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Mihai Nadin *Editor*

Anticipation: Learning from the Past

The Russian/Soviet Contributions to the
Science of Anticipation

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Cognition as Systemogenesis

Yuri I. Alexandrov

Abstract The present report has the following two objectives: to provide a survey of systemic conceptions in psychophysiology that are rooted in the theory of functional systems, and to compare the development of these conceptions with tendencies characterizing progress in world science. On the basis of ample experimental material in the framework of systems psychophysiology, views are formulated on the formative and dynamic regularities of individual experience. Within this framework, applying a systemic approach to the study of cognition entails multidisciplinary investigation of the systemogenesis and actualization of neuro-cognitive systems. Science, being a part of culture, along with invariant characteristics reflecting its global character, possesses also certain local, national features. Peculiarities of Russian science are discussed, as well as the complementarity of local culture-specific components of world science.

Keywords Anticipation · Cognition · Culture · Goal · Learning · Memory · Neuron · Reconsolidation · Result · Science

1 Cognition and Systemic Organization of Behavior

Cognition can be considered as a process of active interaction with the environment that produces knowledge as a means for achieving goals. Or, in a broader sense, cognition is an effective action that enables an organism to continue to exist in an environment [1]. To gain knowledge means to learn individual acts and cooperative interactions [2]. In the framework of this understanding, applying a systemic approach to the study of cognition entails multidisciplinary investigation of the formation (systemogenesis) and actualization of systems subserving behavior.

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A considerable contribution to the development of systemic approaches in psychology and neuroscience was made by Anokhin, the founder of the theory of functional systems (TFS). How did Anokhin's theory, originally formulated to solve problems in physiology, turn out to be such an effective theoretical framework in psychology (see in detail [3])? And how would Anokhin, recognized as a leading figure in physiology, become considered among the giants in psychology [4]? What determines this special value of TFS for psychology?

The idea of a system-forming factor was developed in TFS. This factor was conceived as the process that confines the degrees of freedom of the system's elements, and thereby creates order in their interactions. This concept is generalizable across various systems and enables one to analyze quite different objects and situations. The system-forming factor is a product of systems and has a beneficial effect on the adaptation of an organism to its environment. Furthermore, it is *not past events or stimuli related to them, but future events and their results* that determine behavior from the point of view of TFS (see also [5–7]).

Taking into account the aforementioned ideas, if we consider Behterev's statement "the reaction to external influences takes place not only in living organisms, but also in objects of nonliving matter," [8, p. 21] we can thus agree only with its second half. Indeed, the objects of nonliving matter do respond to external influences. As for a living organism, if we consider it not as a physical body but as an integral individual performing adaptive behavioral act, then we have to admit that its reflection of the world is anticipatory—its activity in any moment is not a response to the past, but a preparation and shaping of future actions.

How can a result that will occur in the future determine current activity, and be its cause? Anokhin solved this "time paradox" using the future result model wherein an aim acts as the determinant, with a corresponding action result acceptor forming before the actual result and containing its predictable parameters. Therefore, Anokhin eliminated the contradiction between causal and teleological descriptions of behavior and made the latter acceptable even for "causalists," that is, those researchers who believe that science deals only with causality, and that no law is possible that does not address causality [9].

TFS assumes that to understand an individual's activity, it is necessary to study not only the "functions" of separate organs or brain structures as traditionally understood (i.e., as immediate functions of this or that substrate, including the nervous system: the sensory, motor, and motivational functions, etc.), but the organization of holistic individual-and-environment interrelations involved in obtaining a particular result. Considering *function* in regard to the achievement of a result, Anokhin provided the following definition of a *functional* system: the idea of "system" is applicable only to complexes of selectively engaged components whose mutual interrelations enable to obtain a beneficial result. This "systemic" function cannot be localized. It is apparent only within the organism as a whole.

According to TFS, associations between elements of an organism are structurally embedded within mechanisms such as afferent synthesis, decision-making, action

result acceptors (the apparatus for predicting parameters of future results), and action programs. These mechanisms provide the organization and realizations of the system (for more detail, see [10]).

2 Systems Psychophysiology

Long-term studies in our laboratory shaped a system-evolutionary approach [11, 12] and a new branch of science: *systems psychophysiology*, which suggests a systems solution to the mind-body problem [13]. In this solution, the organizing of physiological processes into a system is based on specific systems processes. Their substrate is physiological activity, whereas their informational content is mental. The mental processes that characterize an organism and behavioral act as a whole, and the physiological processes that take place at the level of separate elements, cannot be related directly, but only through the informational systems processes. Mental events cannot be related directly to the localized elementary physiological events, but rather to the systems processes of their organization.

Psychological and physiological descriptions are partial descriptions of the same systems processes. We stress that systems processes involve not only the brain but also the whole body (this is also the position defended by “embodied cognition” [14]). Thus, the term “mental” characterizes the organization of activity not only in neurons but also in other anatomical structures of the organism.

This solution to the mind-body problem resembles Hegel’s “neutral monism” (see in [15]), which argues that mental and physical are two aspects of united reality. Chalmers [16, p. 215] formulated a double-aspect principle: “Information (or at least some information) has two basic aspects, a physical aspect and a phenomenal aspect.” We would replace “some information” with “informational systems processes,” that is to say processes that organize elementary mechanisms into a functional system: afferent synthesis and decision making, program of action and acceptor of action result.

From this point of view, mind may be considered as a subjective reflection of the objective relation of an individual to the environment. That is, mind is considered as a structure represented by systems accumulated in the course of evolutionary and individual development. Relations between these systems (intersystem relations) may be described qualitatively as well as quantitatively. Nadin [17] advanced a relational model based on the notion of anticipation.

2.1 Behavioral Continuum

We consider a behavioral act not as an isolated entity, but as a component of a behavioral continuum, the succession of behavioral acts performed by an individual during life. Then it appears that the next act in a continuum is realized after the

result of the previous act is achieved and evaluated. Such evaluation is the necessary part of organizational processes of the next act; these processes then may be considered as transitional, or processes of transition from the realization of one act to the realization of the subsequent act. There is no room for stimulus in a continuum (Fig. 1). The environmental changes that are traditionally considered to be a stimulus for the given act are informationally linked with the preceding behavior in course of which these changes were anticipated, planned in the model of future behavioral result—the goal of behavior.

Then what about unexpected changes? What modifications of the succession of behavioral acts may result from the change in the environment that was not anticipated during the previous behavior and thus is not a result of that behavior? Such change will either have no effect on the planned succession of the acts in a continuum (and in this sense will be “ignored”), or interrupt the succession, determining the formation of different kinds of behavior depending on the situation: repeating the interrupted behavioral act, formation of a new behavior (e.g., orienting behavior). And again, all these behaviors will be aimed at the future and their organization will be an informational equivalent of a future event.

