Anticipation and the Concept of System-Forming Factor in the Theory of Functional Systems

Alexander Saltykov, Sergey Grachev

I.M.Sechenov First Moscow State University, Moscow, Russia
absaltykov@yandex.ru

Abstract. The problem of anticipation is approached in P.K. Anokhin`s theory of functional systems on the basis of a consecutively generated step-wise predictive model (afferent synthesis, decision-making, acceptor of result), which determines the formation of any functional system. In this process, the adaptive result is considered to be a universal system-forming factor. On the other hand, the concept of the system-forming adaptive result poorly agrees with the key role of anticipation in the genesis of functional activity, and necessitates the distinction of several system-forming factors. Anticipation (as the goal of action) is such a factor for complex forms of conscious behavior in animals and man. In other cases, anticipation forms no functional systems, although it participates in their realization and function. For example, genetically determined systems (including congenital forms of behavior) are formed through mutations; conditioned reflexes – due to a primarily accidental achievement of adaptive result, etc. Clarification of the role of anticipation in the genesis of functional systems eliminates internal inconsistency in Anokhin`s theory and facilitates its use in biomedical sciences.

Keywords: anticipation, theory of functional systems, system-forming factor, result of activity

1 Introduction

In the preface to the second edition of a fundamental treatise on anticipation, there is an interesting passage [1, p. xiii]: “The final ground-breaking aspect of this book is that it realizes, within the fundamental theory being developed here, that the similarity between life and mind is simply that both are anticipatory systems”. Anticipation is indeed a central feature of living organisms. In the framework of systemic approaches most generally, this is explained first of all through organisms’ sensitivity to external influences and through the potential unsteadiness of their state. The ability of living systems to change their condition according to expected biologically significant events is one of the most important mechanisms that counteracts their disintegration. This ability is based on the forecasting of and preparation for forthcoming events, i.e., on processes which are embraced by the term “anticipation”. It`s considered that anticipatory systems contain predictive models of themselves and their environment, and that they employ these models in controlling their present activities [2].

Since the mid-20th century, the study of the biomedical aspects of anticipation was pioneered by the theory of functional systems (TFS) developed by P.K. Anokhin [3-7]. As a concept, the TFS dates back approximately to 1932-1933, and it was formulated in its sufficiently mature form in 1935. This occurred on the background of a re-examination of reductionism in natural sciences and medicine during the initial, formative period of general systems theory and cybernetics. In comparison, the term “systems theory” was first used by L.Bertalanffy in lectures delivered at the university of Chicago in 1937-1938 (published between 1947-1950), and N.Wiener`s book “Cybernetics” was published in 1948 [8].

In the framework of TFS, the principles of Bertalanffy`s general systems theory and W.B. Cannon`s conception of homeostasis were consolidated and developed in a new direction on the basis of biocybernetic notions [9, 10]. In this regard, Anokhin`s works were pioneering in the world in their description of reverse afferentation (cybernetic biofeedback), significantly antedating the formation of cybernetics as an independent science [11-13]. The biocybernetic approach of functional systems permitted to formulate a revolutionary idea: the key feature of any living system is the efficient activity of its components (their function), and not their structural organization. According to Anokhin, it’s the functional interaction, including informational interaction of its anatomical components, that determines the structural organization of a living system. The functional principle of selective structural mobilization is always dominant over the structural organization, and accordingly any “true” system in the organism is essentially functional in its nature. In other words, the TFS advanced a principled functionally oriented approach in contrast to the dominant structural approach (to the nervous system, muscular system, etc.) of the reductionist biomedical sciences of the time.

Another distinctive peculiarity of TFS is the concept of the system-forming factor. This factor is seen as organizing the controlled interactions of the system’s component parts by eliminating their superfluous degrees of freedom. The universal and exclusive system-forming factor is considered to be the attainment of an adaptive result. It is postulated that only the adaptive result can form a system, and does this through selective mobilization of any suitable structural component parts through the elimination their superfluous degrees of freedom. Hence the definition of the functional system: it is a complex of selectively mobilized components, the interaction of which promotes the attainment of a biological adaptive result. Every such system is specialized to attaining a specific adaptive result and disintegrates in case of its absence. Later a similar conclusion was formulated by W.R. Ashby [14], who proposed that functional systems aspire to a state of balance with the surrounding environment (homeostasis), and by virtue of this their behavior can be considered adaptive.

