RESPIRATION AND OXIDATIVE PHOSPHORYLATION IN THE VISUAL AND MOTOR ANALYZERS OF SOME MAMMALS

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E. L. Dovedova

Laboratory of Biohistochemistry of the Institute of the Brain, AMN SSSR, Moscow
(Presented by Active Member AMN SSSR, S. E. Severin)
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A number of biochemical investigations [1, 2, 3] have established that the most common sign of the evolution of energy metabolism of the brain of vertebrates is an enhancement of its intensity along with a higher economy and efficiency. During the development of the structure and function of the brain there occurs a gradual improvement of the mechanism of aerobic processes of metabolism that are energetically more efficient. The association between respiration and oxidative phosphorylation reactions is enhanced, as a result of which the content of microergic compounds in the brain increases and the rate of their metabolism increases.

These regularities were established [6, 7] while studying the brain as a whole or its large divisions (cerebral cortex, cerebellum, stem). So far it has not been explained to what extent they are true for individual cellular formations which differ from one another in phylogenetic age, structure, and function and which enter the system of a single analyzer. At the same time such investigations are needed for understanding the relationship of the chemism, structure, and function within such a complex system as an analyzer.

Our purpose was to obtain comparative data on the regularities of the processes of tissue respiration and associated phosphorylation in different links of the visual and motor analyzers of members of different orders of mammals —Rodentia (rabbit), Carnivora (cat), and Primates (the lower monkey Macaca Rhesus), which differ in complexity of the structure and function of the central nervous system.

METHOD

In the study we used 12 mature rabbits, 15 cats, and 14 monkeys. We studied the formations of the visual and motor analyzers in the brain of these animals.

For the investigation of the visual analyzer we took an appropriate region of the cerebral cortex (area 17), the lateral geniculate bodies, superior colliculi of corpora quadrigemina, and retina. In the motor analyzer we investigated the cerebral cortex (areas 2 and 4), ventrolateral nuclei of the thalamus, Goll's and Burdach's nuclei of the oblongata, and the lumbar intervertebral ganglia.

After decapitation of the animal these formations were extracted in the cold, and in the pulped tissue we determined the rate of respiration, loss of inorganic phosphate, and calculated the P/O coefficient.

The respiration rate was determined manometrically (a sample of 100 mg of fresh tissue per test). The incubation mixture (2 ml) consisted of the following components in their end concentration: 0.12 M NaCl, 0.05 M KCl, 0.008 M $MgCl_2$, 0.012 M trioxymethylaminomethane (tris), 0.025 M phosphate buffer pH 7.2, 0.01 M NaF, 0.002 M ADP, 0.05 M glucose, and a solution of hexokinase (1 mg of protein in 1 ml) extracted from baker's yeast by the method of Sols et al. [10].

Glutamic and succinic acids in an end concentration of 0.017 M were used as oxidation substrates. A glucose-hexokinase system was used as acceptors of macroergic phosphate. After a 20 min recording of the uptake of oxygen at 26°, the proteins in the tests were precipitated with trichloroacetic acid and in the centrifugate we determined the loss of inorganic phosphate by Ennor and Rosenberg's method [9] as modified by Kotel'nikova [5]. The loss of

TABLE 1. Intensity of Oxygen Absorption in Visual and Motor Analyzers of Rabbit, Cats, and Monkeys (in microatoms of O_2)

Animal	Exp. No.	Visual analyzer				Motor analyzer			
		Retina	Superior colliculus	Lateral geniculate bodies	Visual cortex	Intervetebral ganglia	Nuclei of Goll and Burdach	Ventrolateral nuclei of thalamus	Motor cortex
Substrate — succinic acid									
Rabbit	7	0,444±0,025	0,490±0,028	0,403±0,042	0,476±0,024	0,280±0,008	0,343±0,021	0,388±0,016	0,596±0,026
Cat	10	0,470±0,019	0,607±0,013	0,550±0,012	0,720±0,013	0,260±0,022	0,325±0,024	0,560±0,018	0,700±0,020
Monkey	7	0,378±0,013	0,481±0,014	0,545±0,035	0,640±0,013	0,270±0,017	0,510±0,025	0,584±0,027	0,580±0,016
Substrate — glutamic acid									
Rabbit	5	0,344±0,038	0,360±0,38	0,380±0,033	0,430±0,018	0,261±0,019	0,200±0,018	0,345±0,030	0,361±0,021
Cat	5	0,460±0,048	0,606±0,032	0,530±0,017	0,580±0,023	0,258±0,013	0,230±0,004	0,505±0,014	0,500±0,028
Monkey	7	0,310±0,025	0,395±0,017	0,391±0,009	0,480±0,018	0,259±0,011	0,340±0,020	0,495±0,021	0,410±0,018

TABLE 2. Oxidative Phosphorylation in Visual and Motor Analyzers of Rabbit, Cat, and Monkey (in microatoms of P)

