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FORMATION AND REALIZATION OF INDIVIDUAL EXPERIENCE

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This article describes the methodological approach of systemic psychophysiology. In the framework of this approach a wide range of experimental data is analyzed: results of neuronal recordings in vitro and in awake normal and pathological animals learning to perform and performing both complex instrumental and simple behavioral acts. Another block of analyzed data is based on experiments with human subjects who learn and perform the tasks of categorization of words and operator tasks, participate in group game activity, and answer the questionnaires of psychodiagnostic methods. As a result of this analysis, the systemic psychophysiology approach is used to describe qualitatively and quantitatively the formation and realization of individual experience.

Discovering the principles of the organization of behavior based on the utilization of experience accumulated by an individual and laws governing the formation of such experience is a multidisciplinary task. It used to be, and it still is a general problem, around which a great part, or even a majority, of specific questions of different sciences are focused. Among these sciences are psychology, neuroscience, developmental biology, genetics, etc. At the same time, the solution of the general problem must be based only on the synthesis of achievements of the mentioned and other disciplines. However, such synthesis is hampered by obstacles resulting from attempts to create a unified description of diverse data, derived from studies in humans and animals, an individual synapse, or a neuron, and a whole organism, complex unlocalized mental processes, and local physiological phenomena. This article was designed to suggest a system of beliefs, based on literature and our own experimental data, within the framework of which the mentioned obstacles may be overcome.

In order to describe the cerebral basis of formation and realization of individual experience (IE), we should, first of all, define the elements of IE (EIE).

Today only a few researchers doubt the statement that the "properties ... of a brain are emergent" and are "systemic," not "just the sum ... of properties" of neurons but a specific quality that emerges as a result of "dynamic interaction" of neurons within a system [46, p. 294]. From the analysis of possible levels of the studies of behavior it can be concluded that the level of "a unified group of neurons" providing a corresponding behavior is the lowest possible (i.e., most elementary) level of analysis where behavior may still be described as an emergent function [22]. In connection with this, the cerebral equivalent of EIE, which is established during the formation of a new behavior and realized during its subsequent performance, may be defined as an organization of a group of neurons composing the corresponding system. Naturally, the question "What do the authors call a system?" arises, and this question must be answered before we can use this understanding of EIE in order to describe the formation and realization of IE.

From our point of view, the most well-developed and noncontradictory version of a systemic approach to analysis of the neuronal basis of behavior is the theory of functional systems elaborated by P. K. Anokhin and his school [19]. The major distinguishing characteristic and advantage of this theory is the definition of a system-creating factor – the result of a system, which is understood as a desired relation between an organism and environment, achieved through the realization of that system. In other words, the principal determinant of a system is an event that is not in the past compared to behavior – a

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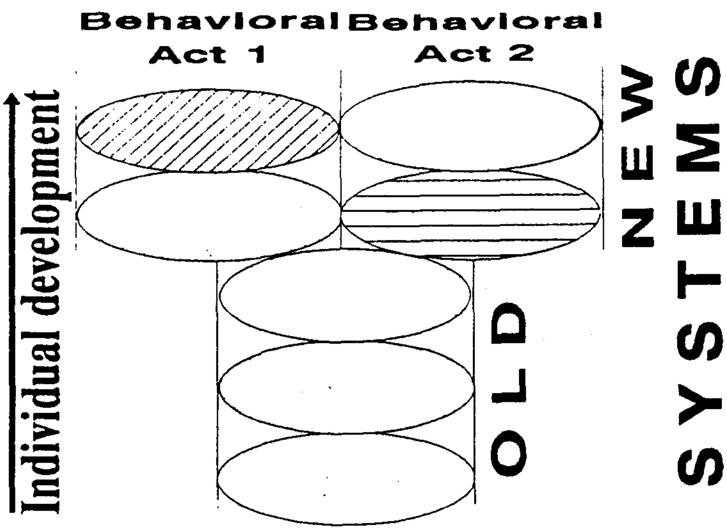

Fig. 1. Systemic structure of behavior. The scheme (see text for explanation).

stimulus, but in the future – a result. Thus a system is understood as a dynamic organization of activity of components with different anatomic localization, the interaction of which takes the form of mutual assistance in the process of providing a result, adaptive for an organism.

It was demonstrated that the mutual assistance during achieving any behavioral result is ensured by uniting synchronously activated neurons situated in different brain structures [52]. Facts confirming this suggestion have been constantly accumulating [24], and are considered to be more and more important for the understanding not only of a definitive behavior, but also of learning as well. The association of synchronously active cells may ensure the achievement of the result even during the first trial acts and serve as a base for further consolidation: "Neurons wire together if they fire together" [54, p. 760].

Besides the aforementioned systemic idea, another important source-concept of the theory of functional systems (1935) was the idea of development (see [49]). Both ideas were merged into the concept of systemogeny which stated that during early ontogeny those differently localized elements undergo selective and accelerated maturation that are essential for achieving the results of the systems, providing for the survival of an organism at the early stages of individual development [19]. Nowadays the idea that many regularities of modification of functional and morphologic characteristics of neurons, as well as of control of gene expression, serving as a basis for the formation of adaptive behavior in adults, are comparable to those found at the early ontogenetic stages becomes a commonly accepted issue [18, 22, 54].

