

LABORATORY 8

Laboratory of Sensory Information Processing

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The leading researchers of the laboratory include:

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Dr.Sc. (Techn.)	D. S. Lebedev	Dr.	T. Podugolnikova
Dr.Sc. (Math.)	D. G. Lebedev	Dr.	E. Rodionova
Dr.Sc. (Biol.)	I. Pigarev	Dr.	M. Smirnov
Dr.Sc. (Biol.)	G. Rozhkova	Dr.	V. Vedenina
Dr.	K. Golubtsov		P. Maximov
Dr.	E. Maksimova		D. Nikolaev
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FIELD OF RESEARCH

The main research area of the laboratory is investigation of information processing in sensory systems and in nervous system of man and animals in general. These researches are aimed onto:

- elaboration of adequate models which show how the studied principles of information processing in the nervous system are realized in the formation of complex behaviour;
- elaboration of mathematical models simulating significant functions of distinct divisions of sensory systems, including peripheral, central and sensorimotor levels of information processing;
- comparison of principles and solutions of similar problems in live and technical information systems intended to improve the later;
- designing and implementing diagnostic methods and devices for ophthalmology.

To cope with the problems mentioned, different approaches and methods are used by the laboratory researchers, including neurophysiological, psychophysical and morphological methods, as well as animal behaviour field studies and computer simulations of sensory processing. Among the most important problems is description and classification of numerous functional types of neural units which are involved in the sensory information processing at several levels of integral nervous system. Thus, in vision the peripheral level of information processing is represented by the retina, while the brain visual centres (cortex and caudate nucleus in cats and monkeys, diencephalon and mesencephalon in fish and in frogs) represent the central level. Investigation of neurons' functional types is performed by means of both neurophysiological and morphological methods. Microelectrode experiments are aimed on recordings of responses from separate single units (neurons) at different levels of the retina, which itself is composed of several distinct layered nerve structures, each of them being a complex ordered network built of different neuron classes. These experiments are performed on immobilized live animals using their visual stimulation.

Morphological studies specify those neural structures and morphology of the nerve cells which are subject of neurophysiological investigation. Functional features of neural components are the matter of comparison to some distinct forms of sensory-guided integral behaviour of the same experimental animals (fish, amphibia cats), this way providing the background for modeling of corresponding neural circuits in terms of computer simulations. Such, computer simulations include modeling of neural event underlying of information processing at the level of cone receptor population (in primate retina), as well as interaction of receptor and horizontal cells in the retina (in fish). General principles of sensimotor information processing (such as colour and size constancy in visual perception, binocular vision mechanisms, spatial orientation, echolocation in moths, bioacoustics in locusts during the breeding period) are the matter of psychophysical experiments on both healthy subjects and medical patients having different sensory disturbances; as well as in behavioural experiments on animals. Basic researches provide the background for applied outcomes in the form of diagnostic methods and devices for medical ophthalmology, which are as well being designed and implemented by the laboratory staff.

For the purpose of aerospace monitoring of the Earth's surface, monitoring of marine biological communities, and distant detection and recognition of a pin-point target outside the atmosphere the algorithms for determination of objective reflectance properties of observed surfaces from the reflected radiation under unknown natural illumination conditions have been developed. The conditions for illumination spectra under which these tasks are solvable by local approach have been found: in order for spectral invariants of surface colour to exist it is necessary and sufficient that the illumination spectrum would follow the well-defined formula depending on a series of generators of wavelength and on some quantity of free parameters (number of degrees of freedom for the illumination manifold). By its appearance this formula is identical to the Bouguer-Lambert-Beer formula describing spectral content of the light transmitted through the solution of dye mixture. This implies automatic satisfiability of the found conditions for illumination in aquatic environment. It has been shown that the natural illumination on the Earth's surface also meets these conditions. Suggested algorithms solve the problem in four stages: 1) acquiring of an input image, 2) elimination of diffuse background contribution, 3) calculation of observed object color parameters invariant to the illumination in the form of colour-opponent combinations of signals from different sensors, 4) discrimination stage. The contribution of various factors to algorithms' errors has been estimated, the questions of application of the algorithms are examined, methodic recommendations for necessary computations in specific applications are suggested. (V. V. Maximov, P. V. Maximov)

