Extrapolation Ability in Animals and its Possible Links to Exploration, Anxiety, and Novelty Seeking

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Abstract. The term “extrapolation ability” was used for the first time by L.V. Krushinsky in his concept of animal reasoning. Extrapolation is the ability of an animal to anticipate the position of a (food) stimulus after it has changed its location and disappeared from the animal’s view. Experiments have proven that this ability is not a simple trait, but requires a constellation of various optimal cognitive functions. Only several genetic groups among laboratory rodents are able to anticipate food reward on the basis of extrapolation, as opposed to instrumental learning. The paper includes data on extrapolation ability in mice with various chromosomal rearrangements, showing non-random performance on the extrapolation task in animals carrying specific types of mutations. Experiments in which mice were selected for extrapolation ability demonstrate concomitant changes in other cognitive tasks and traits (fear-anxiety, reactions to novelty). Future studies should involve both the combination of several experimental paradigms and correlational analysis to futher delineate the genetic underpinnings of anticipation as expressed in the extrapolation ability.

Keywords: cognitive behavior, L.V. Krushinsky, animal reasoning, extrapolation ability, response latency, anxiety, reaction to novelty, hyponeophagia, selection, genotype, chromosomal mutations, laboratory mice

1 Introduction

The ability to anticipate physiological needs and to predict the availability of desirable resources is a recognized brain function [1]. At the same time, the capacity of the brain to anticipate and to form predictions go beyond this definition. This paper presents analysis of experimental data on the ability of animals (laboratory mice) to follow stimuli and anticipate their future position. In particular, their *extrapolation* ability has been tested and evaluated in different conditions. The paper analyzes data on extrapolation ability in mice with chromosomal rearrangements of different types, showing non-random performance variability on the extrapolation task in animals carrying specific types of such mutations. It is shown that selection experiments in which mice are selected for their ability to solve the extrapolation task also demonstrate changes in the solution of other cognitive tasks, as well as animal reaction to novelty.

The concept of animal *elementary reasoning*, developed by Leonid Viktorovich Krushinsky (1911-1984), asserts that elementary reasoning is the ability of an animal to apprehend (grasp) the empirical (physical) laws which function in the environment and which determine the connections of objects and events. Among such abilities, the *extrapolation ability* (strongly associated with the name of Krushinsky in the minds of Russian biologists) signifies the ability of animals to extrapolate the position of a (food) stimulus after it has changed its location and disappeared from the animal’s view behind an obstacle.

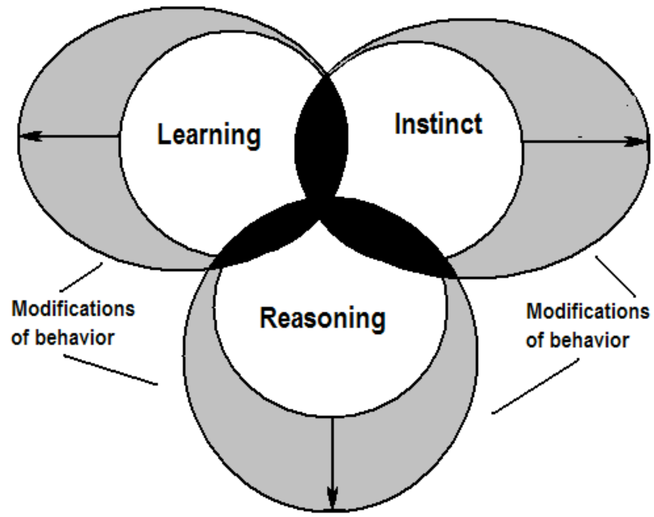

Fig. 1. The hypothetical scheme introduced by L.V. Krushinsky to illustrate his main concept on the possible interactions which could take place during behavioral development between instinctive endowments, learning capacities, and reasoning ability – defined by him as the principal components of animal behavior. The areas around each circle visualize the variability of respective behavioral traits, arising as the result of deviations due to environmental and/or genetic and epigenetic causes.

Testing the ability of different animal species for extrapolation of the direction of stimulus movement after it disappears from the animal's view was the first experimental paradigm on animal reasoning introduced by Krushinsky into laboratory practice. Extrapolation ability is thus defined as the ability to foresee a future object displacement on the basis of perceived movement direction, and it is based: 1) on the animal's capacity to *know* (or *understand*) the law of object permanence (if an object becomes invisible for some reason, this does not mean that it doesn't exist any more) and 2) on understanding the law of *object movement*.

