REVIEW

NEUROLOGICAL MECHANISMS INVOLVED IN DEEP SEA DIVING

By

BALDEV SINGH

Emeritus Scientist, Department of Physiology, All India Institute of Medical Sciences, New Delhi

Sea diving came early in the vertebrate marine life. When these vertebrates were to breathe oxygen from air on the surface of the sea and were to find food in its depth, diving became handy to fulfill these two needs. Teresterial vertebrates did not need diving and resorted to it only under special circumstances. Man learns to dive as a hobby or as a profession as in pearl divers or fishermen or as a training to serve in the naval wing of the armed forces.

There has been a long standing interest in the study of diving including the study of its neurological mechanisms. Over a 100 years ago, this field of enquriy began when it was noticed that aquatic vertebrate animals during diving did not get such symptoms as great discomfort, loss of consciousness and convulsive efforts which are so common in acute respiratory arrest in man and many other air-breathing teresterial vertebrates. The enquriry has been shifted in course of time from the functional adjustments themselves to the mechanisms involved to elicit, control and integrate this performance.

This presentation deals only with the neurological studies which are of course closely related to several other physiological processes which simultaneously are active during diving. Much of this work has been done in the natural divers such as the duck and recently in human beings too during their period of training for some types of jobs and amongst individuals like pearl divers of Japan and Korea.

The study of neurological mechanisms has chiefly been in the following fields :

1. The reflexes.
2. Derangement of consciousness which includes effects of weightlessness and sensory deprivation.
3. The effects of gases i.e. 0_2, Co_2 and N_2 on the neural mechanisms.

1. The study of reflexes :

Irving (1) emphasised that reflex mechanisms play important role in the adjustment needed for diving. The reflexes studied subsequently have been :

(*a*) Reflex apnoea
(*b*) Reflex Bradycardia
(*c*) Reflex adjustment of circulation.

(a) *Reflex apnoea* : Apnoea is an essential part of diving. It is partly voluntary and involves control of higher volitional centres in the cerebral cortex and limbic structures on the pontine and medullary centres. This apnoea starts immediately when the dive begins.

The reflex apnoea has been studied in the duck (2) both in the intact and decerebrate preparations. The conclusions drawn from these experiments, indicate that the respiratory adjustment to water emersion of the head essentially involves the medullary reflex mechanisms entirely independent of higher levels of the central nervous system although this basic mechanism may be influenced by the activity of the higher centres when the latters are intact. Trigeminal nerve is the afferent pathway which induces the apnoeic response upon submersion. The ophthalmic division appears to be the most important branch of the V nerve in this respect, although the mandibular division plays a minor role. The most sensitive receptive area is the nasal mucosa the skin around the nose and the eyes. The efferent arc of the reflex is mainly the vagus nerve. These conclusions were drawn in experiments done on ducks by submerging their head under water and seeing the effects after cutting the various branches of the trigeminal nerve to demonstrate the afferent arc, or cutting the vagus nerve or atropinizing it to prove that it makes the efferent outlet. Also anaesthetizing locally the area supplied by the ophthalmic division of the trigeminal gave information regarding the receptive field.

(b) *Reflex Bradycardia* : It has been noticed that during diving the heart rate becomes considerably slowed. This does not involve any voluntary effort in birds or mammals who dive during expiration. In man on the other hand who may dive after deep inspiration this bradycardia may be due to Val-salva effect.

The reflex mechanisms involved are exactly as in the reflex apnoea. The sensitive area, the trigeminal nerve branches, the medullary centres and the vagus nerve play the role to reduce the rate of the heart.

There are, however, some more suggestions which need further corroboration to be strongly valid. Postural apnoea was postulated by Koppanyi and Kleitman (4), Koppanyi and Dooley (3) etc. This type of apnoea occurs when some of the diving birds are put in the posture of diving. It has been suggested however that postural apnoea reinforces the reflex apnoea produced by trigeminal stimulation.

There has been controversies regarding the effect of Co_2 or oxygen deficiency or pH changes on the respiratory centre. It has been stated that the respiratory centre in divers is insensitive to carbon dioxide and that increased carbon dioxide concentration inhibits respiratory centre in avian divers. These two facts have now been very extensively studied for substantiation and it has been concluded that possibly in some diver birds the respiratory centre during diving is a little less sensitive to Co_2 concentration but in no study the inhibiting effect of Co_2 has been proved. Similar experimental evidence corroborates that the initital apnoea during diving is not produced by either oxygen lack or changes in the pH.

Bradycardia during diving has also been a subject of more investigations. It has been found that in natural divers the bradycardia in diving comes suddenly and immediately as compared to casual divers in which it develops gradually. It is also contended that diving bradycardia in its full fledged form is species specific and it also depends on the age of the animal, the adults showing it in a more marked form. These characteristics and variations have been explained on the effectiveness of vagal influence and the influence of asphyxia and hyperkalaemia. Electro-cadiographic monitoring however, supports that the effect on heart rate is primarly a vagal influence which of course can vary to a degree in species and according to age and that asphyxia and hyperkalaemia play very minor role.