The idea that systemogeny takes place not only during the early ontogenetic period, but also during adult development, because the formation of a new behavioral act is always the formation of a new system, was formulated within the framework of the theory of functional systems nearly 20 years ago [50, 56]. Later it was suggested that the principal aspect of understanding the role of different neurons in the organization of behavior is to take into account the history of behavioral development [8, 9], i.e., the history of successive systemogenies, and the system-selective concept of learning was inferred [51]. The latter concept is in line with the modern ideas of "functional specialization" which substituted the idea of "functional localization" [46], and with the idea of a selective, instead of instructive, principle underlying learning [27]. This concept considers the formation of a new system as the fixation of the stage of individual development – the formation of a new EIE during learning. The basis of this process is the specialization of some "reserve" (silent) neurons, but not the change of specialization of previously specialized units. Thus, the new system becomes an "addition" to existing EIE [51, 53]. The selection of particular neurons from the reserve is governed by their individual features, i.e., by the characteristics of their "metabolic needs" that are genetically determined. Newly formed systems do not replace previously existing ones, but "superimpose" over them: the appearance of neurons with new specializations results in the increase of the total number of units activated in the behavior, whereas the number of neurons with old specializations does not decrease [34, 51]. The suggestions that the number of active neurons is increased during learning, and that learning is accompanied rather by the involvement of new neurons than by "re-learning" of the old ones, has recently been confirmed by other laboratories [23, 63].

What does it mean – "superimpose, but not substitute"? Many experiments in our laboratory have demonstrated that a complex instrumental behavior is ensured not only by the realization of new systems (Fig. 1, New) that were formed during the process of learning of the acts composing this behavior, but also by the simultaneous realization of older systems (Fig. 1, Old) that had been formed at previous stages of individual development. The latter may be involved in the organization of many behavioral patterns, i.e., belong to EIE that are common for various acts (Fig. 1). Therefore, it appears that the realization of behavior is the realization of the history of behavioral development, i.e., of many systems, each fixing a certain stage of development of the given behavior.

These ideas are fundamental for systemic psychophysiology, which suggests the following solution to psychophysiological (mind-body) problem. The organizing of physiological processes into a system is based on specific systemic processes. Their substrate is physiological activity, whereas their informational content is psychical. In other words, psychical and physiological are different aspects of consideration of the same systemic processes [53]. From this point of view, mind may be considered as a subjective reflection of the objective relation of an individual with the environment, and the subjective world – as a structure represented by systems that were accumulated in the course of evolutionary and individual development; relations between these systems (intersystem relations) may be described qualitatively, as well as quantitatively. The range of problems of systemic psychophysiology includes studies of formation and actualization of systems, which are EIE, studies of their taxonomy, and dynamics of intersystem relations in behavior and activity. Thus, it may be inferred that the investigation of formation and realization of IE is the task of systemic psychophysiology; it should be carried out at different levels, ranging from cellular and subcellular to complex human activity.

Individuality of a Neuron

As was noted above, the system-selective concept of learning is based on the following suggestion: neurons are originally diverse in their genetic and, consequently, metabolic properties, and, during learning, neurons with only specific properties are involved. The stability of these properties was demonstrated in experiments with completely isolated nervous cells by using methods of mechanical and enzymatic treatment.

While working with isolated neurons, it has been found that cells retain specific characteristics of background activity that they used to have in the nervous system. So, Alving [17], using the mechanical method of isolation, demonstrated that the spontaneous electrical activity of isolated nerve cells, which she registered before the isolation, stayed similar. Chen et al. [25], using the enzymatic treatment, found that completely isolated identified neurons maintained, after the procedure of isolation, the main electrophysiological characteristics such as the level of membrane potential, rhythm, and patterns of pacemaker spontaneous and elicited activity. The chemosensitivity was also stable after the isolation: the isolated neurons were characterized by chemosensitivity to those neurotransmitters that were effective before isolation. Our experiments were performed on the completely isolated neurons of the snail *Helix pomatia*. These results have confirmed the stability of electrophysiological individual characteristics of identified cells. Not only background activity and chemosensitivity were found to be stable but also the similarity of dynamics of neuronal plasticity [38]. So, from the comparison of these individual characteristics of the same cells in vitro and in vivo it can be concluded that the analyzed properties of adult animals are stable.

Culturing of identified isolated neurons in vitro and analyzing their properties after involvement in forming the new neuronal nets lets us determine if these properties stay stable in such a new neuronal organization. Syed et al. [57] used cultured neurons of *Aplysia* which formed new interneuronal connections. During these experiments the authors tried to describe modifications of the neuronal electrophysiological characteristics, but there were no such modifications elicited by the procedure of culturing or axonotomy; the main parameters of electrophysiological activity were constant. It is necessary to note that each neuron formed new synaptic connections which were similar to those functioning in vivo.

Close results were obtained in two artificial neuronal nets: respiratory and motor. In the latter the transformation of action potential was explored in the course of associative learning. These modifications were similar in the experiments in vivo and in vitro.

Stability of individual properties of neurons was found in the neurotransplantation experiments. The stability of structural, intrinsic neurotransmitter and electrophysiological characteristics of transplanted nervous tissue was also shown [60].

These findings, proving the stability of individual properties of a neuron, support the beliefs about the regularities of learning suggested by the system-selection concept.

Result of Behavior as a Determinant of Formation of Individual Experience

Within the framework of this approach, the specialization of neurons is considered as a systemic one instead of "sensory" or "motor." Thus, we assume that even in conditions of "sensory deprivation," for example cessation of contacts with visual environment, neuronal activity in "visual" structures is necessary for achievement of results of behavior. Indeed, it was found that the activity of neurons in the visual cortex, retina, and lateral colliculus [9, 14] is related to the realization of food-procuring behavioral acts in animals both with "open" eyes and eyes shuttered with light-tight covers. According to the same logic, it should be assumed that during formation and realization of behavior under "motor" deprivation and even in the combination of "sensory and motor" deprivation, the activity of neurons is related to the realization of systems aimed at reaching the results of behavior as well. This is determined by the fact that if an animal restricted to move voluntarily nevertheless is able to reach some behavioral results during passive displacements within an experimental area, then a specific IE is formed, which corresponds to this behavior in freely moving animals, and this means that neurons specialized in accordance with the elements of this IE can be found.