Behavior may thus be considered as a continuum of results [19] and a behavioral act—as a part of a behavioral continuum between one result and the next one [13].

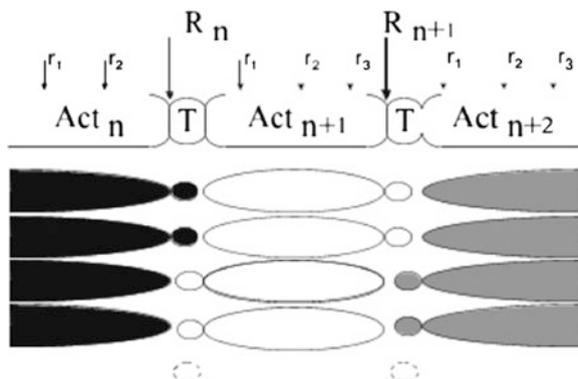


Fig. 1 Behavioral continuum as continuum of anticipated results. *Above* intermediate results (r_1, r_2, r_3) and final results of behavioral acts (R_n, R_{n+1}) corresponding to lower and higher levels of anticipation. *T* transitional processes. *Below* the sets of systems that subserve the realization of the successive acts in continuum (each set is represented by its own shading). *Open dashed ovals* systems to which “additional” neurons belong that were inactive in processes of realization of the studied behavioral acts. It was shown that transitional processes were characterized by the “overlapping” activation of neurons related to the preceding and following behavioral acts, and by activations of “additional” neurons (see details in [13, 18])

2.2 Goal-Directedness of Neuronal Activity

In the framework of reactivity paradigm an individual’s behavior is a reaction to stimuli. This reaction is based on the propagation of excitation along the reflex arc: from receptors through central structures to effector organs. This paradigm treats neuron as an element of reflex arc, while its function is a propagation of excitation. Then it would be logical to consider the determination of activity of such element as follows: “...response to stimulus that affected some part of its [the nerve cell’s] surface may travel further along the cell and act as stimulus on other nervous cells...” [20, p. 93]. Thus reactivity paradigm methodologically treats neuron quite logically: neuron, just like an organism, responds to stimuli. Impulses that a neuron receives from other cells act as stimuli, while the response of a neuron is its discharges following the synaptic input (Fig. 2).

Unfortunately, such methodological consistency was absent in the activity (systems) paradigm. Usually the analysis of “neuronal mechanisms” of goal-directed behavior led authors to the idea that an organism performs goal-directed behavior, whereas its separate element (the neuron) responds to incoming excitation (stimulus).

This eclecticism was overcome and the views at the determination of neuronal activity were adapted to the demands of systems paradigm when the interpretation of neuronal activity as a response to synaptic inflow was abandoned. At the same time it was accepted that a neuron, like any other living cell, realizes a genetic

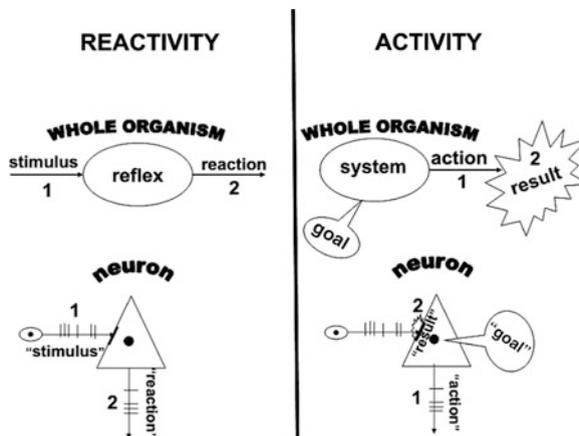


Fig. 2 Individual and neuron in activity and reactivity paradigms. Digits in the schemes indicate the order of events. According to the reactivity paradigm, Stimulus (1) is followed by Reaction (2): behavioral in humans, discharges in neuron. In the latter case, the role of a Stimulus is played by discharges of a neuron, the axon of which (parallel to the arrow labeled “Stimulus”) contacts the target neuron. Reaction implies discharges of target neuron. According to activity paradigm, Action (1) (behavior in human, discharges in neuron) leads to achievement of Result and its evaluation (2)

program which requires metabolites received from other cells [12]. Then the succession of events in neuron's activity appears analogous to that characterizing an active goal-directed organism, while neuron's discharges are analogous to the activity of an individual (Fig. 2).

Neuronal activity, like any behavior of an organism, is not a response, but a way of changing the relation to environment, "action" that removes discrepancy between "needs" and microenvironment, causing modifications in blood flow, metabolic inflow from glial cells, and activity of other neurons. If these modifications are adequate to the current metabolic "needs" of a neuron, they enable the cell to achieve an anticipated "result" (receive a set of metabolic substances binding to neuron's receptors) and cause the cessation of the unit's discharges. It is assumed that the discrepancy between genetically determined "needs" and metabolic substances actually received may be due to genetically determined metabolic changes in the cell as well as to the change of metabolic inflow from other cells. Thus neuron is not an "encoding element," "conductor," or "summator," but an organism within organism, providing for its needs with metabolic substances received from other elements.

The neuron may provide for its metabolic "needs" only by joining with other elements of an organism to form a functional system. Their cooperation, joint activity subserves achievement of a result, i.e., new relation of a whole individual and environment. "From within," at the level of separate neurons, achievement of a result appears as satisfying metabolic "needs" of neurons, and it stops their activity. Activity of the neuron from this position is seen as a means of changing its relations with the environment, as the "action" references the future in eliminating unbalance between "requirements" of the cell and its microenvironment. The neuron itself acts not as a "conductor" or a "summator," but as an organism in ensuring its "needs" at the expense of metabolites from other elements.

So, metabolic heterogeneity of neurons, genetically programmed and based on individual development, i.e., being the product of interaction of phylo- and ontogenetic memory, underlies the diversity of functional specialization of neurons and determines the specificity of their involvement into the newly formed systems. This new approach to understanding neuron functioning requires a new approach to research concerning the neural mechanisms of learning and memory (see below; more details in [21]).

2.3 Systemogenesis

The key concept in the TFS is development. Both concepts, development and result of a system, are merged into the concept of systemogenesis. Systemogenesis refers to the idea that, during early ontogeny, those differently localized elements of the nervous system and body that are essential for achieving the results of the systems undergo selective and accelerated maturation, thus ensuring the survival of the organism at the early stages of individual development [10].

Shvyrkov [22] suggested that systemogenesis takes place also during learning in adults, because the formation of a new behavioral act is always a formation of a new system. The principal factor in understanding the role of different neurons in the organization of behavior is the history of behavioral development, that is, the history of successive systemogenesis [21, 23–25]. The system-selection concept of learning [22] is in line with the idea of a selective, rather than an instructive, principle underlying learning [26]. This concept considers the formation of a new system to be a fixation of the stage of individual development: the formation of a new element of subjective experience during learning.

