PROCEEDINGS OF THE YEREVAN STATE UNIVERSITY

Chemistry and Biology 2026, **60**(3), p. 158–165

Biology

THE EFFECT OF NORMOBARIC AND HYPOBARIC HYPOXIA ON THE ELECTRICAL ACTIVITY OF THE BRAIN AND CARDIORESPIRATORY RESPONSE

M. A. KARAPETYAN [1*], N. Yu. ADAMYAN [2**], E. S. GEVORKYAN [2***]

[1] *Laboratory of Human and Animal Integrative and Adaptive Physiology, Research Institute of Biology, YSU, Armenia*
[2] *Chair of Human and Animal Morphology and Physiology, YSU, Armenia*

The subject of study is the comparative assessment of electrical activity of the brain and cardiorespiratory response during normobaric and hypobaric hypoxia. For the normal functioning of the mechanisms for maintaining the body's energy balance, it is necessary to preserve the parameters that characterize the functional abilities of oxygen transport systems. The experimental results show that atmospheric pressure is not the main factor influencing the electrical activity of brain cells and the autonomic functions of the body. It turns out that in both hypobaric and normobaric hypoxia, the cause of the observed changes in indicators is a decrease in the partial pressure of oxygen (PO_2) in the environment, which leads to a decrease in oxygen tension in the blood (PaO_2).

https://doi.org/10.46991/PYSUB.2026.60.3.158

***Keywords*:** hypobaric and normobaric hypoxia, neuronal activity, cerebral cortex, heart and respiration rate.

Introduction. Providing the body with oxygen is one of the most pressing problems of modern physiology and theoretical medicine, since hypoxia underlies the pathogenesis of most diseases, and an in-depth study of these processes is of great practical importance.

For the normal functioning of the mechanisms for maintaining the body's energy balance, it is necessary to preserve the parameters that characterize the functional abilities of oxygen transport systems. Several classifications of hypoxic conditions are known. The most well-known classification includes 4 large classes: hypoxic hypoxia, anemic hypoxia, congestive or circulatory hypoxia, histotoxic or tissue hypoxia [1].

In addition to these classes, acute and chronic hypoxia are also distinguished. Acute hypoxia occurs, when there is a sharp decrease in the access of oxygen to the body: during fast flight on aircraft, when "ascending" to a height, when the body breathes under conditions of a gas mixture containing little oxygen (hypobaric

* E-mail: marietta_karapetyan@ysu.am
** E-mail: nona.adamyan@ysu.am
***E-mail: emma.gevorkyan@ysu.am

hypoxia, HH). Chronic hypoxia develops with chronic diseases of the blood and respiratory system, as well as with prolonged stay in the mountains, in environmentally unfavorable conditions (densely populated cities, regions with large industrial facilities), where there is low PO_2 in the atmospheric air.

For all types of hypoxia, the vector of metabolic disorders is the same: the formation of energy bonds slows down, the energy potential of the cell decreases, and biosynthesis processes are suppressed. The latter is especially pronounced in the synthesis of proteins and their complexes, as well as lipids of various types, i.e. substances included in the structure of cell membranes. All types of oxygen deficiency, regardless of their genesis, necessarily lead to disruption of oxidation processes in the cells of the central nervous system. Weakening of oxidative processes in the brain, including neurons of the respiratory center, leads to weakening of breathing and its stop (apnea). Studies of the effect of hypoxia on the body are carried out by reducing the partial pressure of ambient O_2 (PO_2) either by reducing barometric pressure (HH), or by reducing the O_2 fraction in the inhaled air under normal atmospheric pressure conditions 760 *mm* Hg (normobaric hypoxia, NH).

In some studies, barometric pressure is taken as the main parameter of interest [2–5]. Recent evidence challenges these assumptions, suggesting that physiological responses to hypoxic stimuli are PO_2 dependent, independent of barometric pressure [6–11].

The results of experiments on studying cognitive functions in conditions of NH and HH are ambiguous. The human brain requires a constant supply of oxygen to function effectively. Therefore, moderate to severe hypoxia can impair cognitive abilities, leading to possible problems in decision making. It has been suggested that cognitive abilities do not differ between NH and HH [12].

