# IN VIVO STUDY OF THE OXYGEN TENSION IN THE BRAIN TISSUES DURING PROLONGED ACCELERATION*

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Translated from Byulleten' Éksperimental'noi Biologii i Meditsiny, Vol. 55, No. 1, pp. 43-48, January 1963
Original article submitted April 25, 1962

During changes in the velocity of movement of a body (acceleration), forces of inertia arise in a direction opposite to the action of the acceleration. These forces are usually called overloads. Overloads are of greatest importance to man in connection with aviation and, in particular, with cosmic flight, where they may attain considerable magnitudes and may act for a long time.

In the pathogenesis of the disturbances caused by overloads on the body, an important, and sometimes decisive, role belongs to changes in the hemodynamics and respiration. It has been found that overloading leads to changes in the EKG [1, 7], in the blood pressure [5, 9], the velocity of the blood flow [19], the stroke and minute volumes of the heart [17] and the gas exchange in the lungs [2, 13, 15].

The circulatory and respiratory disturbances during overloading lead to a lowering of the oxygen saturation of the blood [11, 16, 18]. These experimental facts have led many researchers to assert that one of the more important factors limiting the ability of the organism to tolerate overloading is cerebral anoxia [6, 8].

Indirect evidence of anoxic changes in the brain during overloading is provided by the results of electroencephalographic investigations [14] and the study of conditioned reflexes [3]. No direct evidence of changes in the oxygen content in the brain tissues during the action of acceleration could be found in the literature, and the present research was accordingly devoted to this subject.

## EXPERIMENTAL METHOD

To study the anoxia of the brain tissues the oxygen tension was measured by a polarographic method using platinum electrodes implanted into the brain of a dog† [4a]. Certain indices of the general condition of the organism were recorded simultaneously, together with the EKG, espiration and, in some experiments, the EEG. Overloading was produced by rotating the animals in a centrifuge in different positions. The duration of action of overloading was 1 min and the magnitude of the overloading ranged from 2 to 12 g. Altogether 156 rotations were carried out on 12 dogs.

In the first series of experiments we studied the action of overloading in the direction from head to pelvis, in the second series from pelvis to head, and in the third dorso-ventrally, The oxygen tension ($pO_2$) was recorded in relative values (in percent). The $pO_2$ while the animal was breathing air before rotation in the centrifuge was taken as the initial level (100%).

## EXPERIMENTAL RESULTS

After the first experiments using the polarographic method it was clear that marked changes in the oxygen tension took place in the brain tissues during the action of overloading. In subsequent experiments a definite relationship was found between the degree and character of the changes in the $pO_2$ and the magnitude, direction and duration of action of the overloading forces on the animal body.

The most marked changes in the oxygen tension were observed during the action of overloads in the direction from head to pelvis.

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*Delivered at a meeting of the Moscow Society of Physiologists on March 9, 1962.
† For a detailed account of the method see the article by E. A. Kovalenko in the journal: Patologicheskaya fiziologiya i éksperimental'naya terapiya, No. 1, 1961.