The last assumption was tested in experiments [32, 33] with single unit recordings of CA1 complex-spike cells in awake rats slightly restrained in a sling and displaced on a computer-driven robot. The rat was displaced within a square arena (3 m × 3 m) from one corner to another along the walls and diagonally. A drop of water was delivered (as a "reward") every time the rat approached one of the corners which remained the same throughout the whole experiment from training to definite behavior under investigation. We found that about half of the neurons increased their firing rate significantly while the rat was passively transported in particular parts of the arena, though these neurons had "spatial specificity" of low resolution, i.e., their "firing fields" were larger compared to the results obtained in freely moving animals [47, 48]. Some of these neurons maintained the same spatial selectivity of discharges when the rat was displaced on the robot in total darkness.

These results could be interpreted from the positions of the current dominant views about the hippocampus as a pivotal structure for the formation of a high-level representation of space on the basis of convergence of multimodal sensory information [47]. From our point of view, these data could be considered as support for the idea of the determinative role of results of behavior in the formation of the elements of IE. Then, the representation of space is considered as a reflection of the environment divided into elements according to the results achieved in this environment ("space of results") on the basis of some sensory "modalities." Formation of this representation is formation of EIE. This also means that the existence of various spatially selective neurons which are active when the rat approaches one of the corners independently of the direction and speed of passive displacements (i.e., independently of different means of attainment of the animal's contact with a particular place of the arena) is due to the fact that this place is in a constant spatial relation to that corner in which the animal was "rewarded" with water. Disappearance of specific activations in hippocampal neurons when a restrained rat was placed inside the "firing fields" of these neurons, i.e., into the parts of the arena in which these neurons had increased discharge activity when tested in freely moving rats [30], appears to relate to the change in the character of behavior from food-procuring to a defensive one, and, hence, the other set of elements of the IE is involved in the realization of this behavior. A behavior context dependence for spatial selectivity of discharges of the hippocampal neurons was shown earlier by Alexandrov et al. [13] and Wiener et al. [62].

Thus, the results support well the assumptions stated above. Apparently, even in restrained animals passively transported within the "space of results" consisting of objects used for satisfaction of different needs of the animal, the activity of neurons is related to the realization of EIE which reflect the subjective "division" of the environment in accordance with the results achieved in this environment. This is similar to what was found in freely moving animals, though the structures of IE (both the set of elements and the relationships between the elements) in these cases are probably different.

Learning History and Systemic Organization of Behavior

From the suggestion that the structure of IE is determined by the history of its formation, one may suppose that systemic organization of the same behavior, formed by different learning strategies, is different because the different history means the formation of different IE structure. The role of learning history was demonstrated in our experiments. Rabbits were trained on food-procuring behavior in a cage with two feeders and two pedals at the corners (scheme, Fig. 2). At the moment, only one pedal was effective – pressing that pedal switched on a feeder disposed along the same wall. Two different strategies were used during the training of the animals. The animals of one group were trained to execute the whole behavioral cycle