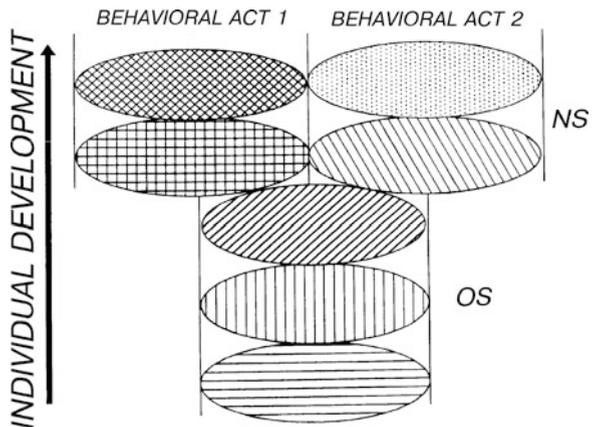
The neural basis of this process is the specialization of “reserve” (“silent”) neurons, but not a change in specialization of already specialized units. New neurons appearing in neurogenesis are also likely to be involved in this process [27], in which new systems (NS, Fig. 3) are added to the existing ones (OS, Fig. 3) [11, 22]. They do not substitute the previously formed systems, but instead are ‘superimposed’ on them (Fig. 3).

Specializations of neurons in relation to systems of specific behavioral acts have been shown in both humans and animals (see in [11, 22, 23, 29, 30, 31]). New systems cannot be formed without relevance to the achievement of specific results. In this sense there is no difference between knowledge and the experience of action performance.

Neurophysiological studies have demonstrated that specialization of recently specialized neurons does not change during a single-unit recording lasting for weeks and even months, and that there are many “reserve” (“silent”) neurons in different brain areas ([32–44] and others).

It has been shown [11, 22, 45] that behavior is realized by new systems that were formed during learning of the acts composing this behavior, and by the *simultaneous* realization of older systems formed at previous stages of individual development (Fig. 1). The latter may be involved in many behavioral patterns, that is to say they may belong to elements of subjective experience that are common for various acts (see Fig. 3).

Fig. 3 Systems structure of behavior. 1, 2 different behavioral acts. OS old systems. NS new systems. Arrow course of individual development



Therefore, behavior is the realization of the history of behavioral development. Multiple systems, each fixing a certain stage of development of the given behavior, are involved.

Our single-unit recordings during instrumental behavior have demonstrated that, generally, neurons with new specializations are abundant in the cerebral cortex (though different cortical areas may vary with respect to this parameter; for instance, the motor cortex is dominated by neurons specialized with regard to systems formed at early stages of individual development: so-called *old*-system neurons, for example, “movement” neurons or “food-taking” neurons).

The cingulate cortex is dominated by neurons specialized with regard to *new* systems formed when animals learn instrumental food-acquisition tasks in an experimental cage (e.g., “pedal-pressing” neurons), whereas phylogenetically archaic and peripheral structures have very few of them, if any [11].

It is reasonable to assume that the specificity of the “projection” of subjective experience to cerebral structures is determined by the particular characteristics of neurons composing these structures. These characteristics determine the involvement of neurons of a given structure in the formation of a particular behavior. Neurons participating in a functional system are located in different anatomical areas.

Thus, coming back to the systems solution to the mind-body problem, we can conclude the following: When describing the formation of neuronal specializations and activity of specialized neurons, we simultaneously describe the structure and dynamics of the subjective world.

2.4 Similar Environmental Variations Can Be Reflected Differently in the Activity of Central and Peripheral Neurons Depending on the Goal of Behavior

One might think that the stimulus produces a brain activation which depends on the physical parameters of the flash, whether this flash is a signal for food or for electric shock presentation. If these parameters are the same, then characteristics of an activation are the same. Experimental data show that it is not the case. The activation of neurons evoked by the flash depends on what behavior deploys after this flash: food acquisition or avoidance. This may be derived from Shvyrkova and Shvyrkov’s [46] experiments, which showed that the sets of neurons activated in the visual cortex are different during presentation of *identical* flashes that induce different types of behavior (food acquisition and defense).

So there is no *perception* of a stimulus pattern per se. There is no ‘objective’ coding of physical parameters of stimulus which at the *subsequent* processing stages becomes ‘subjective’, as many have suggested. Perception is subjective at all stages of its deployment. It is always *interpretation* in terms of needs, and the

vocabulary of these terms is formed during individual development with respect to the peculiarities of given development occurring in a given society.

The activation characteristics of a central neuron in relation to the stimulation of a given receptive surface depend on the context of the behavior during which this stimulation occurs. The differences in the neuronal characteristics can be observed both in the activity characteristics (change of receptive field) of the neuron and in the set of the neurons activated (disappearance or appearance of receptive field) when applying similar stimulation in behavioral acts characterized by different goals.

A relatively long time ago it was shown, in experiments with recording single neurons from the somatosensory and visual cortex in rabbits [47] and rats [48], that, while the parameters of the neuron receptive field stimulation are the same, neuron activation characteristics and the presence of activation per se depend on the goal of behavior, which includes contact with objects in the environment.

Somatosensory and visual cortical unit activity was compared in experiments on unrestrained rabbits during receptive field testing and natural “self-stimulation” of the receptive surfaces of surrounding objects in the course of food-acquisition behavior. Unit activity evoked by receptive field testing may correspond completely (Fig. 4a), partially (Fig. 4b), or not at all (Fig. 4c) to its activity during food-acquisition behavior, that is to say neurons demonstrating connection during testing with particular receptive fields (parts of the body or retina) may preserve, modify or lose it during food-acquisition behavior.

Consequently, on the basis of the activity of a neuron evoked by testing, it is impossible to reliably predict its activity during realization of food-acquisition behavior, for even neurons with identical receptive fields may have different activity in a food-acquisition situation.

Receptive field testing in an alert animal is not simply stimulation of a certain part of the body surface or visual field, it is alteration of the environment which causes the realization of passive-defensive or orienting-investigative behavior. From our viewpoint, activity of the neuron in a given situation can be regarded not as a response to a definite afferent volley but as activity subserving the corresponding behavior: in a “passiv” behavioral situation (receptive field testing) and/or in the situation where active goal-directed behavior is realized.

We obtained similar results at the level of *peripheral* elements [49]. The characteristics of responses of 23 peripheral mechanoreceptive units of the arm to tactile pulses of varying amplitude (50–950 μ) were studied by means of human micro-neurography during two different tasks: counting deviant auditory signals or defining the amplitude of tactile stimuli. For 18 units, differences were obtained between the two task situations when thresholds, latency of the first impulse, mean frequency of impulses or number of impulses in responses to identical tactile stimuli were compared (see Fig. 5).

