ROLE OF INTEROCEPTIVE IMPULSES IN THE MODULATION OF EMOTIONAL AND BEHAVIORAL RESPONSES

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Chronic experiments on rabbits with a gastric fistula and electrodes implanted into deep brain structures showed that stimulation of the gastric receptors leads to modulation of emotional and behavioral responses evoked by electrical stimulation of the hypothalamus, amygdala, and hippocampus. The effect depends on the intensity of interoceptive stimulation and on nature of the emotional response, which has its own cerebral control systems.
KEY WORDS: *interoceptive impulses; emotional behavior; hypothalamus; limbic system.*

The role of information from the external environment in the regulation of emotional behavior has received very little experimental study. The work of Chernigovskii et al. [9] yielded important information on the role of interoceptive information from organs of the alimentary tract in the food behavior of animals.

Experiments were carried out to study the extent to which stimulation of gastric receptors is reflected in the character of motor and autonomic components of various types of emotional and behavioral responses evoked by electric stimulation of the hypothalamus and other emotiogenic zones of the limbic system.

EXPERIMENTAL METHOD

A gastric fistula (Basov) was formed in male rabbits and nichrome electrodes (diameter 100 μ) were inserted into the lateral and ventromedial zones of the hypothalamus, the basal-medial and lateral amygdalar nuclei, and the ventral and dorsal zones of the hippocampus [15]. The brain structures were stimulated by square pulses from an electronic stimulator (60 Hz, 2 msec, 30 sec). By increasing the strength of the current (with a 0.5 V step) the thresholds of general alerting, of the orienting-investigating reflex, and of various types of aggressive, defensive, and epileptiform responses were determined. The ECG and respiratory movements were recorded on the 4 ÉÉG-1 electroencephalograph. Relatively free behavior of the animals was allowed during the experiments. All indices were recorded before and during interoceptive stimulation and again 15, 30, and 60 min after its end. Measured stimulation of the gastric receptors was carried out by means of a rubber balloon inserted into the stomach, which could be distended with 50-100 ml warm water. After the end of the experiments the location of the electrodes was verified in serial histological brain sections.

EXPERIMENTAL RESULTS AND DISCUSSION

Aggressive-defensive reflexes (fear, panic running away, tapping with the paws, etc.) were observed most frequently in response to stimulation of the nuclei of the amygdala, ventromedial hypothalamus, and hippocampus. Responses of orienting-investigative type and food-getting reflexes appeared most frequently in response to stimulation of the lateral

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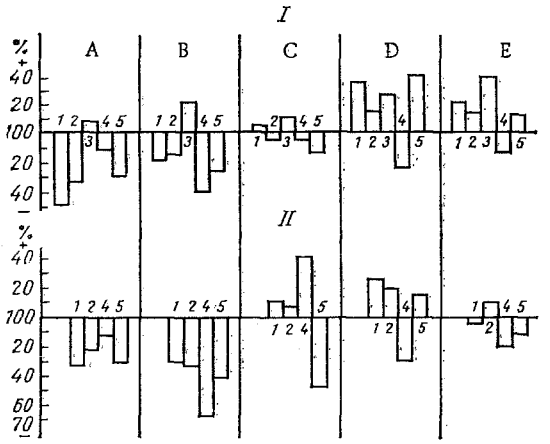