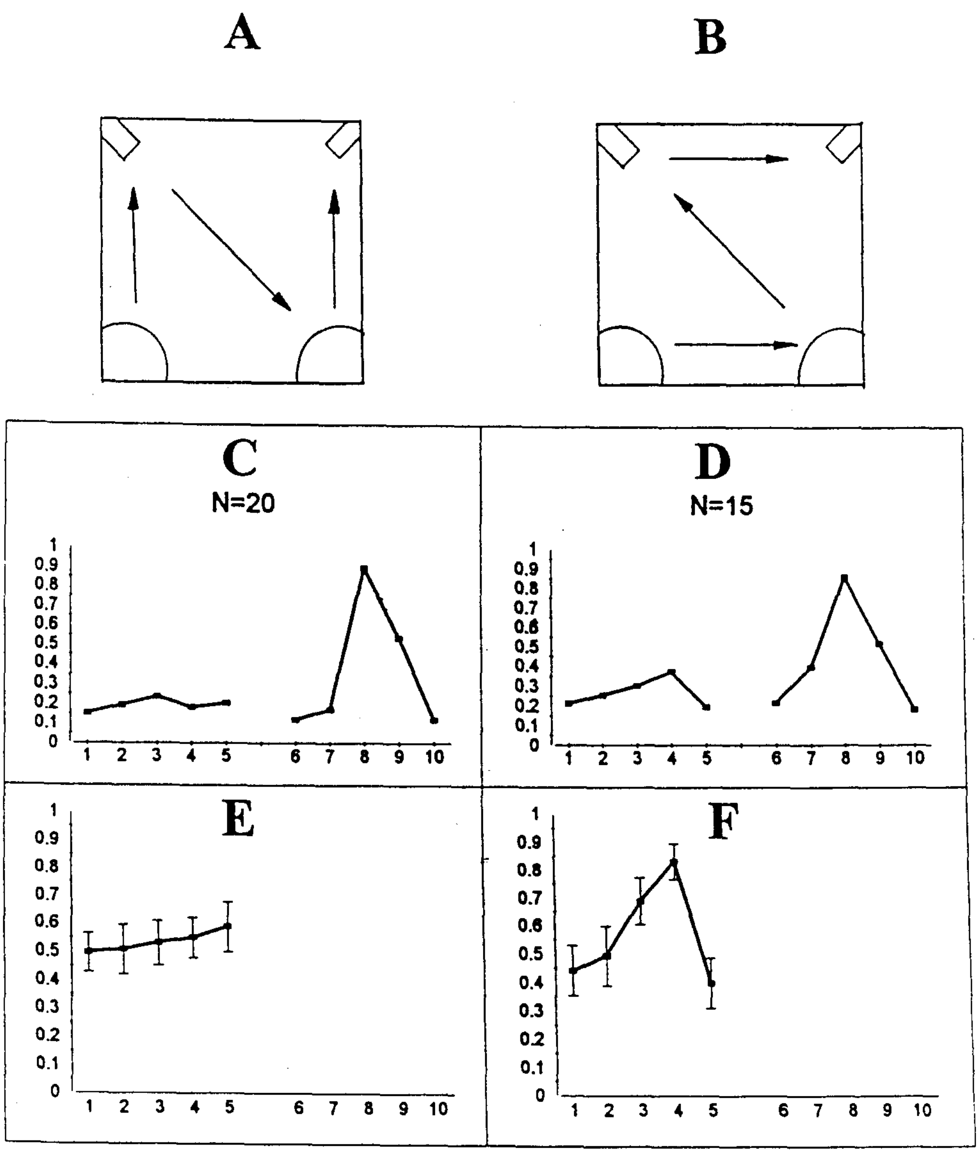

Fig. 2. Activity patterns of limbic cortex neurons as a function of learning strategy. A, B) Schemes of learning strategy; the arrows show the sequence of forming of behavioral acts. C, D) Collective activity patterns of neurons, specialized relative to approaching the first (C) and second (D) pedals in the training sequence for rabbits trained by strategies A and B, respectively. Along the abscissa) numbers of the behavioral acts; along the ordinate) averaged frequency of the activity, normed with respect to the frequency of impulse activity in the specific act. E, F) Collective patterns of nonspecific activity, normalized with respect to its maximum, for groups of cells represented in parts C and D, respectively.

along one wall of the cage (pressing the pedal, coming to the feeder and seizing the food, pressing the pedal, and so on), then along the other wall. The animals of the second group were trained to obtain food from one feeder, and then from the other; to press one pedal, and then to press the other one [35-37].

In this behavior the neurons that showed activation, for example during a given movement in any situation, were considered as specialized relative to old systems. The cells, whose activation was permanently and selectively related, for example to approaching and/or pressing a pedal, were considered as specialized relative to new systems acquired by a rabbit during training in the experimental cage. In the activity of such neurons a "specific" phase was distinguished – expressed activation; it appeared during that behavioral act, in relation to which this neuron was specialized. This activation was usually several times greater than the "nonspecific" activity of this neuron, which was recorded during other behavioral acts and which, unlike the specific, was much more variable and did not appear in 100% of the cases. Earlier we have shown [35] that systemic specialization of a neuron is its permanent characteristic. That is why neuronal activity can serve as an index of specific EIE actualization [53], and "nonspecific" activity of a neuron may indicate the specific system retrieval from memory during performance of other behavioral acts. Thus, studies of the activity of system-specific neurons during cyclic food-procuring behavior may reveal the relations between the specific system and other functional systems of analyzed behavior. Thus, the observed intersystem relations give a representation of IE structure acquired by learning.

The reflection of the learning history in patterns of specialized neuron activity was studied in experiments with registration of the activity of limbic cortex neurons (area retrosplenialis) in rabbits. The averaged frequency of activity and the activation probability were calculated for each behavioral act. Each of two behavioral cycles (along a concrete wall of the experimental cage) was divided into five stages (behavioral acts): seizing food in a feeder, turning a head to a pedal, approaching a pedal, pressing a pedal, approaching a feeder. So, all food-procuring behavior in the cage consisted of ten stages: 1st-5th on the left side of the cage and 6th-10th on the right side. For each stage we have defined the mean frequency of neuronal activity during the time of its registration; the distribution of frequencies form a pattern of neuronal activity in behavior (Fig. 2).

For the further analysis we selected neurons specialized relative to new systems of the acts of approaching and/or pressing pedals ("pedal" neurons), as well as the acts of approaching and/or seizing food in one of the feeders ("feeders" neurons). Comparison of the activity patterns of neurons with similar specialization showed that their nonspecific activity differed greatly (Fig. 2C,D). However, the distribution of frequencies was not random. There was additional activation of the neurons, specialized relative to the second (in accordance with the order of training) pedal when the rabbit pressed the first one. Supplementary analysis by normalization of the nonspecific activity frequency with respect to the maximal frequency of activity among nonspecific acts (Fig. 2E,F) allowed us to relate the appearance of this activation to a definite strategy of training. It appeared only when the formation of corresponding acts, related to the first pedal, directly preceded the formation of the acts of approaching and pressing the second pedal in the history of training. Thus, among the systems of behavioral acts formed during training sequentially one after another and performed by an animal at the different sides of the cage, we found facilitating intersystem relations manifested in a raised degree of actualization of later formed system while an animal performed the previous one. Achievement of an act's result is provided by realization of specific EIE as well as others. Whereas the specific EIE are realized in the act in all cases, the probability and degree of actualization of nc.ıspecific ones are considerably less.

A similar phenomenon was found for "feeder" neurons as well – in the nonspecific activity of cells specialized relative to the second (in the order of training) feeder, an additional activation was detected. Where exactly this activation appeared – during approaching and pressing a pedal at the other side of the cage or during seizing of food from the other feeder – depends on the strategy of training, i.e., which act preceded the specific one (for this neuron) in the animal's training.