It was further hypothesized that all physiological variables (capillary and tissue oxygenation, cardiovascular performance) and subjective variables (perceived exertion, dyspnea, sleep quality, response to hypoxia and workload index) would differ between NH and HH [13]. However, physiological differences after exposure to NH and HH are currently the subject of much debate. It also remains unclear how brain cells respond to NH and HH.

The purpose of this study was to study the effect of acute NH and HH on neuronal activity of the brain and heart (HR) and respiration rate (RR).

Materials and Methods. The experiments were carried out under acute experimental conditions on white male rats weighing 180–230 *g*, anesthetized by intraperitoneal injection of Nembutal (40 *mg*/*kg*). Animals were purchased from "Sedward Limited Liability Company" (sedvardd@mail.ru). All of the above studies were carried out on 2 groups of animals. There are 12 rats in each group. Animals were obtained and kept in a special breeding facility that operates according to international bioethics standards. All data generated or analysed during this study are included in this published article (and its supplementary information files). All experimental protocols were approved by Yerevan State University.

All experimental protocols were approved by Yerevan State University.

All methods were carried out in accordance with relevant guidelines and regulations. All methods are reported in accordance with ARRIVE guidelines (https://arriveguidelines.org/).

Pecording of Neuronal Activity. For the purpose of extracellular recording of the impulse activity of neurons in the medulla oblongata and the cerebral cortex (sensomotor zone), anesthetized animals were fixed on a stereotaxic apparatus, and glass microelectrodes (diameter 1 *mm*, resistance 3–5 *m Ohm*) filled with a 2 *M* NaCl solution were inserted into the corresponding brain structures. To record the electrical activity of neurons in the respiratory center (RC) of the medulla oblongata, the cerebellum was removed, and the search for RC neurons was carried out in the *obex* zone.

Registration and analysis of the impulse activity of neurons was carried out using a computer program specially developed for the analysis of biological signals. Consecutive sections of interimpulse intervals, including up to 1200 action potentials, were analyzed. This article presents indicators of the average firing rate of neurons.

Recording of RR and HR. Respiration rate is measured using a carbon sensor attached to the rat's chest. The sensor consists of a thin elastic tube filled with graphite. Through electrodes coming out of the ends of the tube, the respiratory rate signal is transmitted and evaluated by a computer. The heart rate was recorded using a cardiograph.

***Hypobaric Hypoxia Conditions*.** In the first series of studies, changes in the above indicators were studied under conditions of HH. Various degrees of HH (moderate and acute) oxygen deficiency were created in a laboratory pressure chamber (36×26×50 *cm*) by pumping out air. After searching for a working neuron in the corresponding area of the brain, the animal was placed in a pressure chamber.

Registration was carried out under conditions of normal atmospheric pressure (PO_2 = 142 *mm* Hg, N), then in the dynamics of oxygen deficiency (at different "heights"): with moderate hypoxia (I phase) – at an "altitude" of 4500–5000 *m* (PO_2 = 98–85 *mm* Hg), with acute hypoxia (II phase) at an "altitude" of 7500–8000 *m* and (PO_2 = 64–58 *mm* Hg,) and after "descent" to conditions of normal atmospheric pressure (N^1).

The "ascent" and "descent" of the animals in pressure chamber was carried out at a speed of 15–20 *m*/*s*. At all altitudes, impulses from the pressure chamber were fed to the monitor screen, where impulse activity and respiratory rate were displayed, as well as to an electrocardiograph.