By considering the adaptive result as the single and universal system-forming factor, Anokhin presumed the exclusively adaptive biological role of any systemic activity. Unfortunately, this affirmation factually ignored possible maladaptive and ambivalent forms of functionality (pathological pain syndrome, pathological scratch reflex, some forms of epilepsy, etc.). On the other hand, it is well known that numerous genetically determined functional systems (not necessarily adaptive) are formed through mutagenesis, i.e., according to structural changes that lead to the creation of previously absent structural components of a future system. We therefore propose that additional system-forming factors need to be considered to explain the origin and stability of functional systems, as the concept of the adaptive result is not applicable to them as a universal system-forming factor.

Furthermore, the functional principle of selective structural mobilization is not always dominant over the structural organization – in some cases of systems' formation, it is possible that the key role belongs to primary structural changes that lead to the creation of previously absent structural components of the future system. The key role of innate or ontogenetically acquired structural changes is most evident in the case of functional systems with pathogenic (maladaptive) biological significance. Thus, the distinction between structural and functional determination becomes critical when analyzing the activity of not only healthy (physiological), but also pathological and ambivalent systems. The original formulations of Anokhin may therefore need to be extended to account for the changing relations between systems' properties in various circumstances of normal and pathological functioning.

As indicated, the theory of functional systems is oriented to the analysis of anticipatory processes by its consideration of future possibilities (adaptive results) and their modeling as the factors determining systems' behavior, instead of attributing this role to antecedent events (stimuli). However, further distinctions will be proposed between the future results on the one hand, and their anticipation on the other hand to account for their role as system forming factors. This is particularly relevant to enhance the applicability of the theory in its biomedical aspects.

2 The Role of Anticipation in Anokhin`s Theory of Functional Systems

Anokhin used the terms "anticipatory reflection of future events" and their "forestalling" when analyzing living systems` ability to change their condition according to expected events. This ability formed the central problem of his theory. To explain it, Anokhin developed an *informational model* of the behavioral act (Fig. 1), which is formed and self-regulated on the basis of anticipation and biofeedback. This model has been used not only for the analysis of behavioral acts, but also emotional, homeostatic, and sensory manifestations of biological activity. The model represents and explains the universal mechanisms (stages) of systemic activity: afferent synthesis, decision-making (establishing the goal of action), the acceptor of the action result (its anticipatory model), and the realization of action through efferent synthesis.

Anokhin`s scientific school stressed the role of the functional system as an independent principle of life – determined by the internal requirements of the organism, the present environmental influences, mechanisms of memory, and the persistent programming of future action results. Anticipatory reflection of future events and/or preparation for them in advance plays a key role during each stage of a functional system's formation and its modifications. In this sense, the concepts of "anticipation" and "functional system" are inseparable. Let us discuss this in more detail based on the example of behavioral reactions.

According to Anokhin [5-7], the parameters of the action result are prognosticated already during afferent synthesis – in the first stage of functional system's formation. At this stage, by combining motivation, memory, situational and triggering afferentation (Fig. 1), the question which results are required from the system for the realization of its future adaptive activity is already decided in a highly diffuse way. Prognosticated parameters become more distinct at the decision-making stage (determining the goal of action) and particularly during the subsequent formation of the acceptor of action result. The acceptor occupies a *central position* in the model and effectively realizes the anticipatory function (anticipatory reflection) of the result parameters. It permits to form a program of action, oriented to adaptive changes in current behavior. The programming of action is not necessarily limited to "active" behavioral acts, as "passive" preparation (pretuning) to forecasted events is also possible.

Information about the parameters of an accomplished behavioral act is sent through reverse afferentation (feedback) channels to the acceptor and is compared there with the prognosis. This is necessary for the organization