The sensitivity of the units was higher during the magnitude estimation than during the counting task. The dependence of the activity characteristics of the

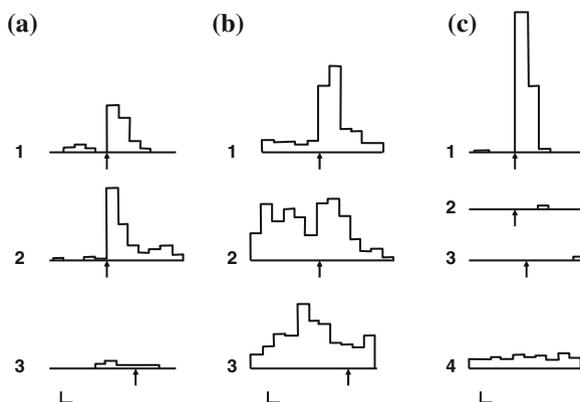


Fig. 4 Comparison of activity of three somatosensory cortical neurons (**a–c**) during testing of their skin receptive fields and during food-acquisition behavior. (1) Histograms of unit activity during testing, drawn relative to times of contact with receptive surface of skin of nose (**a, b**) and corner of the mouth (**c**). (2) Histograms of unit activity drawn relative to time of pressing lever. (3) Time when nose crosses plane of opening into feeding bowl. (4) Histogram of unit activity while animal sits quietly. Calibration (*below*): 5 impulses, 200 ms. Instant relative to which histograms were constructed are marked by *arrows*, $n = 10$. Neurons whose activity is shown in the histograms in **a, b** were located $100\ \mu\text{m}$ apart and had the same receptive field on the contralateral side of the nose, i.e., activation due to contact of the object with this zone during testing was observed in both neurons. However, during realization of food-acquisition behavior they showed different patterns of activity. One neuron (**a**) in this state was activated in full agreement with its activity during receptive field testing, only as a result of contact of the nose with the feeding bowl (**a, 2**, on *right of arrow*); activation was absent at times other than during contact of the receptive zone with objects during approach to the feeding bowl (**a, 2**, on *left of arrow*), during approach to the lever and pressing it (**a, 3**), and also during taking food, either from the hand or from the cage floor. Activity of the other neuron corresponded only partially to activity during receptive field testing: Activation on contact of the nose with the feeding bowl was observed in this cell, just as the previous one (**b, 2**, on *right of arrow*). This neuron, however, was also activated during approach to the feeding bowl and lever (**b, 2, 3**, on *left of arrow*), when the receptive zone was not in contact with any environmental objects. Analysis of activity of a third neuron (**c**) showed no agreement between activities in situations of receptive field testing and food-acquisition behavior realization. On palpation and displacement of a contralateral area of skin between the nose and the mouth, marked activation was observed (**c, 1**). However, during realization of food-acquisition behavior, neither when food was taken from the feeding bowl (**c, 2**), when both contact between receptive zone and feeding bowl and food and displacement of the skin inevitably took place, nor during pressing the lever (**c, 3**) was activation observed. It is interesting to note that differences in the characteristics of activity of this neuron were discovered not only on comparing two behavioral situations (receptive field testing and realization of food-acquisition behavior), but also during analysis of a third situation—when the animal was sitting quietly (**c, 4**), when in the absence of any contact between receptive zone and environmental objects, increased (compared with the testing situation) activity appeared (compare **c, 4** and **c, 1**, on *left of arrow*—the interval in which contact between receptive surface and object also was absent)

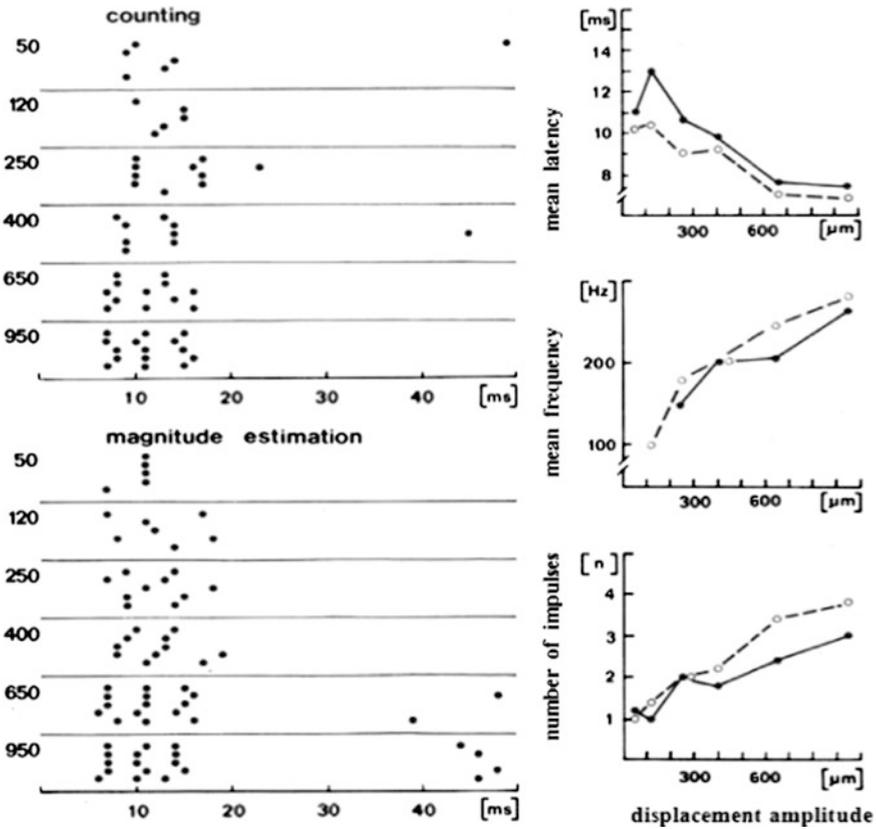


Fig. 5 An example of the task effects on the unit activation. Slowly adapting unit Y14M5. The counting task presented as the first one. On the *left* are the responses to stimuli of different amplitudes, each *dot* representing one impulse and each *line* one response, during counting and magnitude estimation task (the stimulus amplitude in μm given on the *left*). On the *right* are the average latency, mean frequency and number of impulses for each stimulus amplitude; counting task (*black dots, continuous lines*) and magnitude estimation (*open dots, broken lines*)

peripheral units on the behavioral context indicates that this activity is a result not only of external influences but also of central (efferent) effects. Such interaction clearly undermines concepts of unequivocal peripheral “coding” of stimulus features by the receptors. It may be further hypothesized that the modifications of the receptor activity during different behavioral acts are related to those behavioral changes of central sensory neuron activity discussed in the preceding paragraph [50].

The results show that the reorganization of the neural processes according to the goal of the subject is not limited to the central nervous system but involves the periphery as well. The characteristics and even the thresholds of activations of peripheral elements during identical tactile stimuli presentation are dependent on the subjects’ goals.