Normobaric Hypoxia Conditions. In the second series of studies, a model of NH was created. Tracheotomized animals, fixed on a stereotactic apparatus with implanted microelectrodes and electrodes for recording impulse activity, HR and RR under normal atmospheric pressure (PO_2 = 142 *mm* Hg, N), were supplied with a hypoxic gas mixture (7% O_2 in nitrogen) from a Douglas pouch through a tracheatomy tube [14]. The hypoxic gas mixture was composed according to the formula

$$O_2\,(\%) = ((B–47) \times 21) / (B_1–47),$$

where O_2 (%) is O_2 content in % in the gas mixture at the simulated height; 21 – value of O_2 content (in %) in atmospheric air; B is the barometric pressure at the simulated altitude (8000 *m*); 47 – partial pressure of water vapor (t = 37°C); B_1 is the barometric pressure, at which the experiment is carried out.

$$O_2\,(\%) = ((267–47) \times 21) / (690–47) = 7\%,$$

7% O_2 in nitrogen corresponds to an altitude of 8000 *m*.

The RR of gases in the bag was obtained using a gas analyser OXYBABY® 6.0 P. Registration of HR, RR and impulse activity of the cortex and medulla oblongata was carried out normally (before breathing the gas mixture), after 2 *min* and 5–6 *min* of breathing the gas mixture (NH) and after disconnecting from the gas mixture and transferring the animal back to breathing ordinary atmospheric air.

In the acute hypoxic stage of NH and HH, the animal can be kept for no more than 10 *min*. The reliability of the average values was determined using the Student's *t*-test ($p<0.05$). All work with animals was carried out in accordance with the rules of the European Convention for the Protection of Experimental Animals (Directive 2010/63/EU).

After the experiments, the animals were first anesthetized and then were euthanized by intra-abdominal injection of Nembutal (Nembutal 40 *mg*/*kg* × 3).

Results and Discussion. The central nervous system plays a major role in the adaptive activity of physiological systems and the adaptation of the body to various environmental conditions. An objective criterion of the functional state of the central nervous system, in particular the cortex and other brain structures where the processing and integration of afferent impulses occurs, is the electrical activity of these structures.

In our experiments, in the zone of the respiratory center (RC) of the medulla oblongata, in addition to phasic respiratory (expiratory and inspiratory) neurons, reticular neurons (RN) were recorded that did not detect respiratory periods in the impulse. The number of these neurons (54 neurons) is 3–4 times more than phasic ones. As is known, RNs localized in the RC region are involved in the regulation of breathing and, depending on the functional state, either have a general tonic effect on them or are themselves involved in generalized respiratory reactions [15].

Full compliance with the activity of the central nervous system, its electrophysiological correlates and behavioral reactions is also found when animals are at an "altitude" of 8000 *m* (Tab. 1) and after 5–6 *min* of exposure to NH (Tab. 2). The basis of all these changes is the restructuring of the central nervous system activity under severe conditions of hypoxia, which is reflected in the electrical activity of the brain [16].

Table 1

Changes in the frequency (imp/s) of impulses of neurons of the cortex and medulla oblongata in the dynamics of oxygen deficiency ($p < 0.05$)

Conditions	Cerebral cortex	Medulla oblongata
Before the "rise" (N)	14.5 ± 1.1	19.6 ± 1.4
4500–5000 *m* (I phase)	24.5 ± 1.9	22.5 ± 1.9
7500–8000 *m* (II phase)	5.9 ± 0.31	6.3 ± 1.2
After the "descent" (N^1)	13.4 ± 0.9	25.5 ± 2.1

Table 2

Changes in the average frequency (imp/s) of impulses of neurons in the cortex and medulla oblongata under conditions of a hypoxic gas mixture ($p < 0.05$)

Conditions	Cerebral cortex	Medulla oblongata
Norm (N)	13.5 ± 1.2	18.6 ± 1.3
In 2 *min* (I phase)	26.5 ± 1.9	22.7 ± 1.9
In 5–6 *min* (II phase)	7.9 ± 0.5	10.3 ± 1.3
After switch off gas mixture (N^1)	14.4 ± 0.9	23.5 ± 1.9

