REVIEWS

Subjective Uncertainty, Purposeful Behavior, and Theory of Functional Systems

A. B. Saltykov and N. K. Khitrov

Translated from *Byulleten' Eksperimental'noi Biologii i Meditsiny,* Vol. 130, No. 10, pp. 364-369, October, 2000
Original article submitted June 22, 2000

Neglect of probability prognosis orients the theory of functional systems to description of rigidly determined forms of behavior (congenital behavior, frontal syndrome, *etc.*). The authors suggest an original concept for analysis of behavior under conditions of subjective uncertainty based on probability estimations. It contains all classical components of a behavioral act model developed by P. K. Anokhin. The role of probability prognosis at the stages of making decision (purpose) and formation and realization of the program of actions is argumented. Two new components are added to the classical model: memory buffer and system of making probabilistic decision for modifying the program of actions. Such an approach essentially extends the potentialities of using the theory of functional systems, making it usable not only for rigidly determined behavior but for behavior under conditions of subjective uncertainty.

Key Words: *probability prognosis; purposeful behavior; theory of functional systems*

Human and animal behavior is usually realized under conditions of deficient or contradictory information about the environment. Lack of strict determination promotes the formation of subjective uncertainty, which is reflected in the use of probability estimations by the individual. Neurophysiological structures were revealed (frontal lobes of the cerebral cortex, hippocampus) responsible for probability prognosis (PP) [5, 8,18,19] and their involvement in the organization of the most complex forms of behavior was proven [7,9, 15,16,23-25]. On the other hand, the concept of PP is almost completely ignored within the framework of highly prevalent theory of functional systems (TFS), which impedes the systemic analysis of behavioral activity.

The attitude of P. K. Anokhin, the founder of TFS, to the use of probability estimations was rather skeptical. He wrote that "the phrase "probability (?) prognosis" does not correspond to the physiological essence of events and disorients the readers interested in our work. The probability of prognosis, *i. e.* parameters of acceptor of action results, is always maximum and equal to one, because it reflects the requirement of the organism for the present moment. By contrast, the result is always less probable with respect to acceptor of action result and therefore the phrase "probability prognosis" is hardly useful in studies of living systems" [2]. P. K. Anokhin's opinion still has a great impact on his disciples and followers. However, his arguments cause certain doubts. Strictly determined behavior completely ruling out the use of probability estimations is often not optimal. P. K. Anokhin noted that "the result is less probable in relation to acceptor of the result of action", *i. e.* the objective probability of attaining the adaptive result is usually far below one. Therefore, permanent equality of the probability of prognosis to one obviously contradicts the objective reality! In other words, optimization of behavior on the basis of more accurate prediction, with greater consideration for the actual reality, is possible in prin-

I. M. Setchenov Moscow Medical Academy

0007-4888/00/0010-925$25.00 ©2000 Plenum Publishing Corporation

ciple. *The uncertainty of the environment objectively promotes the formation of subjective uncertainty, i. e. a concept on the degree of disarray (spontaneity) of the environment in the context of meeting the actual requirements of the subject.* However such a process becomes possible only with PP system, and therefore, develops at relatively late stages of evolution.

The classical model of behavioral act [1,2] developed by P. K. Anokhin within the framework of TFS is now well known. However *neglect of probability prognosis inevitably orients the classical model to description of only relatively simple forms of behavior,* characterized by lack or minimal subjective uncertainty. These are congenital or acquired during life stable (routine, automatically realized) forms of behavioral activity and the process of development of conditioned reflexes under "rigidly determined conditions" (reinforcement of the intensity in 100% cases, *a priori* suprathreshold signal, *etc.*). The classical model explains fairly well the main experimental data obtained by I. P. Pavlov's school. In all such cases the behavior is the most effective at probability of prognosis equal to one. This really makes one consider the concept of PP as excessive, which allowed P. K. Anokhin to construct a relatively simple model. Neglect of PP makes unnecessary the evaluation of many acts of behavioral activity (needed for detecting the probability of an event) and concentrates the attention on analysis of a separate behavioral act. This simplification is emphasized by the name of the model and implies immediate restructuring of all its components in case of discrepancy between the actual and expected result. "The orientation-exploratory reaction develops and progresses in all cases when the result of action unexpectedly does not correspond to the characteristics of the result formed on the basis of afferent synthesis, *i. e.* in case of discoordinated behavioral activity. Afferent synthesis is immediately rearranged due to triggering of this reaction, a new decision is adopted, a new program of actions is created, and search in a new direction is carried out until the results of the action do not fully or to a great measure coincide with the characteristics of acceptor of result of action" [20]. Therefore, neglect of PP determines the analysis of only one step (one behavioral act), which is quite enough for description of behavior in the absence of subjective uncertainty. On the other hand, the described situation is rather rare, particularly in humans.