Recent results also demonstrate that the activity of neurons in projectional sensory areas strongly depends on the behavioral context (auditory cortex: [51]; visual cortex: [52]).

2.5 Outwardly Similar Behavioral Acts with Different Goals Have Different Neural Bases

One could think that the same motor behavior would always correspond to the same neuron activity, at least in the “motor areas” of the brain. In fact, although the movement is the same, depending on whether the objects are real carrots or plastic carrots, the activity of the neurons is different. In other words, from the inner view, there are no motor movements per se but only movements-with-a-goal: movements not as a block that may be inserted in this or that behavior but as a special characteristic of entire goal-directed activity. It was shown that the seizure of food objects and visually similar non-food objects is subserved by different sets of active neurons in motor and visual cortex [53].

In experiments on alert rabbits, neuronal activity of the motor and visual cortical areas was studied in behavioral acts of grasping a piece of plastic or carrot from consequently presented cups of the feeder; the animal had an opportunity to seize a piece of carrot after grasping and taking away from the previous cup the piece of plastic. The “visual environment” in which the behavioral acts were realized was identical; plastic and carrot pieces were identical in form and visual characteristics. Behavioral acts of plastic and carrot-pieces grasping were similar in electromio- and actographic characteristics; motor composition of these acts did not differ. Sixty-one neurons were activated in both behavioral acts, 5 only in the act of plastic-piece grasping, 22 only in the act of carrot-piece grasping, in other words 30 % of neurons were activated only in one of the compared behavioral acts (Fig. 6). Characteristics of activations appearing in both acts could be significantly different: different frequency and connection with different stages of the compared behavioral acts.

Thus, in different behavioral acts (grasping a carrot and plastic), which can be characterized as the same movements in the same visual environment, the compositions of the activated neurons of the motor and visual cortical areas differ. We may conclude that the appearance of cortical neuron activations in behavior depends on the goal of the behavioral acts and is not strictly determined by the parameters of the movements and environment.

Essentially different sets of the rabbits’ cingulate cortex neurons are involved in outwardly similar instrumental acts of pedal pressing (or pulling the ring) that lead to food acquisition if the pedals (or the rings) are placed along two opposite walls of the experimental cage [21, 28, 54–56]; (Fig. 7).

It is noteworthy that outwardly different forms of behavior may have more similar brain bases than outwardly identical ones. Sets of the cingulate cortex

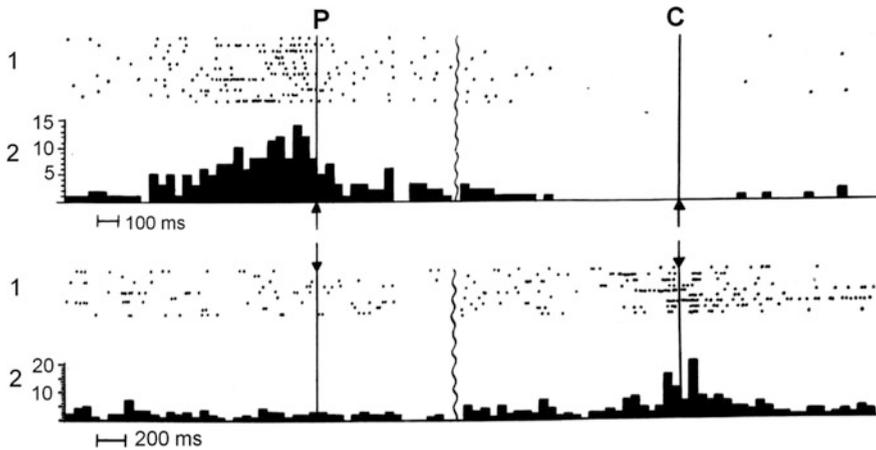
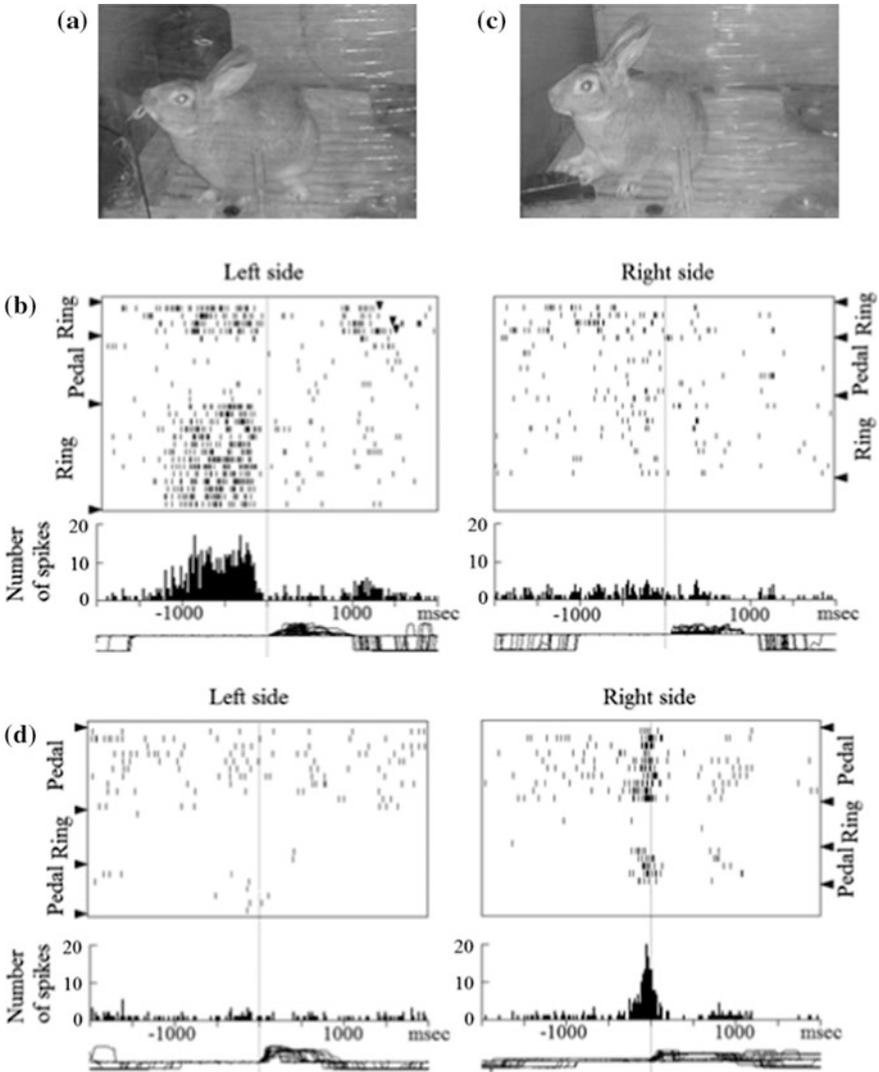


Fig. 6 Examples of neurons of the motor cortex activated only in one of the acts. (1) rasters and (2) histograms of neuronal activity plotted from the start of lifting the head from the feeder (at the top; $n = 12$) and from the phasic burst of the m. masseter EMG corresponding to grasping the object with the teeth (bottom, $n = 9$). The neuron represented at the top of the figure is activated when grasping food with the teeth and at the start of lifting the head from the feeder in the act of grasping the plastic (P) piece (left of the wavy line); in the act of grasping the carrot (C) piece (right of the wavy line) pronounced “inhibition” of activity is noted for this neuron. The second neuron (represented below) is activated when grasping the C piece with teeth (right of the wavy line) but not the P piece (left of the wavy line)

neurons activated in seemingly very different instrumental acts (pressing the pedal and pulling the ring in the same corner of the experimental cage) with the same behavioral result (taking of food from the feeder located at the same wall of the cage as the given pedal and ring) overlap much more [57].