Many years of experimental work with different species of mammals and birds (as well as reptiles) lead Krushinsky to the conclusion that this ability is a complicated brain function, which is present mainly in animals with a high level of brain organization. Primates, most carnivorous mammals, and corvid birds solve the extrapolation task in a statistically significant proportion of cases, while other species (e.g., pigeons and laboratory rodents) prove to perform on the 50% chance level.

L. V. Krushinsky belonged to the Russian school of experimental biology founded by N. K. Koltzov[1], a prominent Russian scientist. Krushinsky's interest in animal behavior combined productively with his experimental skills in endocrinology and physiology. Later, he accumulated extensive experience in the breeding and training of guard and patrol dogs[2]. At the same time, L. V. Krushinsky was an ardent naturalist and his long forest excursions also enriched his knowledge of animal behavior. This is reflected in his theoretical conceptions, which pertained particularly to real and hypothetical natural settings, instead of restricted laboratory environments.

The concept of extrapolation ability presents an example of this. During his trips in the nature, he was always accompanied by his setter-dog. Once it happened that this dog discovered a quail, who escaped into the bushes. The bushes were so dense that the dog could not penetrate them. Instead of trying to get into the bush directly, the dog went slowly round the bush and started to wait for the prey ("presuming" it would appear in this location, if its trajectory is straight). This episode and several similar ones became the starting point for Krushinsky in his suggestion that *an animal could anticipate the future position of a moving object*, i.e., to *extrapolate* the movement of an object on that part of its trajectory which is hidden from the animal's vision. This ability enables the animal to find the object in its

[1] N. K. Koltzov (1872 – 1940) – the founder of Russian experimental biology. He was the first to suggest the ideas of molecular structure of chromosomes and the matrix principle of their reduplication, forestalling the advent of molecular genetics.
[2] Krushinsky was the only Russian author whose works on dog behavior were cited in "Genetics and the Social Behavior of the Dog", the classic work by J.P. Scott and J.L. Fuller, 1965, Univ. of Chicago Press.

new position. Obviously, this type of behavior could be of adaptive value[3]. As the next step in his theoretical considerations, Krushinsky suggested that this ability should be regarded as a particular case of *animal reasoning ability*. He phrased this notion as the ability of an animal to grasp the (elementary) laws (or rules) which connect objects and events in the external word, and to behave in an adaptive way with respect to them. Today, this phenomenon is referred to as the ability to understand (and solve) problems of elementary logic. Krushinsky's theoretical considerations were summarized in sevaral books and numerous papers, and articulate in detail the three main components of adaptive animal behavior distinguised schematically in Fig. 1.

Instances of reasoning ability can occur (and are revealed) in situations where neither instinctive endowments nor previous training help an animal to solve a task, as it emerges accidentally and is not similar to previous experience of the animal. *In other words, reasoning activity is required in Krushinsky's view when an animal has no "ready-made" reaction to respond with in a new situation, while the constellation of events requires urgent action.*

2 The Extrapolation Experiment

2.1 General Outlook on the Obtained Data

In the middle of 1950s, L.V. Krushinsky designed the experimental scheme which permits to evaluate the extrapolation ability of different animals (and to quantitatively evaluate the degree of correctness of animal responses, which was not common for behavioral biology at that time). Initially, experiments were done with dogs and cats, but quickly the number of species investigated grew and birds of several species were investigated as well (crows, rooks, magpies, pigeons, chicken, and several species of birds of prey). Experiments with animals of different species have proceeded also after L.V. Krushinsky's times. In a newly issued book (dedicated to his 100th anniversary), the solution of several other reasoning tests apart from extrapolation has been investigated in crows in numerous experiments, described in detail in [2].

Several years after the start of extrapolation experiments, rodents and foxes were also tested, and still later – brown bears and wolves (not in zoos, but in laboratory). The schematic drawing of *extrapolation* experiment is shown in Fig. 2. Krushinsky's extrapolation test consisted of the following: a hungry animal sees a food bait through an opening (vertical slit) in an opaque screen, and starts to consume the food. After a few seconds of food consumption, the food bowl is moved aside and disappears from the animal's view. The correct solution to the problem is to move in the direction towards which the food disappeared, *extrapolating the position* where it could be reached. The successful test solution would be based on the animal's ability to understand the rule of *object permanence* and also the laws of movement. The latter means that the object's future position (if it moves along a straight trajectory) could be extrapolated on the basis of a mental representation of the hidden object's movement, and thus the animal could *anticipate* the future position of the required object.

