PHYSIOLOGY

MOTOR REFLEXES IN PUPS FOLLOWING EXTINCTION OF DISTANT RECEPTORS

E. S. Airapetyants and N. A. Moiseeva

Laboratory of Interoceptive Conditioned Reflexes (Head – Professor E. S. Airapetyants). The I. P. Pavlov Institute of Physiology (Director – Academician K. M. Bykov), Academy of Sciences USSR, Leningrad

(Received June 14, 1957. Submitted by Academician K. M. Bykov)

In recent years more and more work has been devoted to the study of conditioned reflexes at various stages of ontogenesis. Investigation of this – among the most important – side of evolution of the higher nervous activity has included many aspects. At least two series of experiments should be mentioned which determine the general theoretical approach to the study of the higher functions of the organism in onto- or phylogenesis. In one series it is the consistent features in the mechanism of the establishment of conditioned reflexes (temporary connections) that are revealed as well as properties of various analysors and interaction of external and internal factors in the animal's behavior. In the other series of experiments the objective method using conditioned reflexes serves as a most important tool in the study of the establishment of vegetative and somatic functions and of those regulatory mechanisms which are mediated by the higher levels of the nervous system. Concrete problems in each series are of interest in themselves, but the results, which inevitably criss-cross and overlap in a variety of ways, contribute to a fuller knowledge of general and specific laws of development of the young and adult stabilized organism.

In our laboratory [2] during a period of over 20 years studies have been carried out probing into the mechanisms of interoceptive conditioned reflexes and internal analysors, their interaction with exteroceptive external analysors and some correlation of these studies to ontogenesis was made [20, 21, 22, 23]. The material and generalizations of facts of this sort proved, in turn, to be one of the essential aspects of elaboration of those problems which are grouped under the name of cortico-visceral physiology and pathology and are being investigated by the scientific team working with K. M. Bykov [9, 10]. Spurred on by the logical development of our discoveries, we have begun, in recent years, detailed studies of morphologic and physiologic structure of the central ends of internal analysors on the assumption that it reflects the general principle of dynamic localization put forward by I. P. Pavlov.

It was particularly in this connection that a new subject for investigation presented itself to us, viz. cortical compensatory mechanism which had attracted the interest of many investigators [6, 7, 8]. We took V. S. Galkin's [11] and K. S. Abuladze's [1] results as the point of departure; in their work on simultaneous extinction of 3 distant receptors a profound and irreversible depression of all cortical activity had been found. I. P. Pavlov considered these findings to be highly significant and recommended that they be studied from all possible angles [24, 25].

Our studies begun in 1952 [3, 4, 5] and those of other authors [12, 13, 16, 17, 18, 19] showed that in adult animals subjected to gradual extinction of distant receptors conditions arose under which cortical compensatory mechanisms came into play and a relatively active form of adaptation to new conditions of existence took place. The leading role in this process is taken by the motor analysor which steps in as substitute for vision, olfaction, hearing and vestibular reactions. Among the possible factors determining the degree and time elements in establishment of compensatory functions the type of the animal's nervous system and the time interval between extinction of each analysor have been mentioned.

Work along similar lines carried out by our collaborators (A. S. Batuev, V.Yu. Ermolaeva, K. Libentrau, L. N. Savina, I. V. Orlov) has provided comparative data on fish, squirrels, rabbits, cats and monkeys.

B. N. Klosovsky and E. N. Kosmarskaya [14, 15] reported, after the publication of our work, interesting observations on the general behavior of pups deprived of distant receptors.

In the present communication are presented investigations into mechanisms of substitution of the functions of lost receptors in the dog at various ontogenetic stages.