In the dynamics of hypoxic exposure, phase changes in the electrical activity of individual neurons are observed: two minutes after inhalation of the hypoxic gas mixture, activation of neuronal impulses is observed, as in moderate hypoxia (at an "altitude" of 4500–5000 *m*) created in a pressure chamber. Direct exposure to oxygen deficiency causes depolarization of the cell membrane and an increase in the impulse discharge of neurons. Deepening of oxygen deficiency – at an "altitude" of 7500–8000 *m*, suppression of the impulse activity of neurons is observed, which also occurs in animals of the second group 5–6 *min* after inhalation of the hypoxic gas mixture. This is due to further deepening of depolarization, which leads to a decrease in the membrane potential and gradual inhibition of the impulse activity of neurons. These changes are explained by a violation of the mechanisms of membrane permeability and cellular metabolism due to insufficient oxygen content in the cell. The direct effect of oxygen deficiency causes depolarization of the cell membrane and an increase in the impulse discharge of neurons [17, 18].

In conditions of acute hypoxia – at an "altitude" of 7500–8000 *m*, suppression of the impulse activity of neurons in brain structures is observed; further development of depolarization occurs, leading to a decrease in the membrane potential and a gradual inhibition of the impulse activity of neurons.

When comparing the results of the experiments, phase changes in the electrical activity of individual neurons are observed. These changes are explained by disruption of the mechanisms of membrane permeability and cellular metabolism due to insufficient oxygen content in the cell [17, 18].

Two minutes after inhalation of the hypoxic gas mixture, activation of neuronal impulses is observed, as with moderate hypoxia (at an "altitude" of 4500–5000 *m*) created in the pressure chamber. Changes in the impulse activity of neurons 5–6 *min* after inhalation of a hypoxic gas mixture correspond to those obtained under conditions of acute hypoxia when "ascending" to an "altitude" of 7500–8000 *m* in a pressure chamber.

When comparing the data obtained under conditions of hypoxic gas mixtures with the data from studies under pressure chamber conditions, it is clear that changes in the electrical activity of neurons in both cases are of the same nature, i.e., the observed changes in the electrical activity of neurons are not caused by ambient atmospheric pressure. Consequently, the observed changes are mainly due to the effect of reduced environmental PO_2, which leads to a decrease in oxygen tension in the blood (PaO_2).

Oxygen in the blood is in two states: free (dissolved in plasma) and chemically bound (as part of hemoglobin). O_2 binding to hemoglobin, i.e., the formation of oxyhemoglobin depends on the tension of dissolved O_2 in the plasma. There is a direct relationship between PaO_2 in plasma and the degree of saturation (the ratio of the amount of oxyhemoglobin to the total oxygen capacity of the blood in %) of the blood with oxygen. In healthy people and animals this is 95–97%. The stability of this indicator is determined by the activity of subtle regulatory mechanisms that control respiration and blood circulation [11].

Changes in the electrical activity of the brain are accompanied by characteristic shifts in behavioral reactions: intensification of breathing and cardiac activity, increased motor activity of the animal, etc.

In our study, phase changes under the influence of increasing oxygen deficiency were also recorded in indicators of the body's autonomic functions: heart rate and rate of respiratory movements (Tabs. 3, 4).

Table 3

Changes in heart rate (HR, beats/min) and respiratory rate (RR, beats/min) in the dynamics of oxygen deficiency in pressure chamber conditions ($p < 0.05$)

Conditions	HR	RR
Before the "rise" (N)	460 ± 28	125 ± 11
4500–5000 *m* (I phase)	490 ± 32	156 ± 17
7500–8000 *m* (II phase)	360 ± 2	76 ± 12
After the "descent" (N^1)	470 ± 26	104 ±1 0

Table 4

Changes in heart rate (NR, beats/min) and respiratory rate (RR, beats/min) under conditions of a hypoxic gas mixture ($p < 0.05$)

Conditions	HR	RR
Norm (N)	450 ± 30	130 ± 10
In 2 *min* (I phase)	480 ± 22	160 ± 15
In 5–6 *min* (II phase)	350 ± 35	83 ± 7.0
After switch off gas mixture (N^1)	460 ± 25	115 ± 9.0

Restructuring of indicators of vegetative functions: phase changes in heart rate and respiration at different degrees of hypoxia (Tabs. 3, 4) indicates their participation, in addition to the nervous system, in the adaptive activity of the body in extreme environmental conditions: with moderate hypoxia (altitude 4500–5000 *m*) observed increase, and in conditions of acute oxygen deficiency – decrease in frequency.