Representatives of five vertebrate taxons (fish, amphibians, reptiles, birds, and mammals) have been characterized in terms of their extrapolation ability [3,4]. *The solution of this test upon its first presentation is the most important indicator of subsequent success in solving the task in a given animal group.* At first, most tested animals have no previous experience in solving a problem of this type. During repetitive task presentations, the respective experience is formed and in various ways begins to modify the task solution through training and learning mechanisms. However, during the first trials, the mechanisms of instrumental learning do not yet interfere with the task solution, and are taken to reflect animals' reasoning activity as distinct from instinctive and instrumental behaviors (Fig. 1). Therefore, the extrapolation task presentation score on first trials is considered to be the most informative one concerning extrapolation ability *per se*, as a specific anticipatory *reasoning ability.*

This success could be expressed as the proportion (in %) of correct choices made by a particular group of animals. In several species, this proportion would not be significantly different from the 50% chance level [4]. The same procedure could be used for data on multiple task presentations. The highest values of correct extrapolation task solution were found in carnivores and dolphins, and among birds – in corvids (see [2-3]).

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[3] When Krushinsky's ideas on animal reasoning and extrapolation ability in numerous species were published, they were appreciated by several neurologists and geneticists, but also aroused clamor. The most serious argument from zoologists was that the extrapolation of prey is adaptive for carnivores, but not for rodents. However, experiments showed that rooks (who gather food from soil) and ravens (carnivorous birds) have similar extrapolation indices, while birds of prey, who "need" this capacity showed lower indices than corvids. The main factor corresponding to the degree of extrapolation success was found to be the encephalization index (or Portman index for birds [2]).

[4] The statistical significance of the non-randomness of this proportion was evaluated using Fisher's φ test.

The results of experiments in which the extrapolation paradigm was used raised several problems which were analyzed in detail in Krushinsky's monograph [3]. These were: the scope interspecies differences, direct and indirect influence of previous experience (learning) on extrapolation performance, developmental aspects of this ability, genetic differences, species ecological specialization[5], and the level of encephalization.

It is not possible to analyze all these problems in the present paper – the interested reader is addressed to Krushinsky's monograph[6]. Below, the analysis of extrapolation task solution will be presented in a unique groups of mice – animals with robertsonian translocations (chromosomal mutations) and in mice, selected for the high scores of extrapolation task solution.

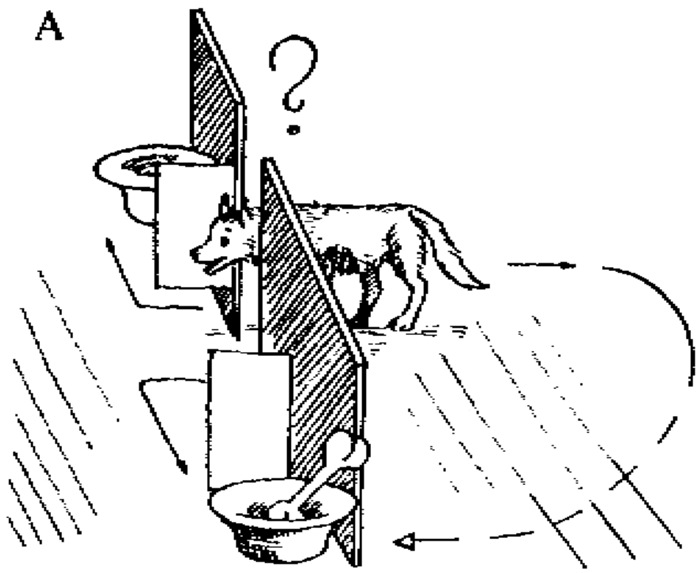

Fig. 2. The "screen experiment" described in Krushinsky's first monograph (English translation published in 1962[7]). This device was used for testing extrapolation ability in mammals and birds. The opaque screen has a vertical slit in the middle. Behind the screen, two food bowls could move along a horizontal rail (not shown). The food can move to the left or to the right and disappears from the animal's view soon (partly with the help of flexible "flaps"). The animal's trajectory for correct task solution is indicated with the broken line.

2.2 Problem of Anticipation and Time Scale of Extrapolation Task Solution

Anticipatory phenomena have been described formally in detailed papers published several years ago in the European Journal of Neuroscience. In this context, anticipatory reactions are regarded as a form of prediction of resource availability, which should be optimized to enhance the survival of the animal [1]. These reactions involve, as Antle & Silver [1] state, all higher order brain mechanisms – learning and memory, reward and punishment, memory and cognition, arousal and feedback associated with changes in internal and external state, homeostatic processes, and timing mechanisms. The general neurophysiological analysis of anticipatory reactions deals here with timing mechanisms on the scale of circadian oscillations [1]. The neurogenetic and physiological studies now give a sufficiently coherent and complicated scheme of these processes [5-6].