The obtained data confirmed the assumption that the IE structure and, consequently, the system organization of behavior, in which this IE is actualized, are determined by the history of this behavior forming.

"Projection" of the Individual Experience onto the Brain Structures and the Possibilities of its Modification

Spinelli obtained impressive data proving the dependence of cortical projections from peculiarities of IE: it was shown that when kittens were trained to move the front paw in response to stimuli with a certain orientation, the area of representation of this paw in the somatosensory cortex was significantly increased as compared to the control animals [55]. Later it was demonstrated that the steady reorganization of receptive fields corresponding to the characteristics of detected objects was induced by learning in adults as well [58]. Analysis of the literature leads to the conclusion that receptive fields and cortical maps may be modified "at all times between conception and death" [61, p. 549], though magnitude of these modifications may differ. For example, it was shown that cortical representation of the fingers of the left hand in strings players was increased as compared to control subjects, and the increase was greater the earlier a subject started learning to play [29]. Traumatic influences, such as amputation of fingers, which forced animals to reorganize their behavior, also induced receptive field modifications and corresponding changes in cortical maps (see review [61]).

Analysis of the results of our many experiments allowed us to conclude that testing of receptive fields of neurons reveals their involvement in subserving these or those behavioral acts [8, 14, 52]. Taking this conclusion into account, it is possible to consider the aforementioned literature data as support of the postulate that the projection of IE to brain structures in animals and humans changes in the course of individual development, and depends on its characteristics.

The study of IE projection to brain structures in the framework of the authors' views implies the comparison of patterns of systemic specialization of neurons belonging to these structures at different stages of individual development in normal and pathological subjects. The pattern of specialization of neurons within the given structure is defined according to the set of systems with respect to which units of this structure are specialized and according to the quantitative relation among neurons belonging to different systems. Comparison of the specialization patterns of neurons in the rabbit's limbic and anterolateral motor cortex at successive stages of learning instrumental behavior revealed that the patterns were changed differently in the studied cortical areas [34, 51]. The change was due to the appearance of a new group of active neurons specifically related to the behavioral act after learning it (e.g., pressing a pedal). The number of such new units in the limbic cortex was significantly greater than in the motor one. Thus the resulting specialization pattern of neurons in these structures was entirely different (Fig. 3, Control): the limbic cortex, as well as hippocampal CA1 and DG, acquire significantly more neurons with new specializations than motor cortex. Recording of unit activity in many cerebral structures during instrumental food-procuring behavior, carried out in our laboratory, demonstrated that, generally, neurons with new specializations were abundant in the cerebral cortex (though different cortical areas may vary with respect to this parameter), whereas phylogenetically archaic and peripheral structures had very few of them, if any (see [8, 53]). It is reasonable to assume that the specificity of IE projection to cerebral structures is determined by the particular characteristics of neurons composing these structures. These characteristics determine the involvement of neurons of the given structure in the formation of the specific behavior.

Can anything besides normal learning cause the change in IE projection? We found that after the recovery of instrumental food-procuring behavior in rabbits that was impaired due to bilateral damage of visual cortex, the pattern of neuron specialization in the motor cortex was changed: the percentage of neurons specialized with respect to new systems increased [10]. Conversely, after acute ethanol administration the portion of active "new" (New) neurons decreased, however not in the motor cortex [12] but in the limbic structures (Fig. 3, compare Control and Ethanol) [11, 13]. This effect is due to selective suppression of the activity of neurons belonging to new systems, especially cells located in the upper (II-IV) cortical layers. A similar increase in sensitivity of relatively new EIE was also found at early ontogenetic stages – in altricial nestlings at the stage of formation of natural behavior [7].

In order to test the hypothesis that the age of EIE actualized during behavior realization is one of the major factors determining the effects of ethanol in humans, we compared the impact of ethanol on event-related potentials (ERP) accompanying actions requiring the use of knowledge that subjects acquired at earlier and later stages of individual development: at the time of acquisition of native and foreign languages, respectively [16]. Considering the results of our previous studies which demonstrate the selective influence of ethanol on neurons belonging to newer EIE, we conclude that the basis of the differential influence of ethanol on EIE of different ages is its more marked effect on those neurons that subserve actualization of IE, accumulated by subjects at relatively late stages of individual development.

In the case of acute ethanol effect we deal with reversible changes of IE projections. In the case of chronic alcoholization (2.5-3 and 9 months), as in the case of local brain damage, these modifications appear to be irrevocable. We found that the main target of the damaging impact of chronic alcoholization are neurons belonging to new systems, neurons localized in those layers and areas of the brain that are most susceptible to acute ethanol administration. Because of these cells, the numerical density of cortical neurons decreases, and the specialization pattern changes. In the limbic cortex, the quantitative relation between neurons belonging to new and old systems is reversed as compared to the healthy animals: after 9 months of alcoholization, neurons belonging to old systems dominate in the population [15].

Thus, the projection of IE to cerebral structures depends on the specific characteristics of neurons in each structure, is determined by the history of learning in the course of individual development, and is modified under pathological conditions.