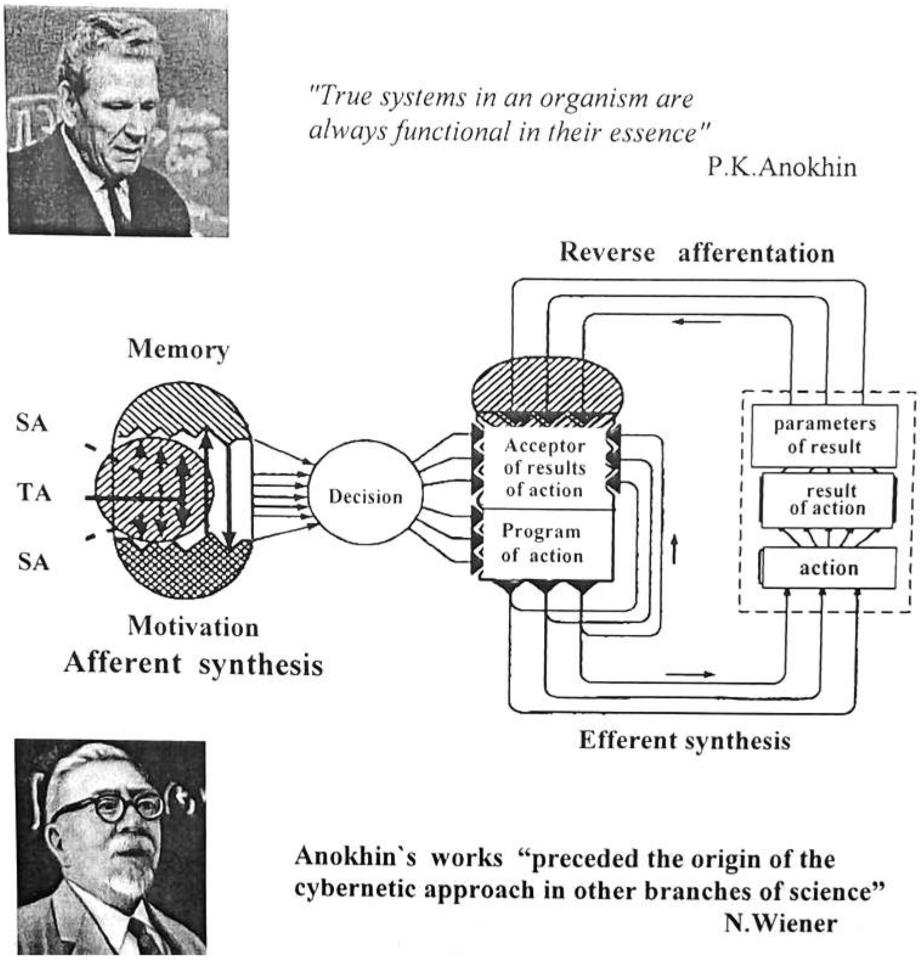

Fig. 1. Anokhin`s Informational Model of the Behavioral Act. TA – triggering afferentation, SA – situational afferentation (Source: [5], with additions).

of the next behavioral act. If the result of a completed action unexpectedly does not correspond to the characteristics of the expected result, the predictive model (afferent synthesis, decision-making mechanism, acceptor of the result) is corrected, a new action program is created, the behavior is changed, and new information about the result the of completed action again enters into the acceptor apparatus, etc. Thus, consistent corrections are realized until the attainment of an expected adaptive result. Together with the latter, the process of functional system formation is completed. It was precisely this circumstance that permitted Anokhin to consider the attainment of the adaptive result as the system-forming factor.

Thus, the phases of afferent synthesis, decision-making, and acceptor of the result are the consecutive formative stages of an increasingly more perfect predictive model of the biologically significant event. This model determines the formation of the program of action and it may be corrected according to information about the results of completed behavioral acts (via biofeedback). In essence, such approach reflects modern understanding of anticipation: systems responsible for its realization need to contain internal predictive models of themselves and/or of their environment, and they employ these models to control their present behavior [2, 15]. Essentially, according to TFS each function (not necessarily behavioral) is determined by anticipation, which can be adaptively changed through feedback. This permitted Anokhin to use the model of behavioral acts also for the analysis of respiration, regulation of arterial pressure, pain sensitivity, and other manifestations of integrative biological functions.

3 The Significance of Anokhin`s Theory for Biomedical Sciences

TFS was considered in the scientific school of Anokhin as a fundamental basis of biomedical disciplines, as a methodological principle, a peculiar conceptual bridge that permits the investigator to appraise analytical data from the point of view of systemic organizations [16]. TFS indeed promoted the study of different vital manifestations from the perspective of dynamical, controlled, self-regulated interactions of structures oriented to the attainment of specific adaptive results. The explanation encompasses and often observes the spatial remoteness and variability of the system`s components, and also the sharing of individual links among systems with different functions. It promotes the verification of homeostatic regulative mechanisms under normal and pathological conditions: during the compensative processes of disrupted functions, emotional stresses, essential hypertension, etc. [13]. The topical diagnostics of local brain injuries became easier on through the analysis of corresponding functional disorders. On this basis it became possible to elucidate the morphological substrate of many functional systems, among them those realizing higher psychological processes (logical thought, free attention, counting, *etc.*). From this perspective new ways for compensating disordered function with the help of stereotactic, clinical psychological and other methods were developed [17].