Studies of systemic mechanisms of behavior under conditions of subjective uncertainty are based on the conditioned reflex experiment. The complexity of detecting a relationship between signal and reinforcement is common for numerous methods; behavior under "rigidly determined conditions" is regarded as a particular case. The degree of uncertainty is traditionally preset by variations of signal intensity from zero (no stimulation) to *a priori* suprathreshold values and by the probability value ("partiality") of unconditioned reinforcement [6,7,16,19]. Behavior is then regarded within the framework of increasing probability and duration of contact with an external object which can meet the requirement of the organism [19], *i. e.* decrease the subjective uncertainty. It was recently discovered that at the initial stages of training the subjective uncertainty depends to a great extent on the probability of accidental performance of behavioral acts necessary to meet one's requirements [11-14,16,17].

As we showed previously [9,15,16], PP neglecting impedes systemic analysis of behavior. For example, it is impossible to explain from the classical viewpoint the development of instrumental behavior with 50% probability of reinforcement. Only an endless succession of coincidences and non-coincidences of results of the next behavioral act with the parameters of the result observed during realization of the previous act can be expected. Immediate restructuring of the afferent signal should take place in each of the numerous "discordance" cases, a new decision or a new program is to be adopted, *etc.* It is still unknown when the simplest reflex will be developed under these conditions and how it will happen [9,16]. However the process becomes clear if we introduce the notion of the *probability of making a decision about modifying (or retaining) the program of actions* (Fig. 1). The process of making the probability decision is usually based on complex estimation of the results of *many* behavioral acts, which necessiates introduction of a "*memory buffer*" into the integral scheme of functional system; this buffer will store the results of behavioral acts performed during realization of the current program of actions. The use of these nonclassical components of the functional system makes unnecessary immediate restructuring of the afferent synthesis, adopting a new goal, *etc.*, at each discrepancy between the actual and expected results of the behavioral act. This, in turn, will help to understand the mechanism of formation of the program of actions and probability environment and will bring us to a concept of systemic organization of behavior (because adaptive result is a systematizing factor). PP within the framework of TFS can be useful in computer simulation of behavioral activity under conditions of subjective uncertainty [16]. The use of "nonclassical components" of the functional system allows the creation of models with a high prognostic (euristical) value, when empirical data are needed only for verifying the detected regularities. Our simulation model of probability training is an example of such an approach [10, 11]. Using this model, we theoretically studied the effect of the probability of accidental performance of trained reaction to instrumental activity under various training conditions; further experiments on animals fully confirmed the detected regularities [12-14,16, 17]. Results of simulation corresponded to the known relationships between the rate of training and other traditionally variable parameters (probability of unconditioned reinforcement, intensity of conditioned stimulus, *etc.*) [11, 16]. This, in turn, indicated the adequacy of TFS integration with the PP concept.