Different neurons of monkey cingulate cortex are active while pressing the same pedal if these acts are involved in different forms of behavior: approach versus withdrawal, in other words, if they subserve food acquisition or avoidance of electric shock to the skin, respectively [58, 59]. Paton and colleagues [60] have shown that different neuron sets in primate amygdala are active during presentation of visual stimuli with positive and negative values.

Outwardly similar behavior of identical auditory signal detection is subserved by different brain activity in a positive emotional situation (goal—earning money) and in a negative one (goal—avoiding money loss). The dynamics of perceptual learning is also different in these situations [61]. In this study the valence of condition had a significant influence on the amplitude of auditory N100. The amplitude was larger in a punishment than in a reward condition. The effect of emotional context revealed in our experiments is consistent with the idea that the brain represents sensory-specific information in accordance with a current task goal [62]. Our results indicate that the brain mechanisms involved in the processing of identical auditory stimuli differ quite early on in the processing stage depending on the emotional context.



Our study, as well as those cited above, has shown that different sets of central neurons are active during outwardly similar acts when they are performed to achieve different goals. Thus, it is possible that auditory-cortex neurons coordinate their activity with different sets of activated neurons in approach and avoidance trials.

◀ **Fig. 7** Activation of neurons in the rabbit cingulate and anterolateral motor cortex appearing in one but not in another outwardly similar act of instrumental food-acquisition behavior. The experimental cage (**a**, **c**) in which instrumental food-acquisition behavior is performed by the animal pulling obliquely on a ring (**c**) or pressing a pedal (**c**) is fitted with paired feeders that automatically deliver a reward when the corresponding pedal (located on the same wall of the cage as the feeder) is pushed or the corresponding ring is pulled. Beneath are shown raster plots of spike activity and histograms of neuron activity in the anterolateral (**d**) and cingulate (**b**) areas of the cortex. In **b**, a neuron in the cingulate cortex is activated on seizing the left but not the right ring. There is no activation on approach to or pressing of the pedals. In **d**, a neuron in the anterolateral cortex is activated on contact with the right but not the left pedal. There is no activation on approach to and seizing of the ring. In **b** and **d**, raster plots and histograms are constructed in relation to the start of pulling the ring and the start of pressing the pedal respectively. The vertical lines passing through all components in fragments **b**, **d** identify the time point at which raster plots and histograms were constructed. Vertical bars on raster plots show individual neuron spikes and horizontal bars show sequences of spikes in an individual cycle of the food-acquisition behavior. Cumulative histograms with a channel width of 20 ms are shown beneath the raster plots. The lowest plots are behavior actograms for all cycles of the food-acquisition behavior performed by the animals during recording of spike activity from the corresponding neuron. Upward displacement of lines on the actograms show pulling of the ring or pressing of the pedal; downward displacements show lowering of the animal's snout to the feeder. In **b**, diamonds show repeat pulls

2.6 Previously Formed Behavior Is Modified by Forming a New Behavior

We recall from above that specialized neurons do not change their specialization in relation to “their” act, and to form new action other (“reserve”) units must be recruited. It may be concluded then that, if we put some memory in our “memory warehouse” and do not use it for some time, it stays on a shelf in the form it had when we put it there. However, this is a false conclusion.

Behavioral data obtained in Pavlov's lab [63] led him to conclude that adding new conditional reflexes immediately influences the state of the previous ones. We consider learning as the specialization of a new group of neurons in relation to a formed system and the “addition” of the latter to previously-formed systems. It is logical that this addition requires mutual coordination of a new element with the ones previously formed and leads to reconsolidation modification of the latter. The molecular-biological characteristics of reconsolidation of memory and underlying modification occurring after repeated actualization have now been identified (see e.g., [64]). Activation of a memory, like its formation, requires protein synthesis for reconsolidation processes. Thus protein-dependent consolidation processes can be linked not only with “new” memories but, more generally, with ‘active’ memories [65].

The concept of reconsolidation modification does not contradict the position presented above regarding the permanence of the system's specialization of neurons. Reconsolidation does not alter the modifications leading to the formation of long-term memory [66]. According to the aforementioned data, neurons that belong to a given system, and which are involved in one behavior, do not change their

systemic specialization when the system provides for another behavior, but they do reorganize their activity.

Based on the data from experiments with investigation of systems neuronal specialization, we have recently concluded that earlier formed systems change after learning the next act [56]. The reconsolidation modification undergone by the earlier formed, 'old' system when a new related system appears was termed "accommodation" reconsolidation [21, 56]. However, for the above conclusion, we used experimental data obtained during recordings of neuron activity *after* learning in earlier acquired definitive behavior for a hypothetical reconstruction of events taking place during the learning of this behavior. The way accommodation reconsolidation manifests itself *during* learning has been recently demonstrated in our laboratory by A.G. Gorkin, who used chronic tetrodes to record the activity of cingulate cortex neurons in rats.

Animals learned the above-mentioned instrumental food-acquisition behavior. At the beginning, they learned to press the first pedal to get a piece of food from the feeder located near the same wall of the experimental cage. After that they learned to press the second pedal located near the opposite wall of the cage. "Non-specific" activity of some neurons appearing in behavior learned first was modified after the behavior near the opposite wall had been established. An example of such modifications of activity in neuron 40103-1, which was specialized in relation to the act learned second (near the opposite wall) can be seen in Fig. 8.

In the activity of the specialized neuron a "specific" phase, expressed activation, can be distinguished; it appears during that behavioral act, in relation to a system in which this neuron was specialized. This activation usually greatly exceeds the 'non-specific' activity of the same neuron recorded during other behavioral acts. Furthermore, 'non-specific' activity is more variable and does not appear in 100 % of cases, as "specific" activations did. The behavioral specialization of a neuron is its permanent characteristic. That is why neuronal activity can serve as an index for the actualization of a specific system, and the "non-specific" activity of a neuron may indicate retrieval of the specific system from memory during performance of other behavioral acts. Thus, we consider "non-specific" activity as an indicator of a relation between the system to which a given neuron belongs and other related systems.