Thus TFS has been widely used for substantiating the now universally recognized views on the systemic structural plasticity (dynamical localization) of higher psychological functions. In this development, the investigations of A.R.Luria played an important role. As well known, Luria was one of the founders of clinical neuropsychology: studies on the mechanisms of higher psychological processes (speech, perception, attention, memory) based on the material of local brain injuries and possibilities of their restoration [18-20]. On the basis of TFS, he developed effective methods for the treatment of post-traumatic agraphia, aphasia, dyslexia, and other disorders. In this framework, the treatment process presumes patients' active efforts towards the reparation of lost function, frequent compensation of the defective link of lost function on the basis of its preserved links (and other functional systems), persistent feedback for the correction of fulfilled acts, and a selection of optimal tasks according to their complexity. Essentially, these processes are realized through *anticipatory goal-oriented activity* [21-22] *and its correction via adaptive biofeedback.*

Luria`s investigations were widely recognized and stimulated research also on the neurochemical maintenance of functional plasticity – e.g., studies on the nerve growth factor (NGF), brain-derived neurotrophic factor (BDNF), insulin-like growth factors (IGF I, IGF II), gangliosides, met-enkephalin, endorphin, timopoetin and other substances [23]. In addition to clinical neurophysiology, TFS promoted the appearance of biocybernetics and functional morphology as independent sciences, the informational theory of emotions of P.V. Simonov, and numerous other conceptions (sanogenesis, adaptive neuronal networks, circular organization of psychosomatic disorders). Later developments of TFS are reflected in the works of K.V. Sudakov, G.N. Kryzhanovsky, and other scientists [16, 17, 24-26]. Its positions are influential for both fundamental disciplines (normal physiology, pathological physiology, psychophysiology, medical cybernetics) as well as clinical ones (neuropsychology, neurology, clinical psychology) [17, 24].

All this notwithstanding, TFS has not acquired the universal significance for biomedical disciplines it could potentially have. This may be explained by *Anokhin`s debatable postulate on the useful result of action: the attainment of this result is considered as a universal system-forming factor and the key sign of all previously formed systems*. We propose that this postulate poorly conforms with the concept of anticipation and produces an internal inconsistency in the theory.

On the one hand, the attainment of the result (as a system-forming factor) is declared as an obligatory precondition for the system`s formation. On the other hand, it is supposed that the same result is being attainted through the activity of a previously formed system. As stated and stressed, the functional system is a complex of selectively recruited components, the controlled interactions of which promote the attainment of a useful result. However, it´s difficult to understand how the first result could be attainted, if this process is being realized by a specialized system that cannot be formed without this result.

The attainment of adaptive result cannot be considered as the universal system-forming factor that coordinates all intrasystemic interactions. The maintenance of causal relationships supposes that the system has been previously formed and only then according to its activity it's possible to attain a corresponding result, including the very first one. At the same time the results don`t create the system, but only stabilize it (if they are adaptive). Obviously, without the stabilizing effect of the adaptive result the evolutionary formation of even the simplest biological systems wouldn`t be possible. Without the adaptive role of reinforcement, the process of conditioned learning wouldn`t be possible. In this sense the attainment of adaptive result could be considered as a system-forming factor. However, it can`t be universal.

It is well known that the majority of functional systems are formed without any participation of the deferred result of their activity. For example, all genetically determined functional systems are primarily formed due to mutagenesis and can nevertheless be considered biological analogues of anticipatory goal-oriented cybernetic systems [21,27]. This is true for all homeostatic systems (external breathing, thermoregulation, *etc.*) and congenital forms of instinctive behavior (imprinting, sexually oriented behavior, *etc.*). After their formation these systems are "working" on the attainment of genetically programmed results without any dependence on their usefulness for the organism (the result cannot be attainted at all in some cases!). In other words, according to the generally acknowledged genetic theory of natural selection, the result has always been attainted strictly after primary formation of the system and this fact completely excludes its system-forming role.

We suppose that even within Anokhin`s model of the behavioral act (Fig. 1), the real system-forming factor is the goal of action as a model of the future result instead of the postulated result [26]. Anokhin emphasized many times that the *complete* regulation of intrasystem relations is achieved only in the stage of goal achievement [5-7]. In fact this implies that the primary formation of the functional system is realized on the basis of the model of the future result, i.e., obviously before the real attainment of this result is achieved (*anticipation as the system forming factor, instead of the result?*). Such a suggestion considerably simplifies the analysis of goal-oriented behavior and other manifestations of biological activity. It should be stressed that the model of the behavioral act, anticipatory in its essence, is widely used in Anokhin`s school for the analysis of emotional, homeostatic, metabolic, and sensory reactions as well [13, 16, 24]. This agrees with the ideas of N.A. Bernstein [28-30], K. Pribram [31], and other authors [18, 32, 33] on anticipation. In fact already Aristotle supposed that all components of living systems operate in harmony and collaboration according to a process directed to the attainment of the final goal and final result [17].