EXPERIMENTAL METHODS

Experiments were performed on 44 pups of different age groups, using the motor-food technique. During the experiment the pup was placed in a chamber with three ply-wood shields on its floor and rubber bulbs underneath them. The bulbs were connected to Marey's tambours. The pup's movements in the chamber were suitably recorded on a kymograph. A pneumatic feeding device was placed at one end of the chamber. In addition to recording the pup's approaches to the feeding device, its respiration was also recorded. A system of positive and inhibitory conditioned exteroceptive and interoceptive reflexes was developed in all the pups; the former were developed in some to the sound of a metronome, in others to touching or pressing of a paw by a rubber cuff, the latter to inflation of a rubber balloon placed in the stomach by way of a fistula tube. Gastric fistulas were made starting at the age of 3 weeks following which conditioned reflexes were developed. Once the background conditioned reflex activity was established the animals were subjected to separate extinction of the visual and olfactory receptors or, depending on the experimental series, to simultaneous extinction of the visual, auditory, vestibular and olfactory receptors.

EXPERIMENTAL RESULTS

During the first few days following enucleation in 12 pups of all age groups disturbances of motor function were seen in all; these were particularly obvious on attempts to walk upstairs: the pups could not ascend the stairs and had to be carried up. However, as early as the 7th to 8th day after enucleation 5-months old pups could ascend the stairs without assistance, whereas 8-months old ones could do so only from the 12th to 14th day after enucleation.

In addition to motor disturbances pups of all ages showed changes in conditioned reflex activity. There was, as a rule, inhibition of positive motor conditioned reflexes, both exteroceptive and interoceptive, and disinhibition of differentiation.

Figure 1 shows a kymogram of an experiment on a pup before and after enucleation. Prior to operation the latent period of the conditioned motor reflex reaction to distension of the stomach was 3 seconds and to the sound of a metronone – 4 seconds.

Destruction of the peripheral end of the visual analysor was carried out when the pup was 6 months old. On the 5th post-operative day the pup failed to react either to the exteroceptive or the interoceptive conditioned stimuli at the beginning of the experiment, and only began to react toward the end of the experiment by approaching the feeding device; the latent period of the motor-food reaction was 18-20 seconds. By the 7th day this pup, and others of the same age group, showed complete restoration of conditioned reflexes, while 8-months old pups showed such restoration only by the 12-14th day.

It was thus demonstrated that substitution of disrupted cortical function following enucleation was the more effective the younger the animal concerned.

When the peripheral end of the visual analysor was removed in 4 pups before their eyes had opened (aged 8-10 days) a lag in the development of motor reactions was observed. These pups began to move about the cage 7-8 days later than control animals. When one of these pups was placed together with seeing pups the former was less mobile, clung to the floor and continually climbed underneath the other pups. Three-week old control pups (seeing) ran up immediately in response to the experimenter's call or noise made by him with the feeding dish, while the experimental ones approached slowly and not at once. It must be mentioned that pups operated at the age of 1-2 months moved about the cage rapidly and ran up to the food as quickly as control (seeing) pups as early as 2nd to 3rd day post-operatively.

Consequently, removal of as yet nonfunctioning visual receptor and the associated abortive termination of development of the central end of the visual analysor produce profound impairment of cortical activity. As can be seen from our experiments, "rearrangement" of analysors is achieved much more smoothly after the whole cortex had matured harmoniously; the process of substituting for visual function occurs more rapidly in pups operated after opening of their eyes than in those operated before this.