The PP system is formed at relatively late stages of evolution. Its insufficiency in lower animals makes virtually impossible training under uncertain conditions, which is in line with the classical concepts (analysis of one behavioral act only). For example, the behavior of fish is characterized by the so-called probability indifference, *i. e.* equally probably choice of numerous alternatives irrespective of the probability (stereotypy) of their reinforcement [6]. However, the probability indifference can be observed in higher animals and even in humans in case of the so-called frontal syndrome, that is, after extirpation or injury to the cerebral frontal lobes. All previously acquired reflexes and habits are usually retained, but the behavior under conditions of the minimum uncertainty becomes inadequate. Since a man usually finds oneself in a situation of greater or lesser deficiency of information, the capacity to adequately predict, realize, and correct one's actions is sharply reduced [3-5]. For example, patient with manifest frontal syndrome feeling hungry is often enable to walk to the hospital dining room because his(her) attention is constantly distracted to accidental external signals.

On the other hand, behavioral adaptation is notably facilitated if the individual can refuse from rigid determination of one's prognosis and use the probability estimations. In contrast to fishes, birds are capable of preferring the most probable alternative [6], which is an evolutional advantage. Higher mammals possess a still higher level of reactions; it is characterized by stable selection of the alternative supported best of all (the maximal winning strategy). *The use of probability estimations suggests the appropriate role of the frontal lobes in neurophysiological support of the formation and realization of program of actions* [5,6,15,16,18,19]. The significance of PP is the highest at the stage of goal formation of a goal characterized by the greatest subjective uncertainty.

Within the framework of TFS the goal denotes a "final result model" [1] and "decision making" [1,20]. Both variants are closely connected with each other, because it is impossible to make a choice (decision) without tentative model of the future result, that is, completely without imagining what one chooses. According to TFS, decision making is based on the afferent synthesis, *i. e. a priori* before of formation of acceptor of the result of action "anticipating" the properties of the future result [1,20,21]. "Acceptor of the result of action... "anticipates" the afferent properties of the result which is expected after making a decision and hence, anticipates the course of events occurring in the organism-environment relationships... This system is organized immediately after decision making" [1]. In other words, first the model of the future result (purpose) is formed and only then its rigidly determined signs are predicted in the acceptor system. But this is the very thing that determines the probability nature of the goal! By contrast, *if PP is neglected, the concept of goal remains useless.* Indirect signs of this assumption can be found in K. V. Sudakov's concept of systemic quantization of behavior [20-22].

According to the concept of systemic quantization, "all variegated vital processes in their incessant

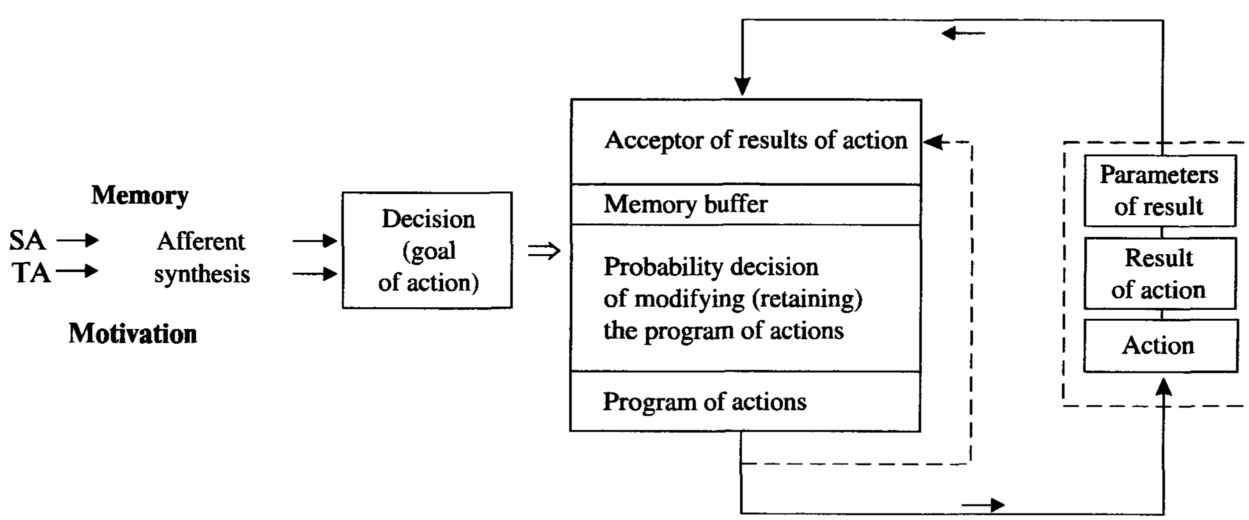

Fig. 1. Model of probability training [15]. TA: triggering afferentation; SA: situation afferentation.