[5] Ecological "predetermination" of extrapolation ability was the subject of most heated debates with zoologists who defended the idea of the instinctive nature of this ability. This argument was not as valid as they suggested, however, as corvids had higher task scores in this ability than birds of prey, who are highly specialized to pursue moving prey (especially honey buzzards who follow visually the flying wasp in order to find it's nest). The confirmation of this view came also from experiments with carnivorous and herbivorous turtles, who are both equally able to solve the task, although herbivorous turtles never chased moving prey.

[6] The monograph was issued first in 1977, 2nd and 3rd editions followed in 1986 and 2009. The English translation was published in 1990 [3].

[7] L. V. Krushinsky. Animal Behavior: Its Normal and Abnormal Development. Consultants Bureau, 1962.

Our brief review will concern a rather narrow area of this large field – namely the capacity of an animal to pick up (visually "grasp"), and then retain in memory a biologically significant event. The next stage of this reaction would be to move in the respective direction and finally, to achieve the goal (e.g., consuming the food). Thus, the time scale of the anticipatory events under consideration is in the range of dozens of seconds and minutes. The reported extrapolation experiments were performed in a relatively rapid pace, which permitted to present an animal with several identical tasks in close succession. This means that our analysis of probable anticipatory abilities in a subject is restricted to short time intervals (instead of hours or dozens of minutes). It also means that phenomena of short term and recent memory are involved, and the respective analysis should take the varieties of memory trace fixation into consideration. Unfortunately, neither L.V. Krushinsky nor his colleagues, who worked with the extrapolation paradigm after he deceased, have paid sufficient attention to the mnemonic aspect of the problem. One way to elucidate this point would be to establish correlations of extrapolation task success with recent memory parameters. While this is one of the prime goals of future experiments, in the current paper, this issue is not addressed as the experiments reported on are mainly concerned with finding and creating groups of laboratory mice with reliably high expression of this trait (respectively, searching for them in experiments with mice carrying chromosomal mutations, and creating them through selection for cognitive traits).

3 Phenomenology of Extrapolation Task Solution in Experiments with Laboratory Mice

Rodents (laboratory rats and mice in particular) solve the extrapolation task in a proportion of cases which is not significantly different from the 50% chance level. At the same time, tests on the extrapolation ability of wild brown rats performed by L. Kuznetzova demonstrated that these rats solve the task in about 80% of cases upon its first presentation. Similar results were obtained when the extrapolation performance of wild and domesticated foxes was compared (M. Sotskaya's experiments) [4, 7]. This data showed that extrapolation ability was somehow compromised (or inhibited) by artificial selection – i.e., by breeding animals in captivity.

Extrapolation task solution in mice with Rb (8,17) 1Iem chromosomal mutation. Extrapolation ability in mice was tested using a device (Fig. 3) somewhat different from the initial "screen" setting (Fig. 1). The changes introduced (apart from box dimensions, adjusted to the size of the mouse) enabled the experimenter not to remove the animal from the box after each task presentation, and thus not to induce additional anxiety (see Fig. 2 and respective caption).
Mice of several genotypes were tested for the extrapolation task (i.e., CBA, DBA/2, C57Br, A/He, BALB/c, 101/HY inbred strains, as well as genetically heterogeneous mice with various chromosomal mutations) [7]. It was confirmed that most of them were not able to solve this task (with the exception of several genetically highly heterogeneous groups of mice bred as crossings of several inbred strains – their performance was above the 50% chance level on some occasions).

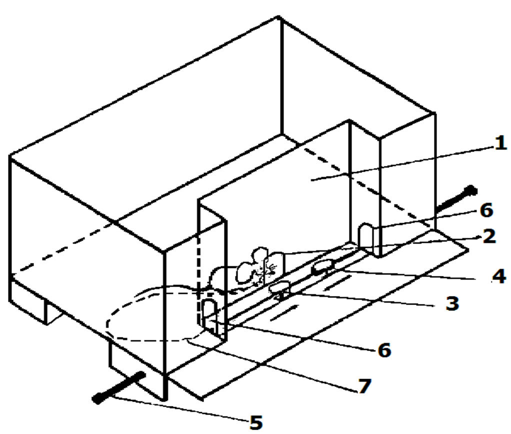

Fig. 3. Experimental box for testing extrapolation ability in mice. 1 – solid, non-transparent wall with a small opening (2) at the center of its base (other sides of the box are also non-transparent). A hungry and thirsty mouse starts to drink milk from the small food cup placed behind the central opening. Two food cups could move on the horizontal rail manipulated by the attached handles (5). 3 and 4 – cups with milk. The cup in front of the central opening (3) is the one from which the mouse starts to drink, another one is for odor and noise control. The latter milk cup is not visible to the animal (as the central opening is small enough). 6 – the side opening, placed in the inserted part of the box, serves to provide milk to the animal in case it makes the correct choice. 7 – the broken

line shows the mouse's way towards the "correct" opening. Thus, the animal has to move in the respective direction (which is chosen either by chance, or on the basis of information inferred from the direction of cup movement), and turn "around the corner". If it moves to the opposite direction and approaches the other side opening, the milk would not be provided – the control cup stays at a distance not reachable by the mouse. The direction of food cup movement alternated in a quasi-random order (according to the protocol, no more than two consecutive cup displacements in the same direction were permitted).