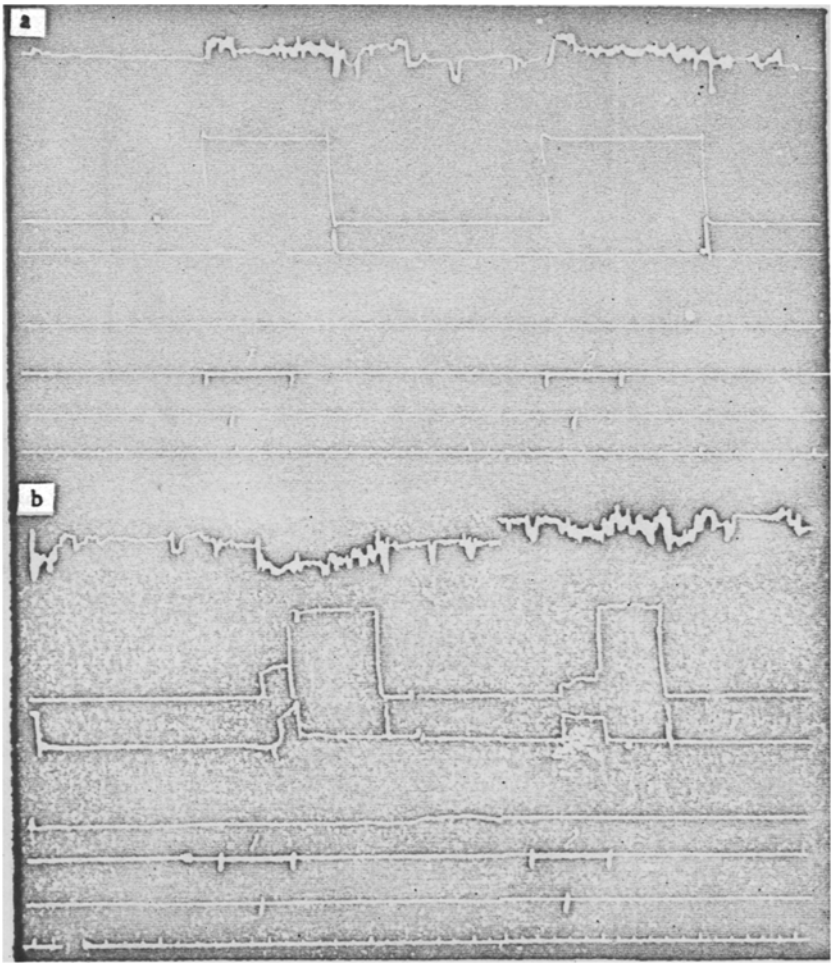

Fig. 1. Conditioned reflexes to distension of the stomach (1) and sound of metronome (2) before enucleation (a) and on the 5th day after enucleation (b) in a pup aged 6 months.
Records from above down: respiration; pedal nearest to feeding device; second pedal further away from feeding device; third pedal still further away from feeding device; conditioned stimulus marker; unconditioned stimulus marker (placing of feeding device); time marker (10 seconds).

The olfactory analysor is known to be well developed in dogs, and its particular role in the postnatal period has been clearly shown in the work of V. A. Troshikhin [26]. Our experiments were performed on 12 pups. Extinction of the peripheral end of the analysor (section of the olfactory nerves) led to inhibition of all positive conditioned reflexes, both extero- and interoceptive, during the first few days after operation; the conditioned reflex to distension of the stomach was inhibited more than others, and among exteroceptive ones the reflex to cutaneous stimulation proved to be the most sensitive one. Apparently the question of "strength"

arises in this connection, since the stimuli mentioned are, undoubtedly, weaker than the auditory one (metronome). The process of compensation following extinction of olfaction takes place the more rapidly the younger the animal, as is the case in enucleation. Thus, for example, conditioned reflexes are restored after 7-8 days post-operatively in pups aged $2^{1}/_{2}$ to 3 months, after 12-14 days in pups aged 5 months and after 25-26 days in pups aged 10 months.

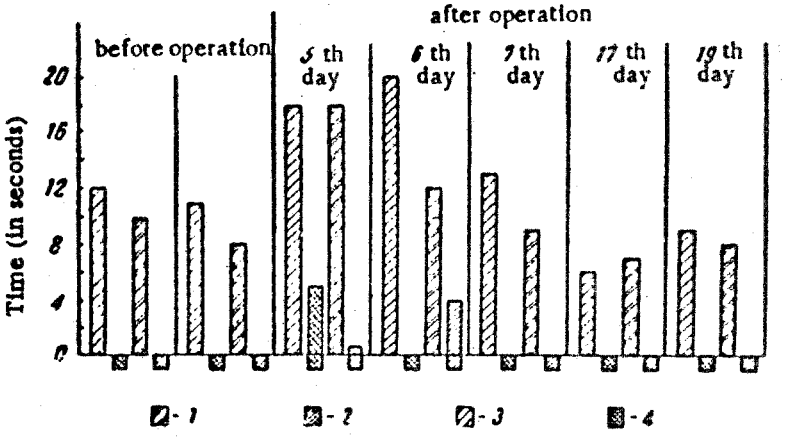

Fig. 2. Average values of latent periods of conditioned reflexes on different days before and after enucleation in a pup aged 5 months. 1) Latent period of exteroceptive conditioned reflex (metronome – 120 strokes per minute); 2) exteroceptive differentiation (metronome – 60 strokes per minute); 3) latent period of interoceptive conditioned reflex to rhythmic distension of stomach; 4) interoceptive differentiation; blocks below zero line – complete differentiation.