From an Animal to a Human Being – a Systemic Perspective

One of the major targets of studies of the cerebral basis of formation and realization of IE in animals is to formulate principles that can be applied to human studies. However, serious methodological problems arise here [26]; one of them is the notion that such principles may significantly differ in humans. That is why Tulving [59] postulates the inadequacy of data obtained in animal studies for the investigation of specifically human functions such as the use of language. We do not oppose the specificity of human experience and understand the necessity of its analysis. However, we think that the aforementioned

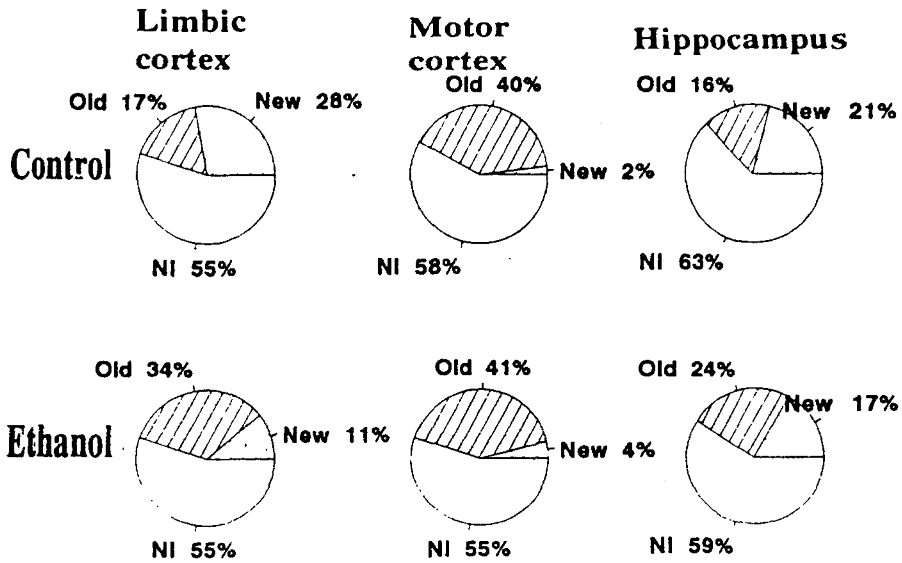

Fig. 3. Relative number of new (New – belonging to new systems formed in rabbits during the learning process in the experimental cage), old (Old – belonging to systems formed at previous stages of individual development), and noninvolved (NI – displaying no activations in a constant relation with this or that stage of behavior) neurons in the limbic, anterolateral motor cortex, and hippocampus in control (Control) experiments and after acute alcohol administration (ethanol, 1 g/kg, i.p., ethanol).

radical point of view, accepted by many scholars, is rooted in structure-functional concepts that correlate activity of cerebral structures with the performance of specific functions, such as sensory processing, generation of motor programs, construction of cognitive maps, etc. Then it follows, quite naturally, that in animal experiments it is impossible to study those specific functions that are not linked to underlying special structures and mechanisms. From our point of view, neuronal activity is related to the realization of systems that are subserved by units with different anatomic localization and that, being different in the level, intricacy, and quality of the result achieved, conform, nevertheless, to common principles of systemic organization. Discovery of these common principles is one of the goals of any systemic study in general, and of systemic psychophysiology, in particular [14, 19, 52]. That is why systemic principles revealed by studies of unit activity in animals may be applied to develop the views about systemic mechanisms of IE use in various forms of human activity, for instance, in the aforementioned task of categorization of words of native and foreign languages, as well as in operator tasks, in group game activity, and in answering questionnaires for psychodiagnostic research (see below).

Obviously the most adequate method to study human IE, enabling the direct description of taxonomy and relations among elements of experience, would be an analysis of the dynamics of activity in neurons specialized with respect to systems of different ages [53]. However, due to ethical and methodical reasons, the most widely used method of investigation of human cerebral activity is still EEG analysis, along with other methods of brain mapping. V. B. Shvyrkov substantiated, theoretically and experimentally, the suggestion that the components of ERP correspond to neuronal discharges and to dynamics of systemic processes at successive stages of behavior realization, including transitional processes ensuring the change of behavioral acts in the continuum, and that brain potentials cannot be classified as sensory, motor, cognitive, etc. [52]. The development of these views helped to reveal that different ERP are just fragments or variations of averaged potential, corresponding to realization and change of behavioral acts [43]. The relationship of neurons of different systemic specialization to EEG waves was also demonstrated [31]. Within the framework of our views, information on the relationship of EEG and unit activity to the dynamics of systemic processes derived from animal experiments may serve as a foundation for using the recordings of gross electric brain activity to study the principles of IE formation and realization in humans.

Manifestations of Individual Experience Dynamics in the Waveform of Event-Related Brain Potentials

A number of studies analyzing the correlation between the ERPs and various aspects of behavior have provided a considerable body of factual evidence. However, the significance of the ERPs as a tool in psychophysiological research on behavior is a widely debated topic (see, e.g., [41]). It can be argued that the most appropriate way to resolve the matter is to examine the ERPs with respect to (1) the activity of units related to certain EIE, and (2) the dynamics of IE inferred from observable behavior.

In the signal detection task, human ERPs identified by traditional means were compared with their analogs in rabbits. The similarity of the temporal structure of behavior in humans and animals enable us to apply the data on the activity of specialized cortical units and to interpret ERPs in humans in terms of the IE dynamics. The behavior of human Ss and animals was considered as a sequence of two acts ("waiting for a signal" and "report") maintained by two diverse sets of EIE. During implementation of the "waiting" act the proportion of units specialized with respect to the act increases towards the result achievement. The transition from the "waiting" to the "report" act coincides in time with concurrent activations of units related to the preceding and following acts. Furthermore, the transformation of the sets of active units is in accordance with the ERPs accompanied observable behavior: the negative-going shift corresponds to the growth of proportion of active units specific to the implementing act, whereas the high amplitude positivity corresponds to the overlapping of activations of units related to successive acts [3, 4].