Therefore, *according to Anokhin`s model of the behavioral act, the attainment of the result (including the first one) is obviously realized after the system`s formation, and this fact excludes its system-forming role*. Functional activity is determined by an anticipatory system (anticipating the goal of action with the consecutive formation of an acceptor mechanism). This anticipation "works" on the attainment of a postponed result without any dependence on its biological significance (for example, it`s possible to form faulty goals, the attainment of which doesn`t promote the satisfaction of any dominant requirements). That is why the functional activity of a system can`t have an exclusively adaptive significance within Anokhin`s theory. On the other hand, anticipation must be considered as a real system-forming factor – although this obviously contradicts the postulate on the universal system-forming role of the adaptive result.

Paradoxically, however, the existence of this contradiction was persistently ignored in Anokhin`s school. "After the first attainment of the useful result by the functional system, this result possesses a unique property: when the definitively developed functional system attains a useful result, which satisfies the initial requirement of the organism, its dynamic architectonics is composed and fixed" [24, p. 43]. The first part of this citation ascertains the attainment of the primary result by the preliminarily ("definitively") developed functional system, but then the classical system-forming role of this result is confirmed (only at the moment of its attainment are "dynamic architectonics composed and fixed"?!). Eliminating the internal inconsistency of Anokhin`s theory requires changing the concept of the system-forming factor and its problematic consequences: the impossibility of functional systems' creation before the moment of attainment of useful results, the impossibility of systems with maladaptive significance for the organism being formed, and the exclusive predomination of the functional principle of selective structural mobilization. On the other hand, these problems require a revision of the significance of anticipation for the process of functional systems' formation.

4 The Significance of G.N. Kryzhanovsky`s Works

A fundamental role in the development of TFS belongs to G.N.Kryzhanovsky's concept of pathological functional systems. These systems are characterized by a pathogenic (maladaptive) significance for the individual in spite of the fact that all of these systems are functional owing to the result (function) as a decisive criterion of their definition. Kryzhanovsky wrote, "A concept took root that a functional system always produces a biologically or socially useful result. Moreover, an opinion exists that if the system does not ensure a useful result, it is not a system. This is a mistake, because a functional system can be either physiological of pathological" [25,p.75].

The novelty of the suggested approach was not only in the wide interpretation of the term "functional system", but also in the revision of the most fundamental postulate of TFS. The result of pathological systems' activity has maladaptive significance for the organism and therefore it can`t produce even a stabilizing effect. Consequently, instead of the result, it is necessary to find another factor that could really play the key role in the formation of pathological systems. Such a factor was found in the form of abnormal hyperactive generators (pathological determinants) [34,35]. With this formulation, *the attainment of a result ceases to represent a universal system-forming factor, although it entirely preserves the role of being a key sign of any previously formed systems* within the framework of TFS.

The creation of a pathological determinant is initiated by primary structural and biochemical disorders owing to mechanical traumas, toxins, mutations, etc. Therefore, pathological systems are considered as morphofunctional formations [34], the self-organization of which is highly determined by underlying morphological changes. This permitted us to suppose an exception to the predominance of the functional principle of selective structural mobilization in the formation of some pathological systems [26], as further discussed below.

5 Modern Theory of Functional Systems

The decisive criterion to mark something as a system is the result of its activity (function), and in this sense, all "true systems in the organism are functional in essence" [5,7]. However, the modern concept of functional systems is drastically widened. A distinction is made between physiological, pathological, and ambivalent systems with correspondingly adaptive, maladaptive, and ambivalent results. From this follows the definition of the functional system as a complex of selectively recruited components whose interaction promotes the attainment of adaptive, maladaptive, or ambivalent result for the individual. The consideration of ambivalent results is of principled importance for biology and medicine, as it indicates the absence of a clear demarcation line between physiological and pathological systems (normality and pathology).

A decisive role in the formation of any system belongs to the system-forming factor, which organizes the key stage of functional systems' formation. At the same time, *there is no universal and single system-forming factor*. In particular, the adaptive result cannot fulfill such role, because many functional systems are formed before its attainment. This peculiarity, as well as the occurrence of pathological and ambivalent systems indicates the existence of a set of system-forming factors. This role may be realized not only by the adaptive result (as in conditioned reflex training), but also by the goal of activity (in most cases of complex behavior which go beyond congenital and conditioned reflexes), by mutations (in congenitally determined systems), by Kryzhanovsky`s abnormal hyperactive generators (in some forms of epilepsy, Parkinson`s disease), and perhaps by other factors. Moreover, e*very system-forming factor can initiate the development of various functional systems (physiological, pathological, and ambivalent)* depending on environmental conditions, peculiarities of homeostasis, *etc*.