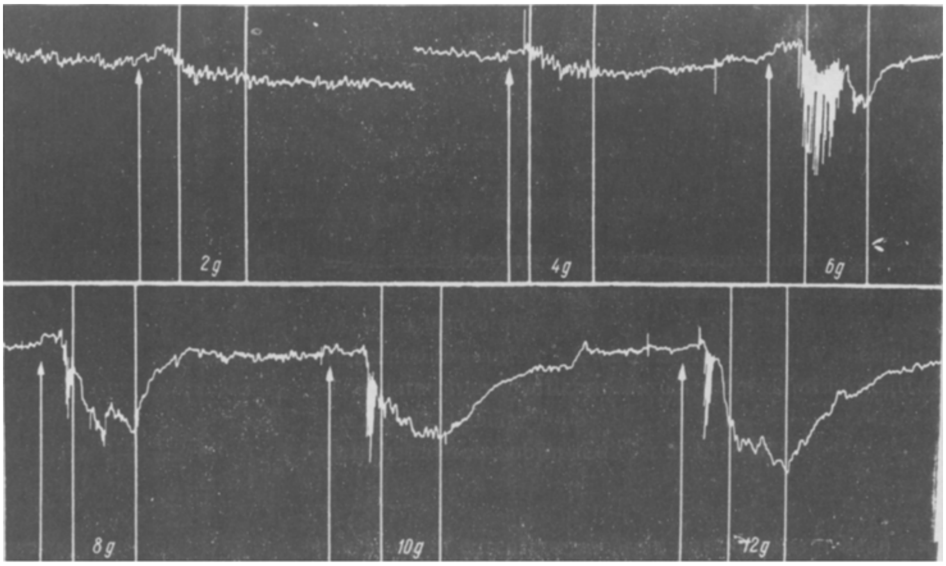


Fig. 1. Oxygen tension in the cerebral cortex of a dog during the action of different overloads (from 2 to 12 g) in the direction from head to pelvis. The arrow indicates the beginning of rotation, the vertical lines the time of action of the overload under investigation.

Overloads of a magnitude of 2-4 g in this direction at the beginning of rotation caused a well-marked, but transient increase in the oxygen tension of 5-10% of the initial level, followed by a slight decrease (to 97 and 93% of the initial level). With overloads of greater magnitude (6-12 g) a transient increase in the $pO_2$ was also observed at the beginning of rotation, but this increase was less in magnitude and duration than in the first case. Moreover, during rotation this increase gave way to a steeper and more sudden decrease in the oxygen tension (Fig. 1), the fall in the $pO_2$ being greater as the overload increased (on the average to 84% at 6 g, to 78% at 8 g, to 74% at 10 g and to 72% at 12 g). Analysis of the pulse and respiration at these overloads showed that, in contrast to the polarogram, the character of the changes in the pulse and respiration was not always dependent on the severity of overloading. For example, with an overload of 2 g the mean pulse rate during rotation was 157/min, at 4 g 141, at 6 g 151, at 8 g 142, at 10 g 173, and at 12 g 149/min. The decrease in the oxygen tension was accompanied by a disturbance of the rhythm and a slowing of respiration and by marked excitation of the animal. The EEG at the beginning of rotation revealed an increase in the frequency of the waves, changing to a slowing of the rate to 4-5 cps, with an increase in the amplitude of these waves. In individual experiments, in which the decrease in the $pO_2$ reached 60-50% of the initial level, arrest of respiration of the cardiac contractions was observed. The lowering of the polarographic curve of the oxygen tension was always fluctuating in character. The rhythm of the waves of oxygen tension at overloads of 4-6 g differed from the rhythm observed at rest by the greater frequency and amplitude of the oscillations, whereas at 8, 10 and 12 g, conversely, with an increase in the overload the frequency was decreased and the amplitude increased (see Fig. 1). Because of the initial increase in the oxygen tension and the high-amplitude character of the $pO_2$ waves during the action of acceleration, it may be assumed that compensatory mechanisms are brought into play, preventing the onset of cerebral anemia during the action of mechanical factors.

The lowering of the $pO_2$ level during overloading took place after a slight delay and the minimum of the $pO_2$ was observed at the end of the plateau of overloading or during braking of the centrifuge (see Fig. 1). Restoration of the $pO_2$ level in the period of the after-effect was slowed as the overloading increased. The results of our experiments confirmed, from a slightly different viewpoint, the discovery [10] of the delay in the fall of the arterial pressure during the action of overloading, and they explained why overloads of great magnitude but short duration are tolerated better than prolonged overloads of lesser magnitude.