(*c*) *Reflex adjustment of circulation* : Hollenberg, N.K., and B. Uvnas (5) found in avian divers in unanaesthetised state a characteristic response of increased blood pressure and decreased skin and splanchnic blood flow with little change in skeletal muscle blood flow during submersion asphyxia with associated pronounced bradycardia. The net result of the circulatory response is to decrease the oxygen supply to areas that can easily withstand oxygen deficit for a limited period conserving the available oxygen stores for organs like brain and heart which are more sensitive to oxygen deficiency. These circulatory responses to asphyxia were completely abolished by denervation of chemo-and baro-receptors in the carotid sinus. In a normal bird, duck in this case, asphyxial stimulus through the carotid sinus produces peripheral vaso-constriction and rise of blood pressure. However there is some evidence to support that the degree of distension of the lungs through receptors in the lung parenchyma and variations in venous return are important contributory factors to the circulatory changes produced during diving.

Of the two elements of asphyxia that is hypercapnia and hypoxia hypercapnia is more effective in producing these carotid reflex effects.

The muscle circulation diminishes but at a later stage. This supplements the initial effects. The exact mechanisms of this effect is not completely understood. It is suspected to be biochemical in nature.

2. Derangement of consciousness which includes weightlessness and sensory deprivation.

The definition of consciousness has been always a formidable task. In this paper it is meant to indicate (*a*) recognition of self, (*b*) recognition of where i.e. the environments in relation to self and (*c*) recognition of time i.e. now as opposed to past and future.

Consciousness can fail in several different ways due to so many causes. Here we shall discuss only those factors which relate to diving

How does the recognition of self pose a problem in diving? This emphasis on self becomes important when it is argued as to what is good and what is bad for this self. This determines motivation which goes a long way to produce behaviour changes from simple neurosis to marked mental difficulties. The ill-effects of diving may in some cases have its origin in the primary fault in motivation.

In the recognition of where i.e. the awareness of environments in relation to the self, primarily involves the sensory inputs through the peripheral receptors and the sensory nerves, both the special cranial nerves as well as the somatic sensory nerves, and visceral afferents.

There is a lot of information available as to the effect of hypoxaemia and hypercarbia, the two states very important from the divers point of view. The effects on vision, on hearing and on vestibular functions have been very well taken up in the proceedings of the first international symposium on submarine and space medicine held from September,. 8-12, 1958.

Regarding effect on visual system the conclusion seems to be justified that high concentration of oxygen under increased pressure has effect on human vision due to changes in retina demonstrable with electro-retinography. It is therefore suggested that unphysiological oxygen pressure should be avoided in subjects with a family history of degenerative disease. Conceivably, a latent hereditary factor could render the retina abnormally susceptible.

However, in contrast to the effects of hyperoxia the visual cells withstand lack of oxygen rather well as compared to the forebrain and the cerebellum.

In the case of the Cochlear nerve electrical potential recorded from the round window (CR) under effect of hypoglycaemia, increased or decreased Co_2, O_2 and nitrogen concentrations in cats indicate that many of the changes seen under these experimental conditions do not pose a serious situation and hence they do not create much of a difficulty. This seems to hold true also of the vestibular nerve.

The effects of gravity free state and sensory deprivation are becoming important propositions to be tackled as the frequency of operations at deep sea level are increasing.

Effect of gravity free state :—Body immersed in water is comparatively less in weight experienced as a sensation by the person floating in the fluid. This sensation is a combination of several impressions conveyed jointly by the somatic touch, pressure, muscle and joint sense, and postural mechanisms in which neck and body righting reflexes and the vestibular nerve play a significant role. The symptomatology produced during the short duration weightlessness in human beings is recorded to be, disorientation, disturbance of neuro-muscular co-ordination, delayed motor responses, motion sickness symptoms, a feeling of falling or floating, and oculoagravic delusions in the dark. In addition the majority of the subjects feel elated. Some subjects feel sleepy, they hyperventilate, perspire, feel dizy or have vertigo and vomiting. There is no serious changes in cardiovascular or respiratory function.

Many of these symptoms are averted if arrangement can be provided for visual orientation, maintenance of comfortable temperature and humidity, and provision of gajets to give a feeling of the sarroundings. A previous training is necessary to avoid many of the ill effects. What is the neural mechanisms of this feeling of weightlessness. It is surmised that utricle in the inner ear plays an important role. The other regions involved are the cerebellum and some parts of the parietal lobes.

The new worlds under the sea are alien and possibly more than passively dangerous. In the deep sea, there is marked attenuation of body feelings in reference to the gravity, there is integumentary isothermicity, no pain, silence, and darkness. This unusual mellieu causes one to come to grips with the inner frontiers i.e. the self, and its relation to the sarroundings. Pain is a very effective stimulus for awareness and if pain is experienced many of the ill effects of sensory deprivation are counteracted.

As the time passes sensory deprivation gives a feeling of being more and more rested even without sleep. During the next few hours, there arises a great craving to experience some stimulus. This leads to ecstatic state, fantasies and hallucinations. The last stages reach in about 6 hours or so. They, however, are reversible.