The computational model of the midget pathways in the central primate retina was improved. The cone co-ordinates and spectral types list of a real macaque retina segment near fovea (Roorda et al., 2001) was used. Using the real macaque retina segment description permits to organise the computer experiments in order to reveal an influence of the random arrangement of different spectral type cones in the retina on processing the visual signals. The new model version consists of several thousands of neurones. This is the first model of such a big volume, which has been described both in the Russian and foreign scientific literature. In the course of the computer experiments the process of forming the yellow-blue opponent signals in the primate retina was investigated. A simplified model of the retinal mechanism of yellow-blue opponency was elaborated. According to our information it is the first model of such a type. Linear transforming signals of all the model neurones uses in the

simplified model. It permits to obtain the responses only to still or periodical (sinusoidal) stimuli. Besides the neurones that comprise the previous versions of the model, the cones of S-types (blue sensitive), "blue" on-bipolar cells, horizontal cells of H-2 type, and small bistratified ganglion cells are included in this version. (D. S. Lebedev)

Dependence of visual acuity on distance was studied using various test stimuli. Earlier, examination of school children and adults by means of our original test charts with Snellen E revealed that, in most subjects, visual acuity was dependent on viewing distance. Since it was argued that this dependence could be an artifact due to some unnoticed defects of our charts, we performed a new series of experiments and confirmed dependence of visual acuity on distance using the commercial test charts with Lea-symbols and spatial gratings. Moreover, we extended the age range of our subjects examining preschool children aged 5-7 yr. Only those children were studied whose vision was defined by the ophthalmologists as being normal. Nevertheless, in most of them, visual acuity was also found to be dependent on viewing distance. This finding is of principal value since it is customary to assume that, at preschool age, the accommodation mechanisms are capable to provide good focussing independently of viewing distance. A special study of children with amblyopia demonstrated the importance of measuring visual acuity at several distances for clinical ophthalmology. It was found that, due to the dependence of visual acuity on distance, the degree of amblyopia could appear to be different being estimated at different distances. Therefore, to find individual optimal strategy of treatment, it is necessary to measure visual acuity of each patient at several points within the range of viewing distances. (G. I. Rozhkova, T. A. Podugolnikova, V. S. Tokareva)

In chronic experiments with three cats all four proposed elements of the macromosaic in the fourth extrastriate crescent (area V4A) were found and investigated. Special attention was paid to comparison of the receptive field properties in the spatially separated representations of the central upper and central lower visual field. Those properties were found to be identical. In all animals elongated and radially oriented receptive fields in the upper visual field were found. Locations of all four elements of macromosaic were marked and found anatomically. It was found that neurons with radially elongated receptive fields were sensitive to the optic flow. For the investigation of the optic flow analysis by the neurons in the area V4A, and in future in another visual areas the device for investigation of neuronal activity and eye movements during the headway motion of the animal along the 6 meters linear trajectory in the natural environment was constructed. Experiments on this new device are in progress. Neuronal activity in the area V4A was investigated during the state of sleep. It was found that neurons, which in wakefulness responded to the visual stimuli, during sleep have synchronized their firing with the rhythmic myoelectrical activity of the stomach and duodenum. These observations opened a new perspective for the future investigation of the function of sleep and the cortical localization of functions. (I. N. Pigarev, E. I. Rodionova)

The aim of this study was to prove experimentally the capability of the hearing system of noctuid moth (Noctuidae, Lepidoptera) to change it's frequency tuning during evoked contraction of metathoracic muscles. To measure the threshold intensity of sound stimulus we recorded extracellularly the activity of prothoracic ganglion interneurons. An application of potassium chloride to the haemolymph of metathorax caused local muscle contraction for several minutes and a rise of auditory thresholds at lower frequencies (by up to 10-14 dB at 10-30 kHz). Over 60 kHz there were an opposite change: after KCl application thresholds decreased by 3 dB on average.