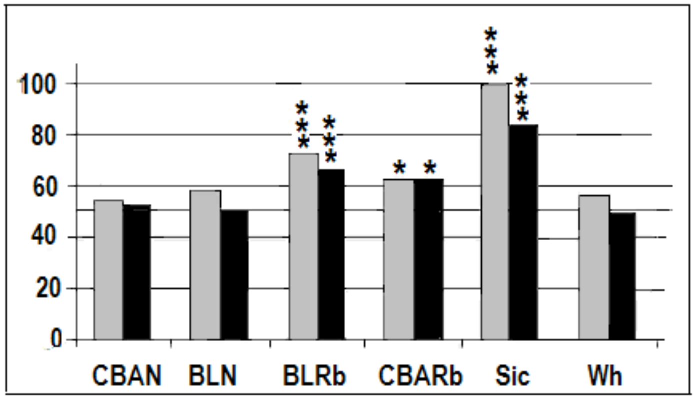

Fig. 4. Extrapolation task solution in mouse groups differing either in genetic background (BL or CBA) or in karyotype (N or Rb). Ordinate – the proportion (%) of correct task solutions. Grey columns – data on the solution of the extrapolation task upon its first presentation. Black columns – extrapolation task success for 1-6 presentations. CBAN — CBA inbred mice (with normal karyotype), CBARb — mice of the new strain with CBA genetic background that carries Rb (8,17) 1Iem. BLN — C57BL/6J inbred mice, BLRb – mice of a new strain with C57BL/6 carrying Rb (8,17) 1Iem, Sic — mice – descendants of the Sicilian wild mice in which the robertsonian translocation Rb (8,17) 6Sic (fusion of the same chromosomes) was found, Wh — mice with the Rb (5,19) 1Wh – the robertsonian translocation with other chromosomes involved in the fusion. *, **, *** — significantly different from 50 % chance level, $p < 0,05$; 0,01 and 0,001 respectively.

At the same time, mice that carried a definite robertsonian translocation, i.e., the fusion of chromosomes 8 and 17, were able to solve the extrapolation task (Fig. 3), regardless of the type of genetic background [4, 8]. These results, illustrated in Fig. 4 (columns BLRb and CBARb), made it possible to analyze some features of concomitant behavioral peculiarities of animals with this translocation[8]. Thus, mice with Rb (8, 17) 1Iem solved the problem of extrapolation on a significantly non-random level.

Comparison of learning vs. extrapolation (in latencies of reaching food). In an attempt to compare the pace of mice's behavioral reactions in extrapolation versus learning paradigms, the latencies of reaching the food by the side openings of the device (Fig. 2) in instrumental learning and extrapolation tests were compared in three mouse groups. In the instrumental learning experiments (also performed in the extrapolation box), the approach to only one side opening was reinforced. Data on the numbers of trials to learning criterion and rates of subsequent reversals are not presented, although mice with Rb (8,17) 1Iem learned more efficiently. In the learning procedure, mice drank milk from the central opening for 3-5 sec. Then the central opening was closed by inserting a carton square (contrary to the extrapolation design, in this case the food did not move, it simply became unavailable). Further, one of the "extended" parts of the box containing the side opening (cf. Fig. 3.) was blocked, so the mouse could move only to the remaining side opening. Walking (or running) to the available opening served as an *instrumental reaction*, learned by the animal to obtain food (reinforcement) only via one particular opening. The latencies of approaching the food were measured in 10 trials on 5 experimental days in the instrumental paradigm, and in 6 trials on 3 days in the extrapolation paradigm [9].

[8] Its name Rb (8,17) 1Iem refers to the Institute of Experimental Medicine in Leningrad, were it was identified by prof. V.S. Baranov

[9] There is thus some methodological discrepancy between two experimental paradigms concerning the number of daily trials and number of experimental days. This discrepancy was due to the fact that these groups of mice were first tested in the extrapolation task, and as the learning experiment with the same groups of mice started, it became obvious that 3 days with 6 task presentations were not enough for instrumental skill acquisition. As numbers of mice with Rb (8, 17) 1Iem were always limited, it was decided to leave the schemes as they were.