In the second series of experiments we studied the action of overloads in the direction from pelvis to head. In view of the severe hemodynamic disturbances in the animals in the inverted position, overloads up to a maximum of only 8 g were used. During the action of overloading in this direction having a magnitude of 2 g an increase in the $pO_2$ was also observed at the beginning of rotation, followed by a slight decrease at the end of the action of the overload (on the average to 95%). During overloads of 4, 6 and 8 g a gradual lowering of the $pO_2$ was observed to values of 90, 86 and 84% of the initial level respectively. The frequency of the $pO_2$ rhythm was increased during overloading. The polarographic curve was of a "saw-tooth" type during the fall (Fig. 2). It was noteworthy that, despite the serious general condition of the animals, the $pO_2$ of the brain tissues fell much less than during overloads in the direction from head to pelvis. When the animals were turned in an inverted position they developed sinus bradycardia, the respiration rate was sharply reduced, and in some experiments respiratory arrest ensued. During overloads of 6 and 8 g, profuse nasal hemorrhages were often observed. This phenomenon indicated a sharp rise of the filling of the blood vessels of the animal's head. In spite of this, however, the oxygen tension continued to fall. Hence, during the action of negative overloads some degree of anoxia of the brain tissues also was present, although this was not the only factor determining the animal's general condition.

Transverse overloads are of the greatest practical interest. It will be apparent from Fig. 3 that during overloads of 2, 4, 6 and 8 g no great changes were observed in the $pO_2$ level of the brain, and sometimes it was actually increased. In other experiments a decrease in the $pO_2$ during transverse overloads began with 8 g (on the average to 93% of the initial level). At 10 and 12 g the lowering of the $pO_2$ was less than during equal overloads in the direction from head to pelvis (to 87 and 80% of the initial value respectively).

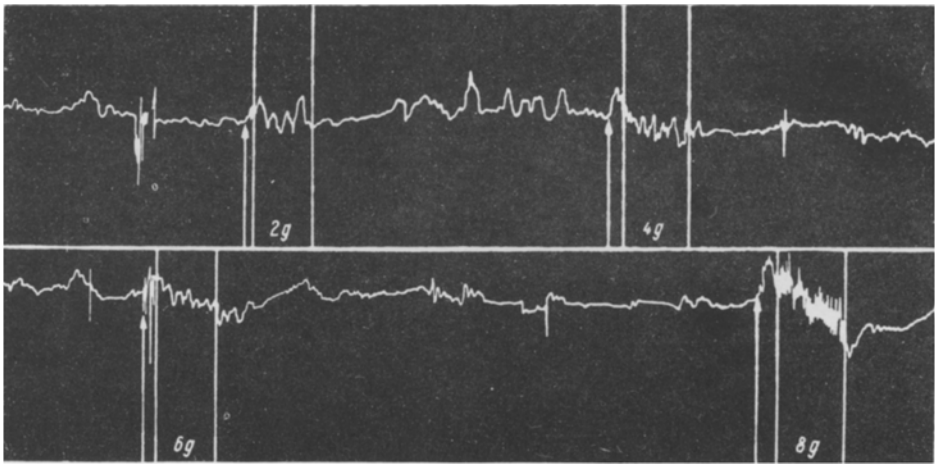


Fig. 2. Oxygen tension in the cerebral cortex of a dog during the action of an overload in the direction from pelvis to head. The arrow indicates the beginning of rotation, the vertical lines the time of action of the overload under investigation.