For example, all genetically determined systems are formed by mutations. These systems can nevertheless often be considered as biological analogues to anticipatory goal-oriented cybernetic systems [21,27]. The anticipatory reflection (forestalling) of future events plays an important role also in the realization of congenital forms of behavior, pain sensitivity, arterial pressure regulation, and other manifestations of vital functions. Beneficial mutations form physiological systems, while harmful mutations produce pathological systems (hereditary diseases). Ambivalent situations are also possible. For example, the pathological mutations which produce sickle-cell disease or talassemia also yield immunity against malaria [36,37].

In pathology, the role of the system-forming factor can be realized by pathological determinants – the abnormal hyperactive generators [25, 34] that are formed by mechanical traumas, intoxicants, or other influences. Corresponding systems induce pathological effects: some forms of Parkinson`s disease, epilepsy, pathological pain syndrome, pathological scratch reflex [34,35]. However, they can be still considered as biological analogues of anticipatory goal-oriented cybernetic systems, specializing in the attainment of determinate results. On the other hand, every pathological system has its structural-functional antipode, a specific antisystem, which counterbalances the pathological system, restricts and inhibits its activity [35]. These antisystems (for example, antinociceptive, antiepileptic, antistress, *etc.*) can be justly termed physiological, since their activity – in addition to being anticipatory and directed to certain biological results – is evidently adaptive. Hence, pathological morphofunctional structures are closely connected with corresponding physiological and adaptive ones, and their interaction indicates the existence of greater combined (pathophysiological, ambivalent) systems operating on the basis of different system-forming factors.

In cases of conditioned reflex training, the system-forming factor is also first realized through the accidental achievement of a useful result, and not primarily by anticipatory reflection. Only after a result has been already achieved does anticipation participate in and modulate the reflex. And this process likewise doesn`t always have an adaptive significance for the organism. It can actually permit the organization of pathological systems. To exemplify this statement, consider the classical experiment of D. Olds (1952) where electrodes were implanted into the areas of hypothalamus which produce positive emotions upon stimulation. By self-stimulating this area via lever-pressing, the animal attains a subjectively positive result, although long-term stimulation usually results in exhaustion and may even lead to death. What kind of system is being formed during this experiment? Initially, this system is physiological with positive reinforcement as its system-forming factor. But it then transforms into a pathological one, as long-term self-stimulation produces severe negative consequences. It seems that until the moment of death the very result of instrumental activity is the system-forming factor, which determines the most specific features and directs further behavior of the system. Withdrawal of this factor triggers a relatively rapid elimination of intrasystemic connections. This can be seen when the experimenter suddenly disconnects electrical current from the electrodes implanted into the hypothalamic areas, after which the subjectively positive result can`t be attainted by pressing the lever – in this case the animal almost immediately stops its self-stimulation and usually survives. In humans, similar situations are represented in cases of drug addiction, alcoholism, customary eating after stress, etc. [17,26]. Probably, there is a potential danger accompanying all kinds of pleasurable stimulation of the limbic centers, such as during pathological passion induced by exciting games (gambling), sex, even TV and shopping [38]. In all these cases anticipation supports the stability of corresponding systems, though it doesn`t form them.

The system-forming factor in most complex forms of purposeful activity, going beyond congenital behaviors and conditioned reflexes, is conscious goal-seeking activity (anticipation). Also this is able to form physiological, pathological, or ambivalent systems. For example, behavioral activity may be guided by false goals whose attainment does not promote any satisfaction of the dominant requirements and has a mainly maladaptive significance [39]. This shows that all manifestations of anticipation need to be analyzed with respect to the organism as a whole, and the various roles that different system-forming factors may have for its functioning on various levels.

In fact, we propose that *the singling out of the several system-forming factors reflects the complementary significance of the functional and structural approaches to the organism, and to the biomedical sciences more generally.* On the one hand, the key stage in functional systems' formation may consist of generating previously absent structural components. The role of system-forming factor is played in these cases by mutations or by pathological determinants (abnormal hyperactive generators). This represents the predominance of the structural principle of selective functional mobilization, which is also the characteristic focus of reductivist frameworks. This can be illustrated by the formation of systems through evolutionary or lifetime mutagenesis (e.g., tumour formation), by donor tissue transplantation (including that of stem cells), by Kryzhanovsky`s morphofunctional formations [25,34], etc. Subsequent to these structural changes, the functional regulation of respective intrasystemic connections and relations is realized comparatively simply and quickly.