Comparative analysis shows, however that extinction of olfaction leads to more pronounced changes in higher nervous activity than that of vision within the same age group of pups. This is illustrated in Fig. 2 (vision) and Fig. 3 (olfaction). The figures represent average values of latent periods for conditioned reflexes in two pups of the same age (5 months).

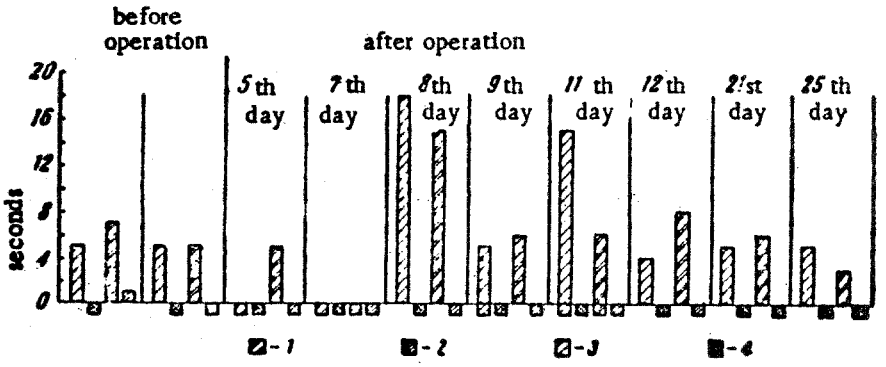

Fig. 3. Average values of latent periods of conditioned reflexes on different days before and after section of olfactory nerves.
Legend the same as in Fig. 2.

Of particular interest are the results of the series of experiments concerned with the study of cortical compensation at early stages of ontogenesis in pups with simultaneous extinction of the peripheral ends of the visual, auditory and olfactory receptors and destruction of the vestibular apparatus. As has already been mentioned, according to data presented by V. S. Gaikin and K. S. Abuladze, adult dogs following this procedure went into a prolonged inhibitory state, the ensuing sleep lasting 23 out of every 24 hours. Quite different phenomena became apparent in our experiments on 16 pups operated on at the ages of from 2 to 10 months.