Reviewing the ERP literature along lines of the mentioned findings we have conceptualized that the slow negative wave and the following high-amplitude positivity are the basic components of a unified potential accompaning Ss' behavior in different experimental paradigms as well as the behavior of animals of various species [43]. It is necessary to note that these components may be conventionally labeled as the CNV-P300 complex, or the readiness potential-motor potential complex, etc. Thus, if S performs a task as a succession of two behavioral acts, then the unified biphasic waveform of potential will be recorded. Therefore, one can state that the unified ERPs' waveform manifests successive stages of transformation of EIE sets underlying ongoing behavior: the negative component represents result-oriented growth of the set's consistency, and the positive component represents decrease of the set's consistency. This outlook permits one to extend the range of the ERPs applicability in the psychophysiological study of behavior up to human voluntary activity. Clearly, the perspective must be provided by a formal description of overt behavior as well as of IE dynamics.

Within this framework, overt behavior and the IE dynamics in correlation with the ERPs were analyzed in Ss engaged in a strategic game with full information and zero sum of two players. Tic-tac-toe on a gameboard of 15 $\times$ 15 was employed as an experimental paradigm [2, 5, 44]. The player's act of the game was defined as the interval between two successive moves of his opponent. The formal description of the act of the game included numerical indices of three successive situations on the gameboard: (1) before and (2) after the player's move; (3) after the return move of the opponent. Acts of the game with identical numerical indices were assigned to the same type. Then the protocol of the game as serial moves of two players was transformed into two protocols of individual behavior of players as serial acts of the game. Stable sequences of 2-7 acts of the game were considered as strategies. Logically, protocols of individual behavior served as a basis for formal description of the player's IE the structure components of which represent the acts of the game and the strategies connected by particular kinds of interrelations.

To select the best description of the IE structure and dynamics, different multiple regression models of the move choice time were compared. The results of the modelling can be explained as follows. After the player's move, alternative IE sets, representing all the likely acts of the game after the opponent's anticipated moves, are actualized concurrently. The player's move rejects actualized IE sets that are in contradiction to the actual situation. At that moment the IE sets, opposed rejected ones are actualized and influence the decision-making, but they are never observed in overt behavior.

The implementing of the act of the game is in close correspondence with the ERPs of the unified waveform: the slow negative shift coincides with the move's choice interval, and the positive wave of high amplitude persists up to the return opponent move. The slow negativity is assumed to correlate with the transformation of the EIE set initial for the move's choice, that is, rejection of alternative components and change of their interrelations. Fragments of the negative wave reflect consecutive stages of the selection of the EIE set specific to an actual move. Correspondingly, the high-amplitude positive potential reflects the actualization of the EIE sets providing all the player's actions possible after all expected return moves of an opponent.

To estimate the extent to which amplitudes of ERPs are determined by the dynamics of EIE, a backward stepwise multiple regression procedure was applied. The maximum amplitudes of raw negative and positive potentials recorded in the playing Ss were used as the dependent variables. The parameters of the EIE (the number of components representing the acts of the game, strategies, the entropy of the components' sets, the indices of their interrelations, etc.) at the corresponding intervals were used as the independent variables. Simulation revealed that nearly 40% of the variance of the ERPs' amplitudes can be explained by the EIE dynamics [6]. Thus, the assessment can be considered as very similar, taking into account that a significant part of the ERP amplitude variance should be referred to postural control, vascular and metabolic aspects of the neural tissue activity, etc.

The remarkable aspect of the data was that players master the game while they continue to play [2, 44]. The total number of acquired IE components is well fitted by a power function of the number of performed moves. In the main, the results imply that the rate of acquisition of the new IE components can be assessed as an exponent of a power function: for the acts of the game and strategies it is less than 1; for interrelations it is significantly greater than 1.

It is our viewpoint that ERPs may serve as indicators of EIE dynamics in the course of its forming and realization.

Dynamics of ERP Characteristics and Intersystem Relations during Skill Development

With repeated performance of behavioral acts, the subjects master their performance [1], i.e., they achieve the ability "to bring about some end result with maximum certainty and minimum outlay of energy, or of time and energy" [39, p. 136]. The transformation of the ERP components accompanying the stages of mastering of behavior [40] can be considered as an indicator of the changes of relations among EIE ensuring this behavior. Hence, the ERP dynamics in the course of improving of behavior allows one to investigate the modifications of intersystem relations.

In our study the subjects were employed in the choice reaction time task which demands prolonged training and, therefore, allows us to investigate changes in ERPs at successive stages of perfection of performance in detail.

In the first series of experiments the subjects were presented equiprobable alternative visual signals in random order. Their task was to release a home button and press a report button corresponding to a signal presented as quickly as possible.

One can recognize at least two steps by which the changes in ERPs proceeded. In the first stage, these changes appeared both in the frontal and parietal ERPs corresponding only to quick and correct report acts related to a given signal, whereas there were changes only in the frontal but not in the parietal ERPs related to the other reports. In the next stage, the frontal ERPs maintained their changed shape during further training; report time became shorter; erroneous reports decreased; and the shape of parietal ERPs became similar to that of frontal ERPs [20]. We propose that these changes, indicating the perfection in the Ss' performance, are related to the changes in the well-known sequential effects.

The second series were based on the assumption that each current report in this task was influenced by the preceding ones, and these sequential effects were reflected on the ERPs and, particularly, on P300. The Ss had to release the home button and press the button corresponding to one stimulus after its onset (Quick-go) and the button corresponding to another stimulus after its offset (after 900 ms, Delay-go) as quickly as possible. The ERPs related to these reports are distinguished by their P300; especially the mean amplitude and peak latency of P300 corresponding to Delay-go reports are significantly larger than the ones of P300 corresponding to Quick-go.