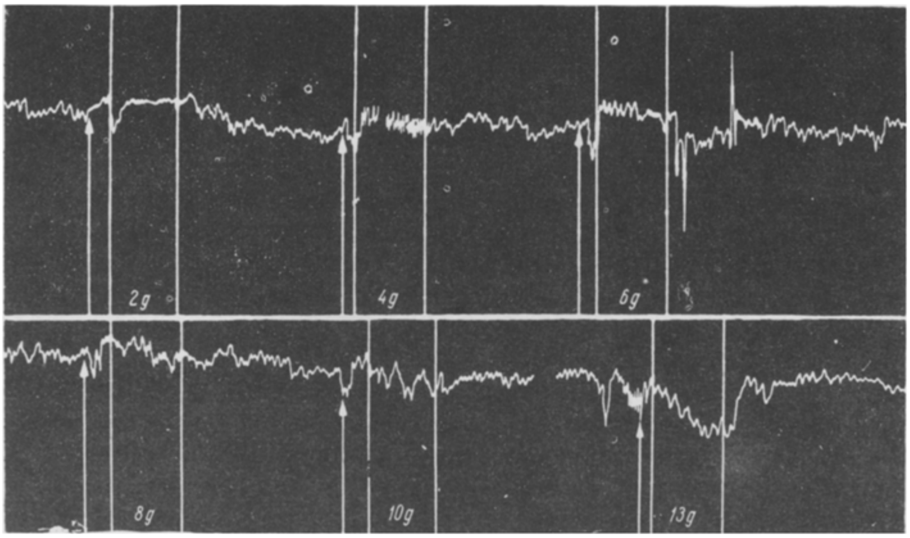


Fig. 3. Oxygen tension in the cerebral cortex of a dog during the action of an overload in the dorso-ventral direction. The arrow indicates the beginning of rotation, the vertical lines the time of action of the overload under investigation.

Hence, the $pO_2$ polarogram during transverse overloads differed in the following respects from the $pO_2$ during longitudinal overloads: 1) the decrease in the oxygen tension took place more slowly, and during overloads of up to 8-10 g the $pO_2$ level was essentially unchanged; 2) the rhythm of the $pO_2$ waves frequently showed great amplitude and frequency. The "saw-tooth" decrease in the $pO_2$ and the subsequent rapid transformation into a smooth curve, together with the slight fall in the general level of the oxygen tension, might indicate that the compensatory mechanisms in this type of overloading were comparatively efficient. The transverse overloads also caused less marked changes in the pulse and respiration.

The experiments of this series disclosed the following fact of practical importance. If the head were situated 15-20 cm above the horizontal plane in which the animal's trunk was secured, the oxygen tension fell more suddenly than if the head were fixed at the same level as the plane of the trunk. The fall in the oxygen tension in the first case could be compared in magnitude with the changes in $pO_2$ during overloading in the direction from head to pelvis.

In conclusion, it should be noted that the decrease in the $pO_2$ during all types of overload, and especially during overloads in the direction from head to pelvis, was evidence that anoxia is one of the fundamental factors in the pathogenesis of the disturbances due to acceleration. It must be emphasized, however, that the magnitude of the fall in $pO_2$ even during maximal overloads (10-12 g in the direction from head to pelvis) was smaller than when the animals were elevated in a pressure chamber to an altitude of 9-12 km, which led to gross anoxic changes in the body [4]. The comparatively moderate fall in the $pO_2$ during large overloads suggests that in these cases $CO_2$ may be retained in the tissues (because of the marked circulatory disturbances), and in our opinion this may contribute toward maintaining the oxygen tension at a higher level during cerebral anoxia. For instance, a special series of experiments showed that during inhalation of a mixture with a low concentration (5-10%) of oxygen, the addition of $CO_2$ (5-10%) caused an increase in the $pO_2$ in the brain tissues almost to the initial level.

These facts suggest that other factors besides anoxia of the brain tissues are concerned in the pathogenesis of the disturbances accompanying overloading.

## SUMMARY

By means of the polarographic method a study was made of the dynamics of oxygen tension ($pO_2$) in the brain tissues of dogs in prolonged overloads occurring during rotation in a centrifuge. As established, the rate of $pO_2$ reduction is dependent on the magnitude, direction and period of acceleration. With an acceleration force of 2-12 g in the head-pelvis direction, $pO_2$ dropped to 92 – 70% of the initial level after one minute of rotation, whereas in transverse overloads (back-chest) – to 98 – 80%. Overloads of 2 – 8 g in the pelvis-head direction caused a reduction of $pO_2$ to 95 – 84%. The $pO_2$ level in the brain tissues also depended on the position of the head in respect to the longitudinal axis of the animal body. But a moderate $pO_2$ reduction in the brain tissue during rotation shows that hypoxia is not the only factor in the mechanism of disturbances caused by accelerations.

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