continuum are subdivided into discrete sections including formation of requirement; activity aimed at meeting this requirement; attaining of intermediate results meeting the initial requirement and constant evaluation of the results attained by means of inverse afferentation. According to this concept, the behavior of live creatures is autoregulated: when requirement appears, it is to be satisfied" [21]. The goal of activity then inevitably becomes a minor component completely determined by the initial requirement and usually even not included in the total quantum scheme. We believe that this simplification is permissible only for rigidly determined behavior (congenital forms, frontal syndrome, *etc.*). Generally, *the goal does not copy the predominant requirement, but represents a subjective model of the future result inevitably containing the probability aspects.* Actualization of one and the same requirement often leads to the formation of quite different models of the future result, depending on individual experience, current information, subjective assessment of physical status, *etc.* Subsequently formed acceptor system realizes the process of comparison of the actual result with the predicted probability reference, whose signs are formed at the stage of goal.

Let us discuss cases with congenital or stable forms of trained behavior. It might be expected that the afferent synthesis system (memory) contains information sufficient for creating a rigidly determined model of a future result, because this result was attained many times before. But even repeated satisfaction due to meeting some requirement does not guarantee the presence of a rigidly determined model in the memory. If the animal feels hungry, this does not mean that it knows exactly what food it will be offered this time and what sensations it will experience. Memory more often contains just several (important for the individual) signs of the future result model, while other signs are only suggested, probable. This is particularly typical of complex requirements, for instance ethical, esthetic, *etc.*, intrinsic only for humans.

The probability aspects of the purpose are still more difficult to ignore when analyzing the process of formation of a new functional system (or significant modification of an existing system). Subjective uncertainty in these cases is so significant that the probability characteristics of the model of future result (purpose) inevitably predominate. Subjective uncertainty is particularly high in realization of behavior before the moment of obtaining at least the first adaptive results. If the individual has never satisfied his(her) requirements yet, the goal of his(her) activity is inevitably subjective, vague, tentative.

Moreover, as a rule the individual has to satisfy several requirements at once, and the choice of the predominating purpose can become tormenting. "In case of neurosis the vector of behavior is as a rule situated between the competing motives... In this situation the subject has to make a choice, and the choice is too difficult... The stress is not very high if one strong motive obviously predominates and can be very high if the competing motivations of moderate intensity are equal" [18]. In the latter case, when the formation of a goal is inevitably realized on the basis of vague (probability) concepts on what is more important for the present moment, essential subjective uncertainty is forming. One possible mechanism of such a choice was described by P. V. Simonov in the requirement-information theory of emotions, according to which the choice of actualized requirement essentially depends on the subjective evaluation of the probability of satisfying it. The evaluation is made on the basis of probability prediction [18,19]. Hence, the stage of decision making (purpose) is usually characterized by the maximum subjective uncertainty, which suggests the use of probability evaluations. Acknowledgement of this assumption helps to understand the experimental fact noted by P. K. Anokhin: "... at the moment of decision making the processed information is integrated in the frontal lobes, from which the signal to choose the optimal behavioral system is sent" [1]. This explains the attenuation of the relationship of behavior to actual requirement in patients with the frontal syndrome [3,4], based on the impossibility of formation of the probability model of future result (goal) under conditions of subjective uncertainty.

Some authors admit the use of PP concept within the framework of TFS, but only with regard to the acceptor system when analyzing the possibility of satisfying the requirement (mainly "means of attaining of the needed result" [22]). The "prediction of characteristics of required result is always rigid" [22], *i. e.* still in strict accordance with the classical approach. We believe that PP is used not so much within the acceptor system for analysis of "means of attaining the required result", but mainly at the stage of formation of the probability model of future result (goal) and for evaluating the results of many behavioral acts in the course of realization of the program of actions. Only this wide-scale interpretation can explain the information mechanisms of purposeful activity, making TFS useful not only with regard to strictly determined behavior, but to behavior under conditions of subjective uncertainty as well.