Animal	Exp. No.	Visual analyzer				Motor analyzer			
		Retina	Superior colliculus	Lateral geniculate bodies	Visual cortex	Intervetebral ganglia	Nuclie of Goll and Burdach	Ventrolateral nuclei of thalamus	Motor cortex
Substrate — succinic acid									
Rabbit	7	0,47±0,050	0,37±0,038	0,39±0,020	0,52±0,017	0,34±0,015	0,49±0,026	0,44±0,046	0,37±0,039
Cat	10	0,66±0,014	0,67±0,010	0,58±0,021	0,78±0,009	0,48±0,001	0,33±0,016	0,59±0,009	0,70±0,085
Monkey	7	0,63±0,009	0,37+0,006	0,60±0,021	0,85±0,025	0,51±0,009	0,44±0,012	0,46±0,008	0,56±0,017
Substrate — glutamic acid									
Rabbit	5	0,49±0,054	0,56±0,023	0,57±0,037	0,56±0,020	0,47±0,022	0,30±0,030	0,40±0,035	0,59±0,024
Cat	5	0,75±0,016	0,80±0,052	0,75±0,014	0,87±0,012	0,57±0,008	0,37±0,007	0,88±0,067	1,08±0,030
Monkey	7	0,69±0,017	0,72±0,030	0,69±0,070	1,11±0,012	0,58±0,015	0,63±0,068	0,96±0,095	0,93±0,084

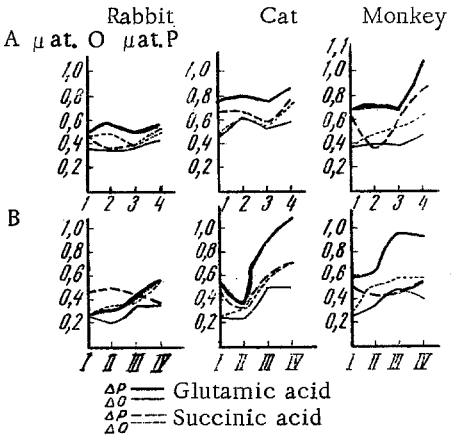

Fig. 1. Rate of respiration and oxidative phosphorylation at different links of the visual (A) and motor (B) analyzers. 1) Retina; 2) superior colliculus; 3) lateral geniculate bodies; 4) visual cortex; I) intervertebral ganglia; II) nuclei of Goll and Burdach; III) ventrolateral nuclei of thalamus; IV) motor cortex.

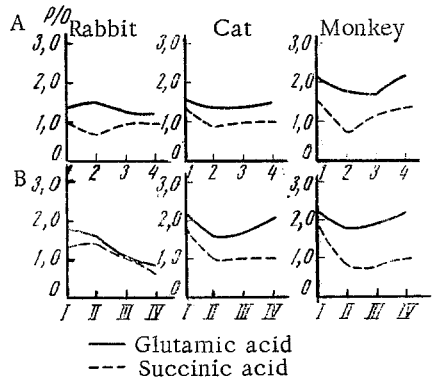

Fig. 2. Association between the processes of oxidation and phosphorylation in different links of the visual (A) and motor (B) analyzers. Designations are the same as in Fig. 1.

inorganic phosphate in the experimental sample in comparison with the control was calculated by a standard curve plotted for certain weighed amounts of KH_2PO_4.

Results of the investigations were expressed in microatoms of absorbed oxygen or of inorganic phosphate per 10 mg of fresh tissue per 1 h.*

EXPERIMENTAL RESULTS

Figure 1 shows curves plotted on the basis of the average data (Tables 1 and 2) obtained in experiments on the determination of the respiration rate and loss of inorganic phosphate in individual links of the visual and motor analyzers of the rabbit, cat, and monkey with the use of glutamic and succinic acids as oxidation substrates. The character of the curves of oxygen uptake is similar for both oxidation substrates. We can note the increase of respiration rate from the inferior formations of the analyzer toward the cortex. These changes were expressed less in the rabbit than in the cat and monkey.

The changes in the magnitude of the loss of inorganic phosphate in similar formations of the analyzers of different animals are similar in the main with those of the respiration rate, however, we did not observe a complete parallelism between these indexes.

A certain level of association between the processes of respiration and phosphorylation is characteristic for each link of the analyzer system. This is expressed in the change of the value of P/O. From the data in Table 3 and in Fig. 2 it follows that the value of P/O for both substrates in the cortex in comparison with other links of the analyzer is not maximal; the same magnitude of P/O is characteristic also for peripheral divisions of the analyzer system (retina and intervertebral ganglia). In the switching links (the nuclei of Goll and Burdach of the oblongata and the ventrolateral nuclei of the thalamus in the motor analyzer, as well as the superior colliculi and lateral geniculate bodies in the visual analyzer) the P/O coefficient is somewhat lower than in the cortical and peripheral ends; this feature is more expressed in the monkey than in the rabbit and cat.

