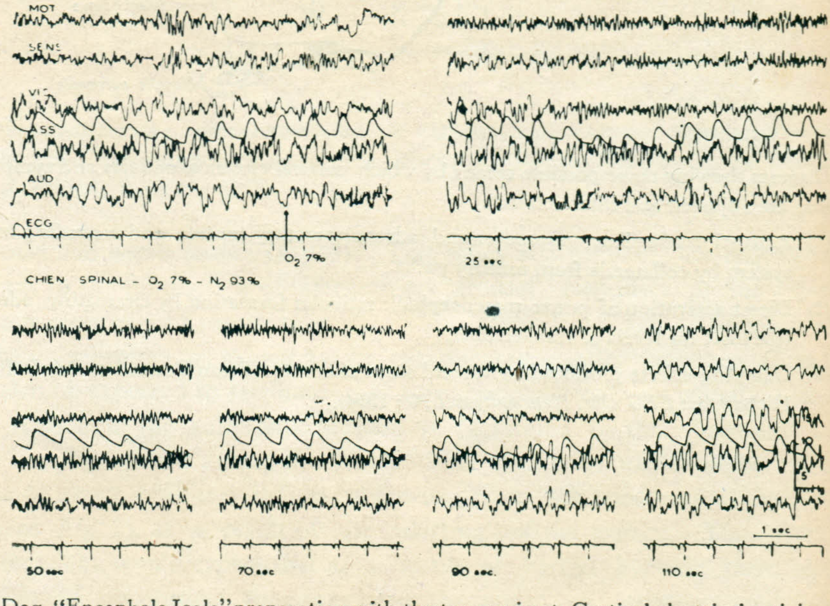

Fig. 5. Dog. "Encephale Isole" preparation with the two vagi cut. Cortical electrical activity, EKG, and arterial pressure before and during hypoxia of 7% O_2 in N_2. Note the onset of a cortical activation in the sensory-motor records at 25 seconds and a generalised arousal at 50 and 70 seconds, cortical deactivation starts at 90 seconds. (From Hugelin, A., Bonvallet., M. et Dell; ***EEG Clin. Neurophysiol.*** 11 : 1959).

sometic centres and, therefore, in this stage, although the neocortical functions would be inhibited, the somatic activities would be facilitated.

Let us now examine this experimental evidence in the light of certain observations made on human beings at higher altitudes. Although such studies are few, they throw an important light on the central nervous mechanisms involved in explaining the observations made at different centres. Von Muralt and Fleisch (Personal communication) have carried out a number of studies at higher altitudes in Switzerland. This is what they report.

At altitudes between 8,000 to 12,000 ft. there is an increase in the tonus of both the sympathetic and the parasympathetic systems. This is called by them as the amphoteric reaction of the autonomic nervous system. As a result of these the following effects are roported by them :—

(i) Increase in retinal sensitivity.

(ii) Increase in the speed of dark adaptation.

(iii) Increase in all reflex times i.e. shortening of patellar reflex, postural reflex, light reflex etc.

(iv) Increase in sensitivity of taste, smell and touch.

(v) Increase in vascular reflexes.

(vi) Increase in sensitivity towards pain.

(vii) Increase in regulation of sugar level.

(viii) Decrease of acid secretion in stomach.

(ix) In general the blood pressure remains constant and the ventilation is increased, and there is a definite increase in the sensitivity of the Respiratory centre to carbon dioxide.

(x) Sleeplessness and Cheyne-Stokes breathing are also observed.

They also observed that above 12,000 ft. these reactions are *reversed*. The tonus decrease with inereased height, the reactions become slower and the reflexes become more and more insensitive.

Thus, oxygen lack in low form, which occurs at the lower altitudes, produces an increase in excitability and lowering of the threshold, as has also been observed in the animal studies. While more pronounced oxygen lack which occurs at high altitudes leads to a failure of the higher nervous mechanisms, as observed in the animals also. The first elements to drop out as a result of this failure are those with the highest requirement of oxygen i.e. carotid body, cortex, respiratory centre etc.

They have also reported that in active mountain climbing, or in those individuals who have been properly acclimatized, slow ascent even to heights of 21,000 to 23,000 ft. provides an adaptation which can be sufficient for periods of weeks, but not in the long run.

So most of the above mentioned observations will be made on those persons who have been suddenly taken to the higher altitudes, and after acclimatization (with its concomitant decreased hypoxic effect) these responses will disappear. On the other hand, if a person stays on higher altitudes for longer duration, the deterioration in some of the central nervous mechanisms would appear again.

Some studies reported previously can now be analysed in the context of what has been stated above. The first systematic observations of mental deterioration at high altitudes were made by Prof. Angelo Mosso (Jokl, 1942), who presented an excessive volume of effects and actual experiences on the subject of effects of oxygen deprivation upon the human body. Mosso mainly stressed the peculiar emotional reaction which occurred during strenuous exertion caused by physical exertion at high altitudes. At about 14,000 ft. he met people, who on their arrival at the summit, were so excited that one might have thought that they were drunk. It seemed as if their entire character had suddenly undergone a change. Others following an exhausting march at great height, lapsed into a state of semiconsciousness in which they remained for a considerable time. He also relates the story of a Professor of Botany who during mountain ascent used to forget the names of the plants which, however, returned to his memory a few hours later when he came down.