On the other hand, the key stage in the formation of systems can also consist of the regulation of functional interactions between already existing structural components (elimination their superfluous degrees of freedom). In that case the role of the system-forming factor is played by the goal of activity (complex forms of conscious behavior) or by the adaptive result (conditioned reflexes) according to the predominance of the functional principle of selective structural mobilization. It is the latter principle which has been investigated in particular detail Anokhin`s school [4-7,13,16]. In some instances, the complexity and involvement of both types of processes may be approximately equal – i.e., of the regulation of functional interactions and the generation of previously absent structural components. For example, the processes of functional recovery after local brain injury are based both on the partial restoration of traumatized structures as well as on the intricate regrouping functional interactions between undamaged structural components [18-20,40].

Conclusion

The decisive criterion for any functional system of the organism is the efficient activity of its components (function), which is oriented to the attainment of a corresponding result. Such attainment presumes goal-oriented activity, and in this sense, all functional systems are anticipatory (akin to cybernetic goal-oriented systems). The general problem of anticipation – how the future is prospectively modeled (represented) in living systems and orients their activity – is approached in TFS on the basis of a consecutively generated predictive model and its adaptive self-correction via feedback. The key role in the initial formation of the functional system is played by the system-forming factor, which orients the initially unorganized interaction between relevant components towards the achievement of a biologically significant result.

However, in addition to adaptive results, there are several variants of system-forming factors, and any one of these factors can lead the development of physiological, pathological, and ambivalent systems. Anticipation (as goal-seeking activity) can be considered as a system-forming factor only in cases of complex behavior, which exceed the boundaries of congenital and conditioned reflexes. Such approach within TFS promotes studying the significance of anticipation for vital activity. It also increases the significance of the theory for biomedical sciences due to the additional possibility of analyzing maladaptive forms of systemic activity.

References

1. Rosen, J.: Preface to the Second Edition: The Nature of Life. In: Rosen, R. Anticipatory Systems: Philosophical, Mathematical, and Methodological Foundations (Klir G.J. series ed.), pp. xi-xiv. Springer, New York/Dordrecht/Heidelberg/London (2012)