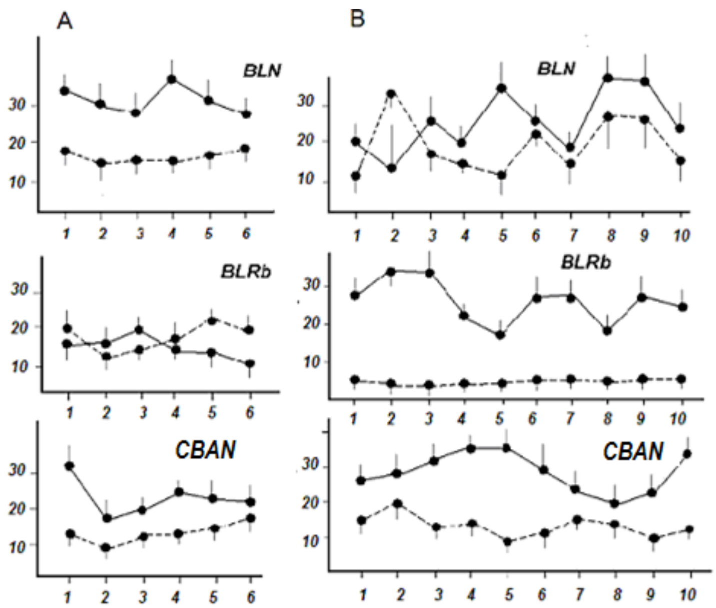

Fig. 5. Mean latencies in approaching the side opening in various mice lineages: CBAN, BLN and BLRb (with Rb (8,17) 1 Iem) specimens in two behavioral paradigms. A – extrapolation task solution (latencies of both correct and incorrect solutions); B – instrumental reaction (approaching a food cup with a fixed position, with 100% reinforcement). The extrapolation task was presented during three experimental sessions (6 presentations in each), and the instrumental learning task during five sessions (10 presentations in each). Ordinates – time in sec., abscissae – task presentations during one day session. Solid lines – mean latencies on the first experimental day, broken lines – latencies on the last day.

The animal samples used in learning experiments had been previously tested in the extrapolation paradigm. The proportion of correct extrapolation task solutions was significantly above the chance level in the Rb (8,17) 1Iem group, but no different from it in the other two groups (data not presented). The latencies in their approaches to the side openings during this test are presented in Fig. 5 A.

Fig. 5 B shows the latencies in acquiring instrumental running skills in three groups of mice during the first and last days of training. The shortening of these reaction times, as an indicator of learning, was much more prominent in the BLRb mice with the Rb (8, 17) 1Iem translocation compared to the CBA mice, and especially compared to the C57BL mice with normal karyotype. This means that in the experimental design highlighting instrumental learning, the reward was acquired more efficiently by mice with Rb (8, 17) 1Iem than by mice of the other two groups (the mean latencies of Rb (8,17) 1Iem mice scores were about 5 s., data not presented).

At the same time, in the mice carrying the Rb (8, 17) 1Iem translocation, there were practically no differences in the speed of approaching the side opening between the 1st and 3rd days of the extrapolation experiment. Thus it could mean that when the anticipatory "mode" was present in their behavior, it did not affect their speed of running, as it did in the instrumental paradigm. In other words, in case of the extrapolation task, the anticipation of obtaining food after it disappears from view was in these mice not expressed in faster (running) response, but was presumably based on adequate use of information about food movement, i.e., these animals performed the search using "logical reasoning". On the other hand, in the two other groups, approaches to side openings in the extrapolation paradigm were quicker on the 3rd experimental day than on the 1st one. It should be remembered that these mice performed the extrapolation task on the 50% chance level. In these groups, the "anticipation" of finding food was expressed solely in increasingly fast running, and the 50% reinforcement schedule made this "worthwhile".

Thus two expressions of anticipatory activity could be noted among the mice of different groups. The first one is based on a cognitive reasoning ability and the second one expressed in the instrumental learning of the performance. It is not possible to conclude which of these is of higher adaptive value per se. One may assume that neither of the two experimental paradigms corresponds to the real life circumstances of the domestic mouse in its natural habitat.