Similarly, other studies reported from Prof. Loewy's laboratory (Jokl, 1942) stressed that when the animals or human beings are 'flown' to altitudes up to about 10,000 ft., their somatic reflexes (patellar reflex) are diminished. On the other hand when such animals were made to 'ascend' above 10,000 ft. the reflexes become intensified far above normal. On going still higher there is so much facilitation of these mechanisms that it leads to the production of convulsions, before a final failure of the central nervous activity. These two types of changes could be explained according to the concept put forward by Dell et al. (1959).

Other studies reported during the Second World War from Russia (Steiman, 1943) also report that 'ascending' to altitudes of 20,000 to 25,000 ft. for short or long periods in either low pressure chamber, or in an observation plane, bring about a series of changes in the neuropsychic functions which could be described in three consecutive phases as follows :—

(i) Excitement.
(ii) Adjustment.
(iii) Depression.

In the first stage of excitement the subject shows an increased interest in the surroundings, quickened perception and an increased tempo of all psychic reactions. They carry out mathematical calculations with great accuracy and in a shorter time.

The second phase brings abont a period of adjustment of the nervous system to hypoxia.

In the third phase there is depression of the central nervous system, with definite depression of neuropsychic activity i.e. growing fatigue, drowsiness, diminished psychic activity, diminished acuity of perception and a very definite diminution in the ability to carry out fine co-ordinated movements. The stimulation of the autonomic centres, particularly the sympathetic, which occurs in the first stage, is now followed by depression. The mental activity deteriorates and the time required for solving mathematical problems now is increased and there are many errors in the solution of these problems. Mental effort becomes very difficult, there is difficulty in concentration, diminution in the powers of observation and slowing up of association processes.

Macfarland (Steiman, 1943) recognises three stages of depression. The most presenting symptoms at an altitude of 14,000 to 17,000 ft. are depression of somatic nervous system and drowsiness. At an altitude of 17,000 to 20,000 ft. judgement deteriorates and a marked depression of neuromuscular co-ordination is observed. At 20,000 to 24,000 ft. memory for events becomes disturbed. Visual acuity and light perception are disturbed and symptoms resembling iminent loss of consciousness develop.

At the lower altitudes or with lower levels of hypoxia as a result of possibly the neocortical alerting stage, it is observed that the visual acuity, depth perception, field of vision, and colour perception etc. are slightly increased and there is increased auditory acuity also. On the other hand, at higher altitudes and higher levels of hypoxia all these acuities decrease.

A number of other random observations carried out at higher altitudes also describe an adverse effect on the anxiety state, learning abilities and routine mental work. It has been stressed by all, that such deterioration of mental functions is related to the height of the altitude or the length of stay, increase in both producing more marked effects. A person suddenly taken to a higher altitude will give all these signs and symptoms which will gradually diminish during the first week as a result of acclimatization. By prolonged stay at high altitudes these mental deteriorations may again reappear gradually.

Sleeplessness and headache are also experienced by many at these high altitudes. Headache is considered to be due to possibly dilatation of cerebral blood vessels, while sleeplessness would be due to a generalized alerting response of the cortex to hypoxia.

A number of observations made at high altitudes also suggest that the motivation of the individual will make a difference in the neuropsychic responses to hypoxic conditions. This has also been observed in the various mountaineering expeditions that the physiological and neuropsychic responses of those with a higher motivation are better than others with a lower motivation. Here, I may quote certain experimental observations made sometime back by Professor Fulton and his group on studying the adaptation responses of monkeys 'flown' in a stratochamber. It was observed by them that if certain regions of the limbic system of brain are ablated, these monkeys would collapse at much lower 'heights' as compared with the normal monkeys. It may be emphasized that these regions of the nervous system are intimately related to the emotional and autonomic behaviour of the individuals. It is, therefore, worth studying whether emotionally weak individuals or those with a lower motivation, would adapt and acclimatize less than those who have a strong motivation.

In the end, I may again emphasize that controlled scientific studies still need to be done to evolve a complete picture regarding the neurophysiological problems faced at high altitudes and the present random observations have been put forward before you with a view that these may stimulate interest of some of you to carry out more controlled investigations to explain these phenomena.

Before closing I may quote an observation made by Professor Fulton during the Second World War, which appears to be very appropriate to the existing conditions in our country. Referring to the air warfare he said "The war in the air has come to be in a very real sense a physiological war, since the limitations of air combat at the present time lie more with pilot than with the plane, and the Government that succeeds in adequately protecting the pilot through study of his physiological needs, will gain strategic advantage that will undoubtedly be decisive in determining the outcome of the conflict". This quotation can appropriately be applied now to our troops posted at high altitudes.

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