Fig. 1

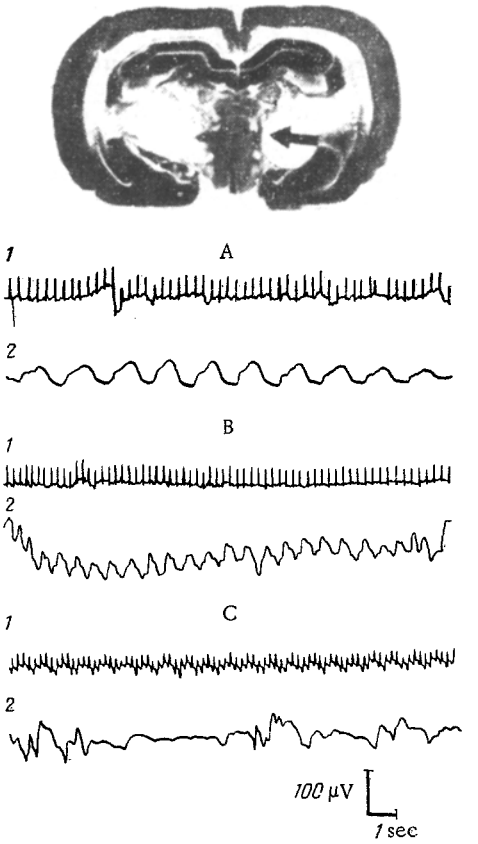

Fig. 2

Fig. 1. Changes in thresholds of emotional and behavioral responses evoked by electrical stimulation of deep brain structures during stimulation of gastric mechanoreceptors (in % of initial level): I) lateral hypothalamus; II) basal-medial amygdalar nucleus. A) Weak stimulation of gastric mechanoreceptors; B) strong stimulation; C) after end of stimulation; D) immediately after measured feeding; E) 30 min after feeding. 1) General alerting; 2) orienting-investigative reflex; 3) food reflex; 4) aggressive-defensive reflex; 5) epileptiform response.

Fig. 2. Change in cardio-respiratory component of behavioral responses evoked by electrical stimulation of lateral hypothalamus accompanied by stimulation of gastric mechanoreceptors: A) background; B) after electrical stimulation (1.8-2.2 V); C) after electrical stimulation accompanied by mechanical stimulation of stomach; 1) ECG; 2) pneumogram. Section through brain of rabbit No. 9 (coordinates: F – 2.5, L + 2.5, H – 3.3) shown above.

hypothalamic nuclei and of the dorsal hippocampus. An increase in the strength of stimulation led to uncontrolled motor responses of epileptiform type (automatisms, tonic and clonic convulsions, generalized responses, etc.), of maximal intensity in response to stimulation of the basal-medial amygdalar zones and of the ventral hippocampus; after stimulation the animals were in a state of excitation. Behavioral responses were accompanied by clear changes in the cardiac rhythm and frequency of respiratory movements. Similar results were obtained by other workers [1-3].

Weak stimulation of the gastric mechanoreceptors usually facilitated emotional and behavioral responses (Fig. 1). The thresholds of the general alerting and orienting-investigative reflexes to stimulation of the lateral and ventro-lateral hypothalamic nuclei and the basal-medial amygdalar nucleus, for instance, were lowered by 32.2-50% ($P < 0.01$); thresholds of paroxysmal responses were lowered by 18.3-41.7% ($P < 0.01$).

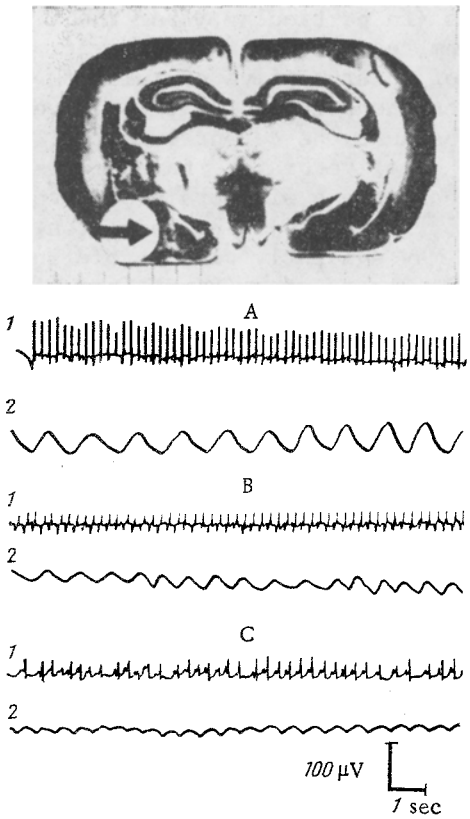

Fig. 3. Changes in cardio-respiratory component of behavioral responses evoked by electrical stimulation of basomedial amygdalar nucleus accompanied by stimulation of gastric mechanoreceptors: A) background; B) after electrical stimulation (3.2-4.5 V); C) after electrical stimulation accompanied by mechanical stimulation of stomach. 1) ECG; 2) pneumogram. Section through brain of rabbit No. 7 (coordinates: F -0.5,L + 5.5, H -5.0)shown above.

In response to stronger stimulation of the gastric mechanoreceptors emotional-behavioral responses also were strengthened, but under these circumstances mainly passive defensive responses (of the fear and running away type) and alarm-rage responses (tapping with the paws, etc.) were predominant and became more marked. The food-motivation reflex evoked by electrical stimulation of the lateral hypothalamus in satiated animals was definitely depressed in most experiments during stimulation of the gastric receptors, especially so far as general motor activity and goal-directed food seeking were concerned; the changes were less marked in the actual eating of food.