Conclusion. So, the experimental results show that atmospheric pressure is not the main factor influencing the electrical activity of brain cells and the autonomic functions of the body. It turns out that in both hypobaric and normobaric hypoxia, the cause of the observed changes in indicators is a decrease in the partial pressure of oxygen (PO_2) in the environment, which leads to a decrease in oxygen tension in the blood (PaO_2).

Received 30.06.2026
Reviewed 20.08.2026
Accepted 26.09.2026

REFERENCES

1. Agadzhanyan N.A., Chizhov A.Ya. *Classification of Hypoxic Conditions*. Moscow, Kruk Publishing House (1988), 20 (in Russian).
2. Millet G.P., Faiss R., Pialoux V. Point: Hypobaric Hypoxia Induces Different Responses from Normobaric Hypoxia. *J. Appl. Physiol.* **112** (2012), 1783–1784. https://doi.org/10.1152/japplphysiol.00067.2012

3. Millet G.P., Debevec T. CrossTalk Proposal: Barometric Pressure, Independent of PO_2, is the Forgotten Parameter in Altitude Physiology and Mountain Medicine. *J. Physiol.* **598** (2020), 893–896. https://doi.org/10.1113/JP278673
4. Mounier R., Brugniaux J.V. Counterpoint: Hypobaric Hypoxia does not Induce Different Responses from Normobaric Hypoxia. *J. Appl. Physiol.* **112** (2012), 1784–1786. https://doi.org/10.1152/japplphysiol.00067.2012
5. Richalet J. CrossTalk Opposing View: Barometric Pressure, Independent of PO_2, is not the Forgotten Parameter in Altitude Physiology and Mountain Medicine. *J. Physiol.* **598** (2020), 897–899. https://doi.org/10.1113/JP279160
6. Angeli C.N., Shute R.J., Slivka D.R. Higher Muscle Tissue Oxygenation when Exposed to Hypobaric Hypoxia than Normobaric Hypoxia. *J. Hum. Perf. Extrem. Environ* **15** (2019). https://doi.org/10.7771/2327-2937.1117
7. Basualto-Alarcón C., Rodas G., et al. Cardiorespiratory Parameters during Submaximal Exercise under Acute Exposure to Normobaric and Hypobaric Hypoxia. *Apunts. Med. de L'esport* **47** (2012), 65–72. https://doi.org/10.1016/j.apunts.2011.11.005
8. Beidleman B.A., Fulco C.S., et al. Cycling Performance Decrement is Greater in Hypobaric Versus Normobaric Hypoxia. *Extrem. Physiol. Med.* **3** (2014), 1–9. https://doi.org/10.1186/2046-7648-3-8
9. Faiss R., Pialoux V., et al. Ventilation, Oxidative Stress, and Nitric Oxide in Hypobaric Versus Normobaric Hypoxia. *Med. Sci. Sports Exerc.* **45** (2013), 253–260. https://doi.org/10.1249/MSS.0b013e31826d5aa2
10. Loeppky J.A., et al. Ventilation during Simulated Altitude, Normobaric Hypoxia and Normoxichypobaria. *Respir. Physiol.* **107** (1997), 231–239. https://doi.org/10.1016/s0034-5687(97)02523-1
11. Ross C.I., Shute R.J., et al. Skeletal Muscle mRNA Response to Hypobaric and Normobaric Hypoxia after Normoxic Endurance Exercise. *High Alt. Med. Biol.* **20** (2019), 141–149. https://doi.org/10.1089/ham.2018.0147
12. Ando S., Komiyama T., et al. The Interactive Effects of Acute Exercise and Hypoxia on Cognitive Performance: A Narrative Review. *Scandinavian Journal of Medicine & Science in Sports* **30** (2020), 384–398. https://doi.org/10.1111/sms.13573
13. Rosales A.M., Shute R.J., et al. Independent Effects of Acute Normobaric Hypoxia and Hypobaric Hypoxia on Human Physiology. *Sci. Rep.* **12** (2022), 19570. https://doi.org/10.1038/s41598-022-23698-5
14. AkopyanN.S. *Electrophysiological Study of Brain Activity during Hypoxia*. Yerevan (1987) (in Russian).
15. Breslav I.S., Glebovsky V.D. *Regulation of Breathing*. Leningrad, Nauka (1981) (in Russian).
16. Sergeev O.S. Reaction of Rat Respiratory Neurons to a Hypoxic Stimulus: *Physiol. Magazine Them. Sechenov.* **81** (1995), 48–55.
17. Tarakanov I.A., Safonov V.A. GABAergic System and its Importance for the Regulation of Respiration: *Human physiology* **24** (1998),116–128 (in Russian).
18. Safonov V.A. *Man in the Ocean of Air*. Moscow (2006), 215 (in Russian).