The opposite changes of auditory thresholds at lower and higher frequencies could be explained by two factors which act simultaneously: (i) the shift of tympanic membrane resonance from 24 kHz to 48-50 kHz due to the tension of tympanic membrane by metathoracic muscles and (ii) general sensitivity fall because of the longitudinal folds that appear on the membrane during its tension. Resonance modes of the mechanical system consisting of scoloparium, ligament and tympanic nerve also play considerable role in determining the frequency tuning of the hearing system. (D. N. Lapshin)

A new opto-electronic device was used for recording the singing movements of the hind legs in the closely related grasshopper species of the *Chorthippus albomarginatus*-group (Insecta: Orthoptera: Gomphocerinae). The leg-movements and the sound were recorded in pure species *C. albomarginatus*, *C. oschei*, *C. karelini* and their hybrids (reciprocal crosses *C. albomarginatus* x *C. oschei*, *C. oschei* x *C. karelini*). Hybrid songs were intermediate between parental songs in some parameters, however, in case of the *albomarginatus/oschei* and reciprocal hybrids, the *albomarginatus*-features were dominant in the songs of both F1 and F2 hybrid males. In choice mating experiments, a response of the F1 hybrid females to the courtship songs of the pure and hybrid males was studied. Hybrid females demonstrated lower selectivity than the females of pure species. They did not distinguish *albomarginatus*- and hybrid males, but chose them more often than the *oschei*-males. Thus, there is a concordance between the inheritance of male song and female preference, i.e. *albomarginatus*-features are dominant. This result supports the idea about a more ancestral *albomarginatus*-signal, which is of a lower degree of complexity than the *oschei*-song (Vedenina, Helversen, 2003). (V. Yu. Vedenina)

The way of diagnostics of a pathology of a visual nerve is offered. The local answer share dependence on intensity and angular size of stimulating light was revealed. Together with a number Helmholtz's Eye Hospital (Moscow) the equipment has been developed on the basis of microprocessor engineering, that allows using the method for diagnostics (including an early one) of glaucoma, pathology of a visual nerve, and retinal dystrophy. The devices for children sight diagnostics has been developed by a method critical frequency of flicker. (K. V. Golubtsov, O. Yu. Orlov)

Equipment for non-invasive record of eye macromotions under natural lighting up was created. Picture of right eye is input to computer using TV system for IR-range. Display is used for more complicated trajectory of motion or for stroboscopic stimulation ("apparent motion"). Mathematical software of this device determines parameters of tracing with accuracy up to 8 angular minutes per pixel at the range of eye turning 48 degrees. Mathematical model of videosystem with circular observation was developed. Algorithm of detection of object ("mark") by system of technical vision was suggested for forming of motion trajectory of mobile robot.

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- **Basic Research Program of Presidium Russian Academy of Sciences "Fundamental sciences for medicine":** Project "Computer system development for multi-focal KЧCM-diagnostics (CHIASMA)". (K. V. Golubtsov)
- **Biological Department of Russian Academy of Sciences Basic Research Program "Integrative mechanisms function regulation in organism":** Project "Research of visual perception constancy and visual illusions mechanisms" (V.A. Bastakov)

- **Russian Foundation of Basic Research (No. 01-04-48632):** "Mechanisms and functions of colour opponency in vertebrate vision" (V. V. Maximov).
- **Russian Foundation of Basic Research (No. 00-04-48704):** "Investigation of topographic macromosaic and the properties of constant presentation of depth in fourth extrastriatal layer (visual zone V4A) of occipital cortex of cat" (I. N. Pigarev).
- **Russian Foundation of Basic Research (No. 01-04-49484):** "Mechanisms of age-dependent changes of visual acuity" (G. I. Rozhkova).
- **Russian Foundation of Basic Research (№ 02-04-48256):** "Frequency tuning of the hearing system of noctuid moths (Lepidoptera, Noctuidae) (D. N. Lapshin).
- **Russian Foundation of Basic Research (№ 03-04-49372): Russian Foundation of Basic Research (№ 03-04-49372):** "Study of effectiveness of the cortical excitatory projections on caudate nucleus and putamen in sleep waking cycling and of the hypnogenic effect of electrical microstimulation of caudate nucleus". (E. I. Rodionova)
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- **Russian Foundation of Basic Research** "Partake in Europe Conference on Visual Perception (ECVP), Paris, France, 2003, 01.09-05.09". (D. S. Lebedev).
- **Alexander von Humboldt Foundation Grant (Equipment): No. V-8151/03073** (V. Yu. Vedenina).

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