Unlike other animals in the skin-motor analyzer of the rabbit the association between oxidation and phosphorylation decreases from the peripheral to the cortical end of the analyzer.

The respiration rate in similar formations of the analyzers of the rabbit is lower than in the cat and in the monkey, wherein the uptake of oxygen in the cat is even somewhat higher than in the monkey. The loss of inorganic phosphate of the cat and monkey is greater than that of the rabbit; the increase of phosphorylation is more noticeable on glutamic acid than on succinic. The conjunction of respiration and phosphorylation in the series rabbit-cat-monkey is enhanced on glutamic acid, whereas on succinic acid it remains at almost the same level with the exception of the peripheral links of both analyzers in which the P/O ratio noticeably increases.

The results of the present investigation show that for each formation of the motor and visual analyzers there is a characteristic level of respiration and oxidative phosphorylation. As a rule the rate of oxygen uptake and loss of inorganic phosphate are least in the peripheral ends of the analyzers; they are somewhat higher in the switching links and reach highest values in the cortical ends.

* The data obtained in the study were processed statistically, and the magnitudes of the mean square deviation (m) did not exceed 10-15% of the average value.

TABLE 3. Conjugation of Respiration and Phosphorylation in Visual and Motor Analyzers of Certain Mammals (P/O)

Animal	Exp. No.	Visual analyzer				Motor analyzer			
		Retina	Superior colliculus	Lateral geniculate bodies	Visual cortex	Intervertebral ganglia	Nuclei of Goll and Burdach	Ventrolateral nuclei of thalamus	Motor cortex
Substrate — succinic acid									
Rabbit	7	1,06±0,14	0,75±0,07	0,97±0,10	1,09±0,21	1,30±0,06	1,43±0,11	1,10±0,13	0,62±0,10
Cat	10	1,40±0,10	0,99±0,06	1,09±0,09	1,09±0,06	1,85±0,08	1,02±0,10	1,05±0,07	1,0±0,11
Monkey	7	1,68±0,06	0,77±0,01	1,11±0,10	1,32±0,07	1,90±0,08	0,86±0,06	0,79±0,10	0,97±0,07
Substrate — glutamic acid									
Rabbit	5	1,42±0,27	1,56±0,025	1,34±0,08	1,31±0,28	1,80±0,12	1,60±0,12	1,16±0,17	1,14±0,11
Cat	5	1,63±0,14	1,43±0,11	1,41±0,11	1,50±0,16	2,20±0,09	1,61±0,19	1,74±0,17	2,16±0,20
Monkey	7	2,22±0,63	1,83±0,12	1,76±0,12	2,29±0,60	2,24±0,14	1,86±0,13	1,94±0,10	2,26±0,09

This regularity is not manifested for the conjunction of oxidative processes, however, the magnitude of the P/O ratio for different formations of the investigated analyzers is not the same.

The detected differences in the degree of conjunction of respiratory and phosphorylation reactions for each level of the analyzer, as well as regular changes of the relationships of these processes in the studied series of animals, can apparently be associated both with unique features in the structure and function of the investigated formations and with the development and refinement of the processes of oxidative metabolism as the structure of the brain becomes more complicated.

The high and similar conjunction of respiration and phosphorylation in cortical and peripheral ends of an analyzer, formations appreciably differing in structure and function, indicates a certain commonness in the direction of energy and plastic metabolism in them [4, 8].

The lower values of the P/O ratio in the switching links of the analyzers are possibly associated with the predominance in these structures of free oxidation needed for accomplishing all aspects of oxidative metabolism which do not lead to the formation of macroergs.

SUMMARY

By means of colorimetric and manometric methods a study was made of the intensity of respiration and phosphorylation, as well as of the conjugation of these processes in the individual cellular formations of the visual and motor analyzers in the brain of the rabbit, cat and monkey (41 animals were used). Succinic and glutamic acids were used as oxidation substrates. It was shown that within the analyzer limits on both substrates the oxygen intake and the decline of nonorganic phosphate were proceeding from the underlying links to the overlying ones. The conjugation of the oxidation and phosphorylation in the peripheral cortical ends of the analyzers was almost identical, being somewhat greater than in the switch links.

In the analogous links of the analyzers in the series rabbit—cat—monkey the oxidative and the phosphorylating activity increased on both substrates. The conjugation of the respiration and phosphorylating activity processes on the glutamate exhibited a considerable rise, whereas on the succinate the P/O coefficient increased only in the peripheral links, and showed almost no change in the rest.

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All abbreviations of periodicals in the above bibliography are letter-by-letter transliterations of the abbreviations as given in the original Russian journal. *Some or all of this periodical literature may well be available in English translation.* A complete list of the cover-to-cover English translations appears at the back of this issue.