Մ. Ա. ԿԱՐԱՊԵՏՅԱՆ, Ն. Յու. ԱԴԱՄՅԱՆ, Է. Ս. ԳԵՎՈՐԳՅԱՆ

ՆՈՐՄՈԲԱՐԻԿ ԵՎ ՀԻՊՈԲԱՐԻԿ ՀԻՊՕՔՍԻԱՅԻ ԱԶԴԵՑՈՒԹՅՈՒՆԸ ՈՒՂԵՂԻ ԷԼԵԿՏՐԱԿԱՆ ԱԿՏԻՎՈՒԹՅԱՆ ԵՎ ՍԻՐՏԱՆՈԹԱՅԻՆ ՀԱՄԱԿԱՐԳԻ ՎՐԱ

Ուսումնասիրության առարկան է գլխուղեղի էլեկտրական ակտիվության և սրտա-շնչառական արձագանքի համեմատական գնահատումը նորմոբարիկ

և հիպոբարիկ հիպոքսիայի պայմաններում: Օրգանիզմի էներգետիկ հավասարակշռությունը պահպանող մեխանիզմների բնականոն գործունեության համար անհրաժեշտ է պահպանել թթվածնի տեղափոխման համակարգերի ֆունկցիոնալ կարողությունները բնութագրող ցուցանիշները: Փորձի արդյունքները ցույց են տալիս, որ ուղեղի բջիջների էլեկտրական ակտիվության և օրգանիզմի վեգետատիվ գործառույթների վրա ազդող հիմնական գործոնը մթնոլորտային ճնշումը չէ: Պարզվում է, որ և՛ հիպոբարիկ, և՛ նորմոբարիկ հիպօքսիայի դեպքում նշված ցուցանիշների դիտարկվող փոփոխությունների պատճառը շրջակա միջավայրում թթվածնի մասնակի ճնշման (PO_2) նվազումն է, ինչը հանգեցնում է արյան մեջ թթվածնի լարվածության (PaO_2) նվազմանը:

М. А. КАРАПЕТЯН, Н. Ю. АДАМЯН, Э. С. ГЕВОРКЯН

ВЛИЯНИЕ НОРМОБАРИЧЕСКОЙ И ГИПОБАРИЧЕСКОЙ ГИПОКСИИ НА ЭЛЕКТРИЧЕСКУЮ АКТИВНОСТЬ ГОЛОВНОГО МОЗГА И КАРДИОРЕСПИРАТОРНУЮ СИСТЕМУ

Предметом исследования является сравнительная оценка электрической активности головного мозга и кардиореспираторного ответа в условиях нормобарической и гипобарической гипоксии. Для нормального функционирования механизмов поддержания энергетического баланса организма необходимо сохранение параметров, характеризующих функциональные возможности систем транспорта кислорода. Результаты эксперимента показывают, что атмосферное давление не является основным фактором, влияющим на электрическую активность клеток головного мозга и вегетативные функции организма. Выясняется, что как при гипобарической, так и при нормобарической гипоксии причиной наблюдаемых изменений показателей является снижение парциального давления кислорода (PO_2) в окружающей среде, что приводит к снижению парциального давления кислорода в крови (PaO_2).