2. Rosen, R.: Anticipatory Systems in Retrospect and Prospect. In: General Systems Yearbook, vol. 24, pp. 11–23 (1979)
3. Anokhin, P.K.: Problem of Centre and Periphery in Modern Physiology of Nervous Activity. In: Anokhin, P.K. (ed.) The Problem of Centre and Periphery in the Physiology of Nervous Activity, pp. 9-70. Gorki (1935) (in Russian)
4. Anokhin, P.K.: Problems of Higher Nervous Activity. Publisher of the USSR Academy of Medical Sciences, Moscow (1949) (in Russian)
5. Anokhin, P.K.: The Theory of Functional Systems. Uspekhi Fiziol. Nauk 1, 19-54 (1970) (in Russian)
6. Anokhin, P.K.: Biology and Neurophysiology of the Conditioned Reflex and its Role in Adaptive Behavior. Pergamon Press, Oxford (1973)
7. Anokhin, P.K.: Philosophical Aspects of the Theory of Functional Systems. Meditsina (Medicine), Moscow (1978) (in Russian)
8. Wiener, N.: Cybernetics of Control and Communication in Animal and the Machine. J.Willey&Sons, New York/London (1948)
9. Bertalanffy, L. von: General System Theory – a critical Review. General Systems, 7, 1-20 (1962)
10. Cannon, W.B.: The Wisdom of the Body. W.W.Norton & Company, New York (1932)
11. Bedny, G., Seglin, M., Meister, D.: Activity Theory: History, Research and Application. Theor. Issues in Ergon. Sci. 1, 168-206 (2000)
12. Buckout, R.: Psychology in Russia. Society 3, 42-44 (1966)
13. Sudakov, K.V.: To the Centenary of P.K.Anokhin, a Great Russian Physiologist. Integr. Physiol. and Behav. Sci. 33, 171-175 (1998)
14. Ashby, W.R.: Design for a Brain; the Origin of Adaptive Behavior. Willey, New York (1952)
15. Rosen, R. Anticipatory Systems: Philosophical, Mathematical, and Methodological Foundations (Klir G.J. series ed.). Springer, New York/Dordrecht/Heidelberg/London (2012)
16. Sudakov, K.V.: Reflex and Functional System. Publisher of Novgorod State Univ., Novgorod (1997) (in Russian)
17. Saltykov, A.B.: Functional Systems in Medicine. Med. Inform. Agenstvo (Medical Informational Agency), Moscow (2013) (in Russian)
18. Luria, A.R.: Restoration of Functions after Brain Injury. Macmillan, New York (1963)
19. Luria, A.R.: Higher Cortical Functions in Man. Basic Books, New York (1980)
20. Glozman, J.M.: A.R.Luria and the History of Russian Neuropsychology. J. Hist. Neurosci. 16, 168-180 (2007)
21. Hacker, W.: Allgemeine Arbeits- und Ingenierupsychologie (General Labor and Engineering Psychology). Verlag Hans Huber, Bern/Stuttgart/Vienna (1978)
22. Nadin, M.: Quantifying Anticipatory Characteristics. The Anticipation Scope and the Anticipatory Profile. In: Iantovics, B., Kountchev, R. (eds.) Intelligent Computational Technologies and Decision Support Systems, pp. 143-159. Springer International Publishing, Switzerland (2014)
23. Cacioppo, J.T., Tassinary, L.G., Berntson, G.G. (eds). Handbook of Psychophysiology. Cambridge Univ. Press, Cambridge (2007)
24. Sudakov, K.V.: Informational Phenomenon of Vital Functions. Rossiyskaya Academia Postdiplomnogo Obrazovaniya (Russian Academe of Postdiploma Education), Moscow (1999) (in Russian)
25. Kryzhanovsky, G.N.: Disregulative Pathology. Rit-Express, Moscow (2002) (in Russian)
26. Khitrov, N.K., Saltykov, A.B.: Theory of Functional Systems and Human General Pathology. Bull. Exp. Biol. and Med., 136, 1-6 (2003)
27. Nadin, M.: The Interactable and the Undecidable – Computation and Anticipatory Processes. Int. J. of Applied Research on Inform. Technology and Computing 4, 99-121 (2013)
28. Bernstein, N.A.: The Co-ordination and Regulation of Movements. Pergamon Press, Oxford (1967)
29. Bernstein, N.: Essays on the Physiology of Movements and the Physiology of Activity. In: Gazenko, O.G. (ed.) Series: Classics of Science. Nauka (Science), (under the scientific direction of I.M. Feigenberg) (1990) (in Russian).

30. Aruin, A.S., Bernstein, N.A.: The Biomechanical Control of a Safe Labor Environment: Bernstein`s Vision in 1930. Motor Control 6, 3-18, (2002)
31. Pribram, K.: Languages of the Brain: Experimental Paradoxes and Principles in Neuropsychology. Prentice-Hall, Englewood Cliffs/New Jersey (1971)
32. Aruin, A.S., Forrest, W.R., Latash, M.L. Anticipatory Postural Adjustments in Conditions of Postural Instability. Electroencephalogr. Clin. Neurophysiol. 109, 350-359 (1998)
33. Nadin, M.: Anticipation and Dynamics: Rosen's Anticipation in the Perspective of Time. (Special issue) Int. J. Gen. Syst. 39, 3-33 (2010)
34. Kryzhanovsky, G.N.: General Nervous System Pathology. A New Approach. Consulting Bureau, Plenum Publishing Corporation, New York/London (1986)
35. Kryzhanovsky, G.N.: Foundations of General Pathology. Meditsinskoye Inform. Agenstvo (Medical Informational Agency), Moscow (2011) (in Russian)
36. Durand, P.M., Coetzer, T.L.: Hereditary Red Cells Disorders and Malaria Resistance. Haematologia 93, 961-963 (2008)
37. Atkinson, S.H., Uyoga, S.M., Nyatichi, E., Macharia, A.W., Nyutu, G., Ndila, C., Kwiatkowski, D.P., Rockett, K.A., Williams, T.N.: Epistasis between the Haptoglobin Common Variant and α+thalassemia Influences Risk of Severe Malaria in Kenyan Children. Blood 123, 2008-2016 (2014)
38. Linden, D.G.: The Compass of Pleasure. Pengium Group, New York (2010)
39. Pawlik, K., Rozenzweig, M.R.: International Handbook of Psychology. Int. Union of Psychol. Science, New York (2000)
40. Yudofsky, S.C., Hales, R.E.: The American Psychiatric Publishing Textbook of Neuropsychiatry and Clinical Neurosciences. American Psychiatric Publishing, Washington (2002)