The neuron presented in Fig. 8 originally (after first learning; acts 1–6) showed "non-specific" activation during turning the head to a pedal (act 1) and approaching a pedal (act 2). After the establishment of the second behavior (acts 11–16), "specific" activation of this neuron during approaching the feeder (act 15) and seizing food in the feeder (act 16) appeared. At the same time, a significant increase ($p < 0.01$; Wilcoxon's criterion; compare 1 and 2 in graphs above and below) of mean frequency of "non-specific" activation (acts 1, 2 graph below) was revealed, evidencing "accommodation" reconsolidation.

We have found indications of pre-existing memory reorganization at the neurogenetical level also. It was shown that learning-induced expression of immediate-early gene products (c-Fos) occurs in neurons specialized in relation to the pre-existing behavior (water-acquisition task) during the next behavior (food-acquisition task) learning [67, 68].

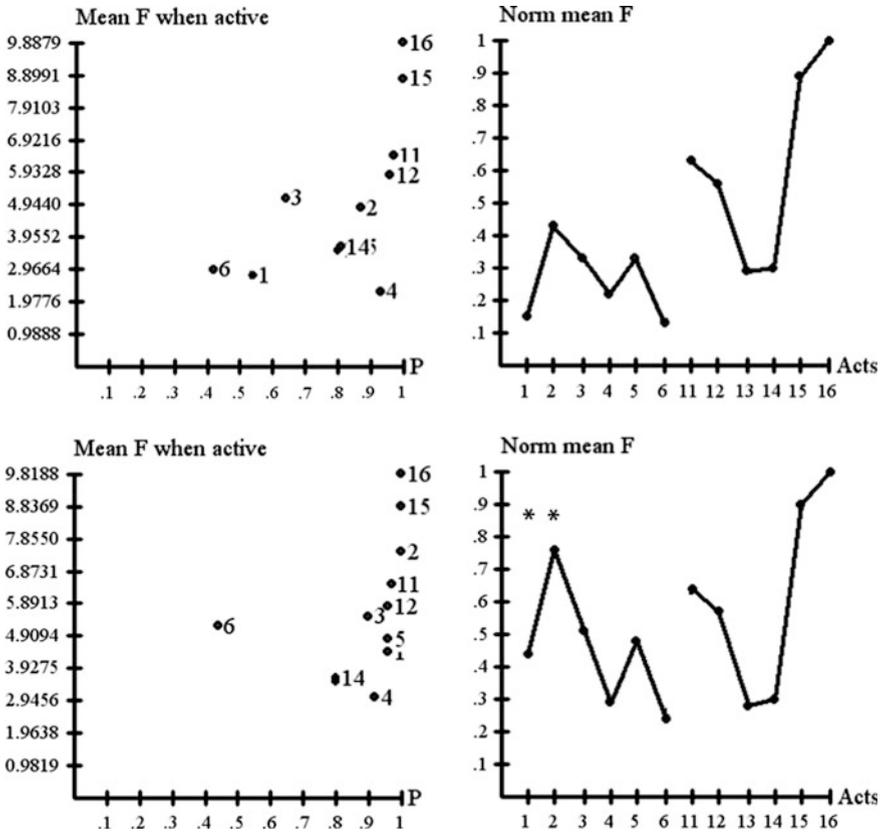


Fig. 8 Change of the activity of cingulate cortex neuron in the previously learned (first) behavior after the establishment of the new (second) behavior. *Above* a pair of graphs demonstrating activity of the neuron in the first realizations of previously learned acts (acts 1–6) and in the first realizations of newly formed acts (acts 11–16). *Below* activity of this neuron in the first realizations of newly formed acts and in the previously-formed behavior after the establishment of the new one. *Left graphs above and below, abscissa*—the probability of the presence of activation in the corresponding acts; ordinate—mean frequency in acts marked with the corresponding numbers (1–16). *Right graphs above and below, abscissa*—the numeric labels of the corresponding behavioral acts (1, 11, turning a head to a pedal; 2, 12, approaching a pedal; 3, 13, stay in pedal corner of a cage; 4, 14, pressing a pedal; 5, 15, approaching a feeder; 6, 16, seizing food in a feeder); *ordinate*—the normalized average frequency of activity in the corresponding acts. *Above* 1, $n = 33$; 2, $n = 33$; 3, $n = 34$; 4, $n = 45$; 5, $n = 33$; 6, $n = 33$; 11–16, $n = 29$ –31. *Below* 1–6, $n = 29$ –31. *– $p < 0.01$; Wilcoxon’s criterion

3 Systems Psychophysiology in World Science

3.1 Transition from Cartesian to Systems Approach

Based on recent theoretical and experimental articles, the following assertions may be made. Neuroscience and psychophysiology are transitioning to a new phase from

Cartesian determinism to systems ideas of activity and anti-reductionism (e.g., [50, 69–86]). This transition is not yet in the mainstream (though, for example, in neuroscience and molecular biology journals the number of articles in which the term “systems” is used has increased by a factor of a hundred), but it is gaining strength and support from authoritative authors.

The present stage, as is usual during a transition from one paradigm to another, is characterized by eclectic expression. The methodological basis of the overwhelming majority of papers reflects a mixture of “activistic” and “responsive” determinism (see [87]).

Systems psychophysiology, having become less eclectic, has essentially outstripped neuroscience and traditional psychophysiology. Empirical regularities that were discovered in systems psychophysiology many years ago have become a subject of close attention of mainstream science only recently. Conceptual transitions, which have already been made or are being made by neuroscience and psychophysiology, largely repeat those undergone by systems psychophysiology (see in [24]).

With respect to the above, it may be asserted that the presence of modern psychophysiology and neuroscience is in the past of systems psychophysiology and TFS. From where did these original ideas emerge? I believe that one of the essential conditions was specifically the culture in which TFS and system psychophysiology were formed.

3.2 Complementarity of Culture-Specific Components of World Science

Science is a part of culture and, along with invariant characteristics reflecting its global character, possesses certain local, national features [76, 88–101]. Certain features characterize not only fundamental, but also applied areas, such as medicine (e.g., radical differences between Western and officially recognized Indian medicine see in [102]).

With respect to cultural influences, we focus upon the specificity of sciences practiced within different cultures, and do not claim a linear causal connection between culture and science, which may be impossible to establish [98]. The true experiment revealing this connection would be difficult. Borders separating science from other components of culture are vague, in particular, because scientific knowledge includes significant volumes of folk knowledge [103].

The diffusion of western science, having its origin in ancient Greece, into western countries was connected with its merging with non-western mentalities, traditions, and language [104], which modified science. Thus it has been shown that in one culture, people can be more inclined to a convergent, and in others, to a divergent style of thinking [101]; (e.g., in Asian and western countries the nature of “probabilistic thinking” differs) [105, 106].