Results of factor analysis. The obtained data were further analyzed. The extrapolation scores (indices of correct solutions and latencies), open field behavior indices, food consumption, etc. were analyzed. The following groups were used in this analysis: Rb (8, 17) 1Iem mice with BL (n=71) background, CBA mice carrying Rb (8, 17) 1Iem (n=35), and CBA specimens with normal karyotype (n=44). The correlations were calculated and factor analysis performed (using the method of principal factors, which provides a single solution for given variables with respect to distinguished factors). The goal of this analysis was to identify the peculiarities of different behavioral traits in mice with Rb (8, 17) 1Iem and with normal karyotype in order to find the plausible cause of elevated extrapolation ability in the first group [9]. Detailed analysis of the factors found for these variables was presented in the original paper [9], see also [10]. Below, the factors which were most tightly connected to differences in extrapolation task success will be briefly described.

The factor of "fear" was found in the behavioral scores of all three groups of mice. It loaded positively and significantly on emotional reactivity ("open field" indices) and on some latency values of extrapolation task solutions. This means that in the absence of fear mice solved the task more quickly.

The group of "extrapolation" factors. One of them loaded positively on the index of the 1st extrapolation task solution and on latencies of further extrapolation solutions. This means that the more successful the first trials were, the longer the further task solution latencies (this corresponds to data presented in Fig. 4, although the experiments were done with a ten year interval). The second "extrapolation" factor was found only in Rb (8, 17) 1Iem mice with BL background. It loaded positively on the index of the first task presentation and on the number of open-field hole-pokes[10]. In sum, the factor analysis data lead to the following conclusions: 1) in mice with CBA genotype, the quick (but random) performance on the extrapolation task was realized mainly on the basis of acquired instrumental reaction, consisting of a stimulus – food disappearance – and a response – searching through the whole area of the box, looking through the side openings in a random manner. Thus these responses are not based on specific reasoning or anticipatory processes; 2) in all mice, the successful (correct) solution upon first task presentation correlated with slower performance in the course of further task presentations (one of the "extrapolation" factors mentioned above), but it correlated with elevated exploration in mice with Rb (8, 17) 1Iem only; 3) several "extrapolation" factors had similar loadings in all mouse groups, which means that all (investigated) mice had similar patterns of behavioral "structure". However, animals able to solve the task correctly were more numerous among Rb (8, 17) 1Iem carriers. In general, the correct task solution correlated not with any single behavioral trait, but with several ones. This could indicate that the correct performance of this *anticipatory behavioral act* may occur optimally when several conditions are present – implying some optimal central nervous system functions and properties. Some of these were considered in detail by Krushinsky [3], and await further corraboration and specification in future research.

Selection for high extrapolation ability. The next experiment elucidated some further details concerning the "internal organization" of the capacity to solve the extrapolation problem. In this selection experiment, mice were bred for high scores of extrapolation ability[11]. The details of our selection procedure are described in Perepelkina et al. [11-12]. It should be mentioned that the mice selected to reproduce not only solved the extrapolation task correctly, but also displayed no signs of fear in the extrapolation box when presented with the task. The CoEX group mice served as controls – they were derived from the same initial population as the EX, but were bred at random[12].

During the first selected generations (F4-F9), the percentage of correct solutions in mice of the selected line (EX) was significantly above the 50% chance level, while control mice scores did not differ from it [11]. At the same time, EX mice were less anxious in the elevated plus maze test (thus the selection for fearless mice was successful). However, the pattern of differences between EX and CoEX changed from F10 onwards. Sex differences also emerged (not discussed here). Moreover, in F11, the extrapolation scores of EX mice were not significantly different from 50% chance level. In these generations, CoEX mice demonstrated variable levels of correct task solutions, as well as variable levels of fear-anxiety indices (not always significantly different from those of EX mice). It looked as if the selection experiment had failed to obtain the expected differences in terms of the cognitive trait that was selected for.

A B

[10] In some varieties of the open-field test, small holes are made in the floor of the arena and while exploring the area an animal dips the nose into these holes. The number of such "hole-pokes' is taken as a measure of exploratory tendency (together with the number of rearing postures).

[11] Unfortunately this experiment remains the only one in which a cognitive trait was selected for.

[12] The six inbred normal karyotype strains were used for creating the heterogenous population. The strains chosen differed by brain weight significantly, as initially this population was used for brain weight selection program [7].