REFERENCES

1. P. K. Anokhin, *Uspekhi Fiziol. Nauk,* **1,** No. 1, 19-54 (1970).
2. P. K. Anokhin, *Physiological Aspects in the Theory of Functional System* [in Russian], Moscow (1978).
3. B. V. Zeigarnik, *Textbook of Pathopsychology* [in Russian], Moscow (1981), pp. 81-92.

4. B. V. Zeigarnik, *Pathopsychology* [in Russian], Moscow (1999).
5. A. R. Luriya, *Higher Cortical Functions in Man and Their Disorders in Local Brain Injury* [in Russian], Moscow (1969).
6. D. N. Menitskii, *Higher Nervous Activity in Humans and Animals in a Probability Organized Environment*, Abstract of Doct. Biol. Sci. Dissertation, Moscow (1981).
7. D. N. Menitskii, *Physiology of Behavior. Neurophysiological Regularities. Manual of Physiology* [in Russian], Leningrad (1986), pp. 130-162.
8. K. Pribram, *Languages of the Brain (Experimental Paradoxes and Neurophysiology Philosophy)* [in Russian], Moscow (1975).
9. A. B. Saltykov, *Uspekhi Fiziol. Nauk,* **30,** No. 4, 39-49 (1999).
10. A. B. Saltykov, I. V. Smirnov, and V. P. Starshov, *Emotions and Behavior: Systemic Approach* [in Russian], Moscow (1984), pp. 260-262.
11. A. B. Saltykov, I. V. Smirnov, and V. P. Starshov, *Zh. Vyssh. Nervn. Deyat.,* **39,** No. 5, 974-981 (1989).
12. A. B. Saltykov, A. V. Toloknov, and N. K. Khitrov, *Byull. Eksp. Biol. Med.,* **110,** No. 10, 344-345 (1990).
13. A. B. Saltykov, A. V. Toloknov, and N. K. Khitrov, *Zh. Vyssh. Nervn. Deyat.,* **40,** No. 3, 467-474 (1990).
14. A. B. Saltykov, A. V. Toloknov, and N. K. Khitrov, *Pat. Fiziol.,* No. 5-6, 5-6 (1992).
15. A. B. Saltykov, A. V. Toloknov, and N. K. Khitrov, *Vestn. Rossiisk. Akad. Med. Nauk,* No. 10, 59-67 (1995).
16. A. B. Saltykov, A. V. Toloknov, and N. K. Khitrov, *Behavior and Environmental Uncertainty (Mechanisms and Clinical Significance)* [in Russian], Moscow (1996).
17. A. B. Saltykov, A. V. Toloknov, and N. K. Khitrov, *Byull. Eksp. Biol. Med.,* **126,** No. 9, 283-285 (1998).
18. P. V. Simonov, *Motivated Brain* [in Russian], Moscow (1987).
19. P. V. Simonov, *Creative Brain: Neurophysiological Basis of Creative Activity* [in Russian], Moscow (1993).
20. K. V. Sudakov, *General Theory of Functional Systems* [in Russian], Moscow (1984).
21. K. V. Sudakov, *Uspekhi Fiziol. Nauk,* **26,** No. 4, 2-26 (1995).
22. K. V. Sudakov, *Physiology of Functional Systems* [in Russian], Irkutsk (1997), pp. 338-365.
23. J. P. Desportes, *Bull. SFECA,* **2,** No. 2, 113-118 (1987).
24. M. C. Porter and R. G. Mair, *Behav. Brain Res.,* **87,** No. 2, 115-125 (1997).
25. R. M. Ridkey, L. J. Durnford, and J. A. Baker, *Brain Res.,* **628,** No. 1-2, 56-64 (1993).