As to language, different languages, within cultures, do not reflect different designations of the same phenomenon, but different visions [92, 93, 107]. Cross-cultural features of thinking and perception have been demonstrated by a large number of works.

Cross-cultural covariance of differences has been demonstrated in language and in cognitive strategies concerning (1) spatial orientation [108], (2) discrimination of object characteristics, including colors [109–112], (3) perception of mimicked emotion expressions [113], (4) risk assessment [114], (5) confidence in the correctness of choices [115], and moral reasoning [116]. It was shown also that native speakers of different languages distinguish different (also in number) fragments during description of the same visual scenes [117, 118]. It has been shown that native English or Chinese speakers solve arithmetic problems using different cognitive strategies enabled by different patterns of brain activation [119–121].

Recently, arguments have been presented in favor of a connection between national features of thinking, culture and politics with local features of different areas of science: natural sciences in general [122], cosmology [123], statistics [124], neuroscience [125], geology and geography [126, 127]. For purposes of our discussion, it is important to underline that a number of authors highlight features of Russian science [89, 91, 94, 95, 97, 98, 100, 128, 129]. I believe “systematicity” and “anti-reductionism” are key among them [96, 130]. Apparently, a detailed substantiation of systemology in Bogdanov’s “Tectology” [131] appeared at the time when the founder of the general theory of systems (Bertalanffy) was only 12 years of age. Similar advances can be noted for TFS. For good reason, the origins of TFS may be linked with formation of the systems approach, which “released biological thinking from the deadlock of Cartesian *mechanicism*, and emphasized that “development of the concept of functional systems by Anokhin and his collaborators, dated 1935, anticipated development of both neuro-cybernetics (Norbert Wiener 1948) and the general theory of systems (Bertalanffy) in 1960” [132, p. 222].

At the same time, Cartesian mechanicism in the natural sciences and social sciences are considered especially characteristic of Western science [76, 98, 99]. Certainly, anti-reductionism can be found not only in Russia:

Eager to study a living subject,
And to receive a clear view of it, —
The scientist first drives away the soul,
Then divides the object into parts
And observes them, but what a shame:

Their spiritual bond
In the meantime has vanished, it was carried away!

One cannot attribute these lines to a Russian mentality. They belong to Goethe. More likely, they can be connected with ideas of German philosophy (and science; see in [133, 134]) whose creators included Goethe’s friends and correspondents

who, as well as Spinoza before (“nature of the part is determined by its role in the whole system”); in Edwards [135, p. 531], considered systematicity the primary characteristic of cognition and viewed knowledge as a system. These holistic ideas, undoubtedly, influenced Russian science greatly. Probably, “German thought and literature of that time had *nowhere* such a deep and powerful response, as in Russia” [136, p. 128].

The protest against mechanicism which “exclusively captivated thought of the West” [89, p. 101], “the revolt against Cartesianism—the foundation and symbol of western thinking—took place namely in Russia” [97, p. 101]. And in Graham’s opinion, the “anti-reductionist approach roots deeply in the history of Russian and Soviet thought” [90, p. 102]. Rose notes: “I have opposed...reductionism of the Anglo-American school...to much more perspective traditions... especially to those originated...in the Soviet Union, (and have given rise to views that) behavior cannot be reduced to a simple chain of combinations of various responses; it reflects goal-oriented activity, hypotheses formulation and many other things” [91, pp. 264, 265]. And, to the greatest degree “in the Soviet psychology and physiology, there exists a special Russian tradition of research interpretation” [90, p. 163]. For instance, a connection to the national style of thinking in Russia with features of mathematics development has been highlighted (progress in theory of sets development; [98]). It was probably Nadin’s definite non-deterministic perspective [137, 138] that explains his interest in the contributions of Russian/Soviet scientists.

The above noted intercultural differences become more evident when taking into account the presence of a significant “non-Western” component in Russian culture, thinking (see in [139, 140] and research results. Nisbett et al. [141], after comparison of cognitive processes in people belonging to non-Western and Western cultures, arrived at the following conclusion: in the former cultures, *continuity* is regarded as the basic property of the world, in the latter, the world is represented as discrete, consisting of *isolated objects*. In the former, formal logic is scarcely applied, but *the holistic approach and “dialectic” argumentation are used*. In the latter, *analytic* thinking is used, *a greater attention is drawn to a separate object rather than to integrity* (see also in [142]). In non-Western cultures, it is considered that nothing in nature is isolated but everything is interconnected, therefore isolation of elements from the whole can result only in delusions. These differences appear in comparison of ancient China to Greece (8th to 3rd centuries B.C.E.) and still persist, characterizing features of modern China and other Asian countries in comparison with the North America and Europe.

In discussing “Western” science, I do not imply, of course, a homogeneity of the West. Consider, for example, comparison of features of German and American psychologies, which led [143] and is leading [134, 135, 144] authors to greater expressions of holism and systems character with the former, and reductionism with the latter (see also above). It may be noted that Toomela [144] attributes Russia for the holistic direction, as well.

It is obvious, that treating concepts of global and local knowledge, “national” and “world” science as mutually exclusive is wrong [145]. I assert that a difference of views in the development of world science is positive. Abelev [88] also remarks

that diversity of national sciences is a major value of world science. Obviously, Berdyayev [146] was right when he claimed that truth is not national, it is universal, but different nationalities disclose its different aspects.

World science can be described as a system consisting of diverse components, in which local culturally specific components are complementary and cooperate in producing useful results: development of global scientific knowledge. This mutual cooperation can be appropriately seen as a “division of labor” in the world science, connected with national features of cultures [96]: systems approach and holism predetermine a greater affinity for working out new directions in science, to “chipping off blocks,” and Cartesian analytism and reductionism—to the matter of breaking “blocks” into pieces, to the detailed elaboration of knowledge and to seeking its practical application.

This approach conforms to the carefully justified position of Kulpin [147], according to whom, in Western civilization, knowledge is connected with practical aims, with market needs, whereas in the Russian civilization, connection with momentary practical benefit is considerably less important; not applied, but theoretical knowledge is much more significant.

Bohr applied the principle of *complementarity*, originally formulated in physics, in discussing relations between cultures. This is interesting because obvious parallels with the above discussed “cultural complementarity” can be seen here. Bohr writes, “We can truly say that different human cultures are complementary to each other.” However, unlike physics, he emphasizes, no mutual exclusion of features belonging to different cultures is observed [148, pp. 49, 129].

Following this logic and bearing in mind the above-mentioned connection between features of language and styles of thinking, it is possible to conclude that confusion between languages among the builders of the Babel Tower not only prevented the building’s construction from being finished, but no less significantly, this plurality of languages enabled the birth and mutual enrichment of world cultures. Thus, confusion between languages is not a punishment of mankind for pride, but the award given to it.

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