After the end interoceptive stimulation the thresholds of responses to electrical stimulation of the hypothalamic nuclei returned to their initial level within a few minutes. Responses of general alerting and of the aggressive-defensive type to stimulation of the amygdala and hippocampus were appreciably depressed under these conditions; their threshold levels were increased by 12.5-40.7% ($P < 0.05$). However, during the first hour after the end of interoceptive stimulation the thresholds of these responses returned to their initial level.

Autonomic correlates of behavioral responses also were modified by stimulation of the gastric receptors. Compared with control experiments, electrical stimulation of the hypothalamus and ventral hippocampus, superposed on mechanical stimulation of the stomach, increased the heart rate over the control level (Fig. 2); in most tests the increase in the heart rate was directly proportional to the intensity of interoceptive stimulation. During stimulation of the amygdala, the bradycardia which usually developed was more marked when accompanied by intensive stretching of the stomach walls (Fig. 3). In all experiments stimulation of the gastric mechanoreceptors was accompanied by a further increase in frequency of the respiratory movements combined with a decrease in their amplitude; the rhythm of respiration frequently became irregular.

Immediately after measured feeding of the hungry animal, when the food had a stimulating action only on the corresponding receptors of the alimentary tract (i.e., in the phase of "sensory" satiation) a tendency was observed for the whole range of orienting-investigative reflexes to diminish, but at the same time the manifestations of responses of aggressive defensive type became stronger. The thresholds of the epileptiform responses to stimulation of all the brain structures tested were increased by 39-76.6% immediately after feeding.

The heart rate usually increased in response to stimulation of all emotiogenic zones after feeding; immediately after taking food an increase in frequency of the respiratory movements was observed (in response to stimulation of the amygdalar nuclei and hippocampus) but after 30 min this was followed by slowing and deepening of the movements, evidently through self-regulation of respiration. These changes in emotional and behavioral responses usually continued for 1 h.

Natural food stimulation and inflation of the balloon in the stomach thus altered the thresholds of orienting-investigative reflexes in opposite directions. This was probably because of different changes in the activity of the subcortical and cortical structures of the food center [7].

These results confirm the role of interoceptive impulses (in particular, from the gastric receptors) in the modulation of activity of the system responsible for integration of emotional behavior. The effect depended on the intensity of interoceptive stimulation and on the character of the emotional and behavioral responses themselves, for these have their own cerebral control system. This is not surprising, because the cerebral cortex and subcortical structures, including those belonging to the "emotive brain," have been shown to contain projections of the visceral systems and to have connections with brain structures, stimulation of which evokes viscero-somatic responses [4-6, 8, 10-14, 16]. The modulating effect of interoceptive impulses on emotional manifestations may evidently play a role in the production of a state of "central motivation excitation" and attainment of the result of an imminent behavioral act in connection with a particular internal state of the body.

LITERATURE CITED

1. A. V. Val'dman and M. M. Kozlovskaya, in: Experimental Neurophysiology of Emotions [in Russian], Leningrad (1972), p. 211.
2. F. P. Vedyaev, Fiziol. Zh. (Ukr.), No. 4, 463 (1972).
3. F. P. Vedyaev and T. K. Raisov, Fiziol. Zh. (Ukr.), No. 2, 147 (1975).
4. R. A. Durinyan, The Central Structure of Afferent Systems [in Russian], Leningrad (1965).
5. S. S. Musyashchikova and N. N. Chernigovskii, Cortical and Subcortical Representation of Visceral Systems [in Russian], Leningrad (1973).
6. V. S. Raitses, Uspekhi Fiziol. Nauk, No. 4, 90 (1973).
7. K. V. Sudakov, Biological Motivations [in Russian], Moscow (1971).
8. É. S. Tolmasskaya, Nervous Mechanisms of Coordination of Somatic and Visceral Functions [in Russian], Moscow (1964).
9. V. N. Chernigovskii, The Role of Interoceptive Impulses in the Food Behavior of Animals [in Russian], Moscow–Leningrad (1962).
10. V. N. Chernigovskii, Neurophysiological Analysis of the Cortico-Visceral Reflex Arc [in Russian], Leningrad (1967).
11. V. E. Amassian, J. Neurophysiol., 14, 433 (1951),
12. J. D. French, J. Neurophysiol., 18, 74 (1955).
13. N. E. Miller, Science, 163, 434 (1969).
14. S. R. Sampson and T. J. Biscoe, Brain Res., 9, 398 (1968).
15. C. H. Sawyer, J. W. Everett, and J. J. Green, J. Comp. Neurol., 101, 80 (1954).
16. A. Varbanova, Interoceptive Impulse Activity [in Russian], Sofia (1967).