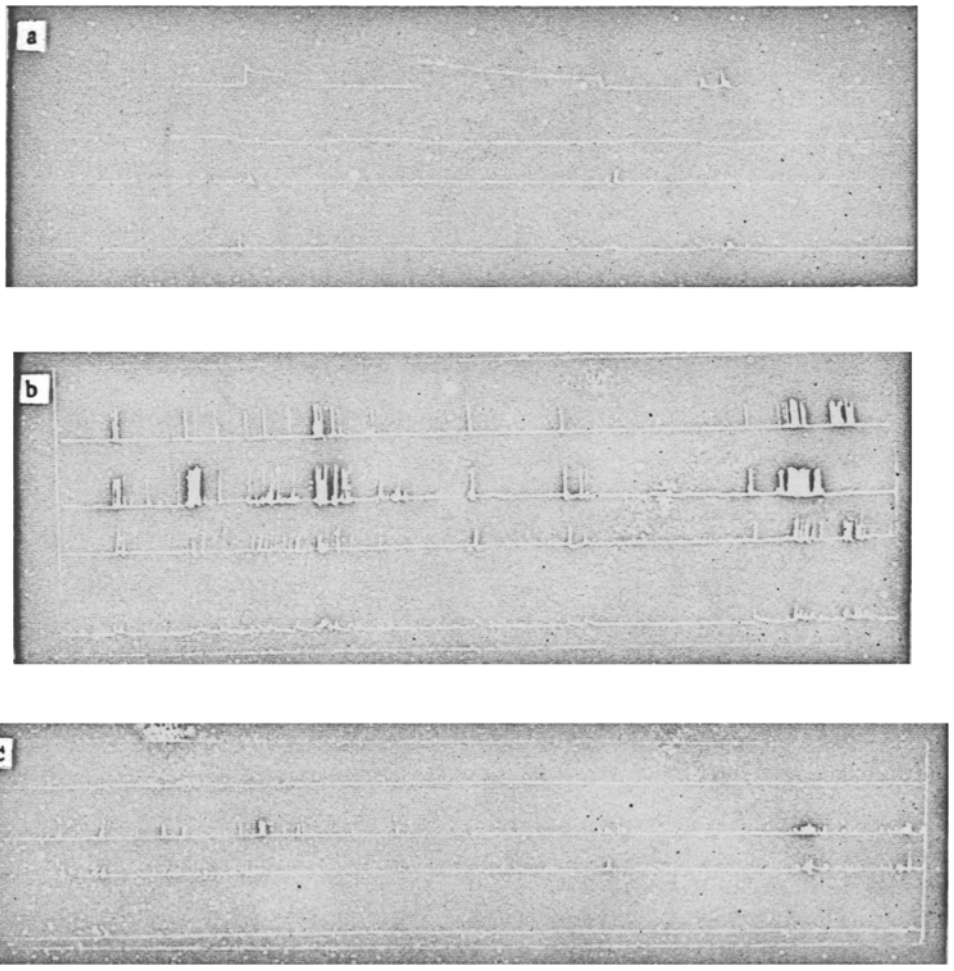

Fig. 4. "Actogram" of the daily activity of 3 pups following operative extinction of 4 receptors (visual, auditory, olfactory and vestibular).
a) 10-months old pup on 18th post-operative day; b) 5-months old pup on 10th post-operative day; c) $2\frac{1}{2}$-months old pup on 2nd post-operative day.

In addition to investigation of their conditioned reflex activity before and after operation, records were taken of the daily activity of the pups. It was found that 10-months old pups subjected to simultaneous deprivation of the 4 receptors mentioned above did not, for a long time after operation, take food spontaneously, did not move about the cage and spent considerable part of the day in an immobile state. On the 12th-15th post-operative day pups of this age group began to move about the cage. Figure 4, a presents records of the daily activity of such a pup on the 18th post-operative day. A different picture emerged in the case of pups operated on at the age of 5 months. They, as a rule, moved about the cage by the 8th-9th post-operative day and by the 10th-11th day their daily activity (Fig. 4, b) differed little from the daily activity of normal (control) pups.

Compensation occurred even sooner at earlier stages of ontogenesis. Pups aged 2-3 months began to walk spontaneously and to maintain prolonged motor activity in the course of a day as early as 2-6 days after simultaneous removal of 4 receptors. Figure 4, c shows the daily motor activity of a 2 ½-months old pup on the 2nd day after operation. The pup moved about the cage spontaneously, took food from a dish and even stood up on its hind legs, resting its front paws on the wall of the cage, without losing its balance.

Pups aged 2-3 months showed as early as the 5th-6th post-operative day well marked orientation reaction, finding the feeding vessel quickly even though they found themselves in the chamber for the first time only after operation. Older animals, subjected to removal of the receptors at the age of 5 months, only began to find the feeding vessel on the 15th-18th post-operative day, while 10-months old pups did not always chose the right direction toward it even as late as the 25th-30th post-operative day.

It follows from the facts cited above that the younger the animal the quicker the establishment of cortical compensatory process (as regards the remaining analysors especially the muscular, and also visceral) even upon simultaneous loss of function of 4 receptors. Of special interest are the dynamics of higher nervous activity mediated by the remaining receptors.*

Do these compensatory phenomena prove to be stable in the course of the animal's further development, becoming ever more complete or, on the contrary, are these phasic phenomena adjusted only to definite ontogenetic periods reflecting high plasticity of young cerebral structure? These and many other questions emerging from the facts and observations described above form the many aspects of our studies.