In the initial stage of the experiment there were the sequential effects both on amplitude and latency of P300. In all the Ss the P300 amplitude increased when it was related to the report preceded by the Delay-go report, and it decreased when it was related to the report preceded by the Quick-go. In four Ss the P300 latency decreased, and in two Ss it increased when the preceding report was alternative to the present one. In the second stage of the experiment the mean report time became significantly shorter, and erroneous reports disappeared. The P300 latency became independent of the preceding report and corresponded to the report form. The P300 amplitude continued to depend on the preceding report. In the third stage of the experiment the report time became more stable, and there were no sequential effects on the amplitude and latency of P300.

Taking into account the suggestion that the P300 amplitude reflects the readout from memory EIE related to a current act [33,43] and on the basis of the obtained data, one can make the following conclusions. In the course of perfection of the tasks under study, the number of EIE actualized in a current report was reduced at the cost of the "inhibition" of active EIE possessed by the preceding response. This perfection was also accompanied by fixation of particular timing of EIE realizations in the report act. It is possible that the changes in the parietal ERPs reflect the processes which belong to the later stages of perfection whereas processes reflected by the frontal ERPs belong to the earlier ones. Inasmuch as the representations of new EIE prevail in the structures whose activities are reflected in the frontal derivations (see [20]), one can propose that the relations among these EIE determine considerably the perfection.

Structure of Individual Experience in Diagnostics of Personality

In the framework of the suppositions presented above some light can be shed on the key aspects of the problem of description and diagnostics of generalized characteristics of individuality. According to the generally accepted notions, an individual peculiarity of a person can be considered as a generalized characteristic only at a certain (high) level of constancy in which it is possible to differentiate two interrelated facets: stability and consistency [45].

The first aspect refers to the temporal constancy of the demonstrated characteristics of individuality. The higher the temporal stability of the individual peculiarity, the higher the probability that the given characteristic belongs to the class of essential features of the individuality. Under a high level of temporal stability individual specificity reflects the most stable components of the IE structure, as well as the strongest relations among them.

The second (more important) facet of constancy – consistency – is connected to specificity of manifestation of an individual characteristic in different situations of interaction with the environment, i.e., in different behavioral acts relevant to this individual characteristic. A high level of consistency of individual peculiarity reflects the specific organization of the generalized experience of coping with the environment. This experience is formed in ontogenesis on the basis of inborn dispositions [21]. The higher the consistency of a characteristic of individuality, the higher, as a rule, is its stability (temporal constancy). The higher level of consistency testifies to the larger expression of a trait of individuality. The emergent nature of their genetic determination was shown for many consistent individual characteristics [42].

Widespread methods of diagnostics of individuality characteristics by means of questionnaires simulate the prototype situation of consistency evaluation of individual characteristic by presentation of items, representing typical situations in which this characteristic can manifest itself. The leading factor that mediates the subject's response selection in personality questionnaires is the structure of the IE as a whole, as well as the experience, related to a subject's evaluation of his/her behavior.

One of the experimental methods, which permits one to modify the structure of the actualized IE, is acute alcohol consumption, which, as we showed, oppresses the activity of new EIE (see above). This characteristic of alcohol allowed us to use it as a methodological mean, which ensures selective inhibitory influences upon some EIE which determine the manifestation of consistent characteristics of individuality.

Computerized versions of the Pavlovian Temperamental Survey, the NEO Five Factor Inventory, and the Structure of Temperament Questionnaire were administered to a sample of subjects. The experimental group of subjects consumed alcohol (1 ml/ kg) before performing the test battery. The control group of subjects completed the tests after receiving an equivalent amount of nonalcoholic liquid. We have found that alcohol does not cause essential change of mean values of scales related to generalized characteristics of individuality. The structure of relations among characteristics does not change significantly. However, the revealed change in the mean value of one of the characteristics ("Conscientiousness" from the NEO Five Factors Inventory) can be explained by the supposition that new EIE in a greater degree are reflected in this characteristic. Under the influence of alcohol, changes in the proportion of preferred variants of responses (matrices of responses) for some test items were detected. It was assumed that in this type of items new IE was actualized to the greatest extent. For a large number of test items of multivariant type, reduction of the latent periods of responses was observed under the influence of alcohol. We assume that inhibition of intersystem relations (formed between EIE, which are associated with different variants of responses) plays the leading role in this reduction.

Test items are selected by the authors of personality and temperament questionnaires on the basis of hypothetical (mainly, intuitive) beliefs about the manifestation of individuality characteristics in different behavioral situations. In the framework of our approach the role of EIE of different ages can be revealed in separate responses to test items of personality questionnaires. Thus, not only features of the structure of IE that mediate individual differences revealed by these questionnaires can be analyzed, but also new methods of test item generation can be designed that are addressed to the EIE formed at different stages of individual development.

Conclusions

To describe the system of views underlying systemic psychophysiology, data obtained in the studies of unit activity in vitro and in awake normal and pathological animals learning new behavior and realizing the previously learned one (both complex instrumental behavior and simple acts) were analyzed. Also, an analysis was conducted on data from experiments with human subjects who learned and fulfilled tasks of word categorization and operator tasks, performed group game activity, and answered questionnaires for psychodiagnostic study. As a result of this analysis, qualitative and quantitative descriptions of principles of formation and realization of individual experience are suggested in the framework of a unified methodology. From the point of view suggested by the authors, the development of a new system – systemogeny – is considered to be the fixation of a stage of individual development, and the performance of a behavior is a simultaneous realization of many elements of individual experience formed at different stages of individual development. The dynamics of formation and actualization of the structure of individual experience is revealed; the interrelationship between elements of individual experience in different forms of behavior and at different stages of its formation and realization are shown.

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