There are some surmises made regarding the neural mechanisms involved in the disorientation in space and time due to sensory deprivation. The reticular tissue of the brain stem and superior medial bank of the temporal lobe are strongly suspected in connection with space orientation. For orientation of time the integrated effects of biological clocks and the central nervous system is very significant.

3. The effects of gases on the nervous system :

(*i*) The effects of carbon-dioxide.

Rapid lowering of Co_2 tension as in hyperventilation increases the tendency to convulsions. In concentration above 20 percent, Co_2 produces unconsciousness. Electro-encephalography shows that lowering of Co_2 tension produces slowing and build up in children or in immature brains. High concentration also produces marked slowing. The neuromuscular junction shows changes in transmission under effect of Co_2.

These effects are explained by the fact that Co_2 has a marked influence on the membrane potential especially the slow components. This effects is more marked on the denderites. It needs the presence of oxygen and proper pH to show these changes in the cell potentials. It is suggested that Co_2 effect is related to the condensation of Co_2 and certain aminoacid groups forming unstable carbamino compounds which participate in reversible biochemical equilibrium reaction.

The effects on the intact central nervous system further depend on the vascuclar changes brought about by Co_2 concentration.

(*ii*) The effect of oxygen and nitrogen :

The effects on nerve conduction of pure oxygen at atmospheric pressure are as follows :

(1) High pressure per se is not injurious to the nerve exposed to non-toxic gaseous environment. (2) Pure oxygen at atmospheric pressure is not injurious for 5 hours. (3) If proper partial pressure of Co_2 is provided the mammalian nerve is not effected for 5 hours under atmospheric pressure. (4) Amphibian nerve shows block if exposed to pure oxygen at 13 atmospheric pressure. (5) Mammalian nerve with proper CO_2 partial pressure is not injured

for 1.5 hours at 13 atmospheric pressure of pure oxygen. The conduction block is reversib if it is maintained only for a few minutes. These experiments were done in nerves deprived o their blood supply.

The injury is a direct toxic effect of oxygen on the metabolic processes which maintai the membrane potential and impulse transmission.

Acute and chronic hypoxaemia are the conditions met more often in altitude effects s they are not taken up here.

Nitrogen at high pressure effects the functions of the nervous system and produces varie symptoms. Deep sea divers at 270 to 300 feet (9 to 10 atmospheres absolute) have difficult in assimilating facts and making quick decision when oxygen and Co2 estimations are withi normal range. Severe emotional disturbances are sometimes observed and loss of consciousnes is reported. These symptoms are produced also in compression chambers even at 4 atmospher pressure

These clinical manifestations are attributed to the narcotic effect of nitrogen. Mor details have yet to be worked out as to how these effects are brought about. Electroencephalo graphically it is found that R type of alpha activity becomes non-reaction and there is depres sion of flicker fusion frequency. This only indicates that the effects of nitrogen on the brai are at more than one level i.e. at the cortical and brain stem levels.

SUMMARY

Studies in deep sea diving have been done in diving birds and in human beings. It has been found that the neurological mechanisms involved in diving are part of an integrated physio logical response.

The neurological mechanisms can be classified as follows :

1. Reflexes
2. Derangement of consciousness including weightlessness and sensory deprivation
3. Effects of gases like Co_2, 0_2 and nitrogen on the nervous system.

1. Reflexes : The reflexes studied are only three :

(*a*) Reflex apnoea
(*b*) Reflex bradycardia
(*c*) Reflex circulatory response

In (*a*) and (*b*) reflexes, the afferent arm is constituted by the trigeminal nerve specially it ophthalmic and mandibular branches. The nasal mucous membrane and area of the eyes ar the peripheral receptor sites. The medullary centres are the central neural structures involve and mainly vagus is the efferent nerve.

For (*c*) reflex the carotid sinus chemo and baro-receptors play a great role. The ne

result of these reflexes is that less blood goes to skin and splanchnic areas and more to brain and heart in a situation where asphyxia is produced by apnoea and bradycardia.

2. Derangement of consciousness including weightlessness and sensory deprivation :

Consciousness is defined to be awareness of one's self in relation to the environments i.e. the space and time.

Consciousness has a concomitant effect called motivation. If motivation is inadequate lot of neurotic symptoms and phobias appear.

Elimination of gravity leads to many peculiar subjective states which can seriously hamper efficient physical and mental performance.

Sensory deprivation as is produced in diving due to unchanging fluid medium disallowing more than very limited range of external stimuli, lead to disorientation and hence mental efficiency gets seriously jeopardized.

The neural mechanisms involved in weight perception constitute the peripheral end organs of touch, and muscle and joint sense, various righting reflexes the vestibular apparatus, the cerebellum and the parietal lobes.

For sensory deprivation the central mechanism involved is diffuse and is constituted by the brain stem and several cortical regions.

3. The effect of gases on the nervous system :

It is suspected that carbon dioxide effects generation of electric potentials and impulse transmission by forming reversible carbo-amides in the cell. This reversibility is helped by the presence of oxygen. High oxygen concentration and pressure produces nerve block due to direct metabolic intoxication which is less effective if adequate quota of Co_2 is provided. The mechanism of the effects of nitrogen in nitrogen narcosis are not clear.

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