SUMMARY

Experiments were performed on puppies of various age. The receptors (olfactory, visual, auditory, vestibular) were extinguished in one stage or gradually, one by one. It was established that disturbances which were thus caused are compensated by the cortex cerebri. The younger the animal the better and the quicker the development of this compensatory mechanism.

LITERATURE CITED

[1] K. S. Abduladze, Texts of the 15th International Congress of Physiology,** Moscow-Leningrad, 1935, pp. 2-3.

[2] E. S. Airapetyants, Higher Nervous Activity and Internal Organ Receptors,** Moscow, 1952.

[3] E. S. Airapetyants, Zhur. Vysshei Nerv. Deyatel. 5, 5, 644-652 (1955).

[4] E. S. Airapetyants and N. A. Moiseeva, Texts of Conference of Czechoslovak Academy of Sciences, Liblitsy u Pragi, 1956.

[5] E. S. Airapetyants, Communications to 20th International Congress of Physiology in Brussels,** Moscow, 1956, pp. 180-184.

[6] P. K. Anokhin, The Problem of Center and Periphery in the Physiology of Nervous Activity,** Gorky, 1935.

[7] E. A. Asratyan, Uspekhi Sovremennoi Biol., 6, 3, 451-468 (1937).

[8] E. A. Asratyan, Adaptation Phenomena in Damaged Organism,** (Moscow, 1948).

[9] K. M. Bykov, Vestnik AN SSSR 1, 19

---

* For reference to the facts cited see N. A. Moiseeva's article in Transactions of III Conference on Problems of Age Morphology, Physiology and Biochemistry (1957). (In Russian).

** In Russian.

[10] K. M. Bykov, Cerebral Cortex and Internal Organs,* (Moscow, 1947).

[11] V. S. Galkin, Arkh. Biol. Nauk SSSR 33, 1-2, 27-53 (1933).

[12] V. A. Kislyakov, Thesis, "Conditioned Reflexes to Motor Reactions Arising on Rotation of the Animal",* Leningrad, 1953.

[13] V. A. Kislyakov, Zhur. Vysshei Nerv. Deyatel. 6, 3, 438-442 (1956).

[14] B. N. Klosovsky and E. N. Kosmarskaya, Byull. Eksptl. Biol. i Med. 40, 9, 3-6 (1955).

[15] B. N. Klosovsky and E. N. Kosmarskaya, Ibid. 43, 3, 19-24 (1957).**

[16] L. V. Lobanova, Texts and Abstracts of Communications to 16th Conference on Problems of Higher Nervous Activity,* Moscow-Leningrad, 1953, pp. 126-128.

[17] L. V. Lobanova, Doklady AN SSSR 96, 5, 1073-1076 (1954).

[18] L. V. Lobanova, Ibid. 108, 2, 363-366 (1956).**

[19] L. V. Lobanova, Ibid. 109, 2, 413-416.**

[20] N. A. Moiseeva, Texts and Abstracts of Communications to 16th Conference on Problems of Higher Nervous Activity,* Moscow-Leningrad, 1953, pp. 147-148.

[21] N. A. Moiseeva, Texts and Abstracts of Communications to Conference on Problems of Evolution of Neurophysiology,* (Leningrad, 1956), pp. 108-109.

[22] N. A. Moiseeva, Zhur. Vysshei Nerv. Deyatel. 6, 3, 394-398 (1936).

[23] N. A. Moiseeva, Transactions of III Scientific Conference on Problems of Age Morphology, Physiology and Biochemistry,* (1957).

[24] I. P. Pavlov, Collected Works,* Moscow-Leningrad, 1954, Vol. III, book 1, p. 208.

[25] I. P. Pavlov, Pavlov's Wednesdays,* Moscow-Leningrad, 1949, Vol. 2, 3.

[26] V. A. Troshikhin, Zhur. Vysshei. Nerv. Deyatel. 2, 4, 561-571 (1952).

* In Russian.

** Original Russian pagination. See C.B. Translation.