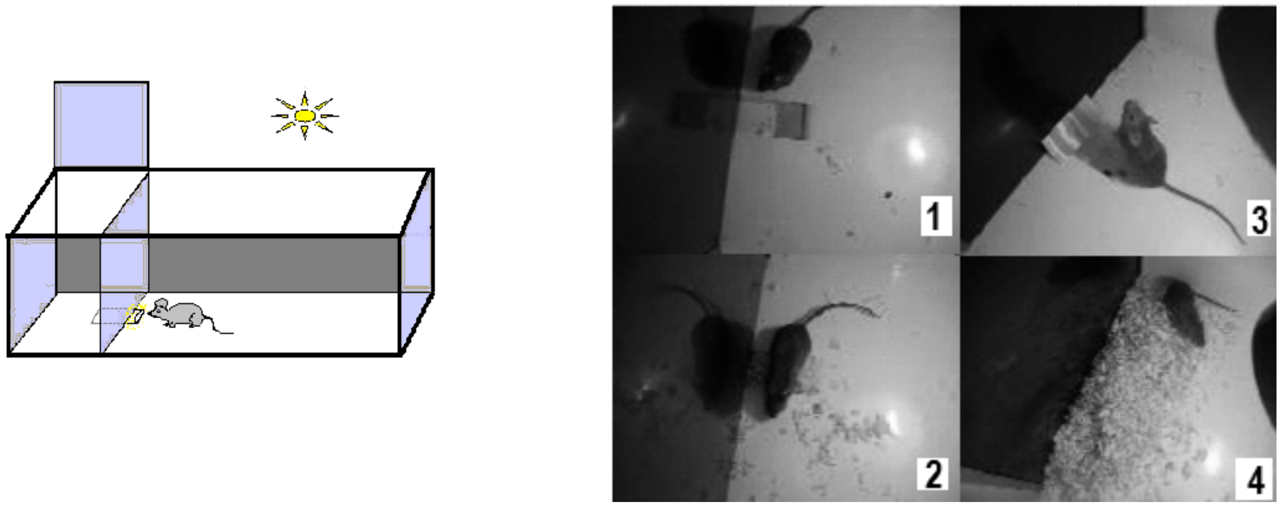

Fig. 6. “Puzzle box” test: A - schematic drawing of the puzzle-box, B – pictures of mice during stages of experiment; 1 – the underpass to the dark compartment is free; 2 – the underpass is covered by wood shavings; 3 – the underpass is hidden by a carton-plastic plug, which the mouse can remove with its teeth, but is unable to push into the underpass opening; 4 – the whole wall containing the underpass is covered by a thick layer of wood shavings.

Presumably the initial selection success, which was seen during the first stage of selection, was inhibited by some (yet unknown) factor which prevented further improvement of the trait, and it was not possible to reveal changes in the “cognitive” status of the selected line using the extrapolation task alone. This idea was confirmed in experiments using another cognitive task – the “puzzle-box” test [13]. In this test, the mouse is placed into the brightly lit compartment of a two-chambered box, the partition between which contains an underpass. Via this underpass, the animal can escape the brightly lit part of the new environment into the dark compartment of the same box (Fig. 6 A). The underpass could be free, or blocked either by wood shavings or a plug (made from plastic and carton), which is light and could be removed by the animal (Fig. 6 B). The performance of EX mice in this test was significantly more successful than the CoEX ones (see Fig. 7 and [12]).

Successful solution of this test is based on the animal’s ability to understand the rule of “object permanence” (i.e., objects which have been in a certain place and become invisible still exist). This test solution also requires a cognitive ability in the “elementary logic” category. The escape reaction which the animal performs either directly, when no obstacle is presented, or after some mental procedure (seeking for the underpass, trying to penetrate the wall, digging in the wood shavings, or removing the plug) is based on fear-anxiety motivation (i.e., not on food motivation, as in case of extrapolation).

The group of EX mice that solved this test successfully in its most difficult stage (the plug in the underpass) surpassed the CoEX control mice significantly in three selected generations. The solution of this test was not determined directly by the fear-anxiety state – CoEX mice were more anxious than EX ones, but were slower to solve this test [12]. This means that the outcome of selection for high scores on the extrapolation task was revealed in the higher ability to solve another cognitive task – the “puzzle-box” test, instead.

The EX and CoEX mice performed differently on one more test – that of hyponeophagia (novelty-induced suppression of feeding). In this test, the reaction of a previously food-deprived mouse to a new type of food (here – cheese) in a new, but non-threatening environment is analyzed. Neophagia indices chosen here as markers of novelty reactions reflect the lack of novelty induced suppression of feeding – hyponeophagia. Therefore, the higher the values of behavioural reactions towards novel food in new environments were, the lower was the novelty avoidance demonstrated by the animal (Fig. 8). The respective values for EX mice were found to be significantly higher in comparison to the CoEX ones.

In the hyponeophagia test, the behaviour displayed towards some novel element in the environment is presumably under the influence of at least two factors: the inhibitory influence of anxiety and the “provocative” influence of “neophilia” (exploration tendency). The EX mice demonstrated a higher prevalence of novelty-reaction in this test and this is in agreement with their presumed elevated cognitive ability.

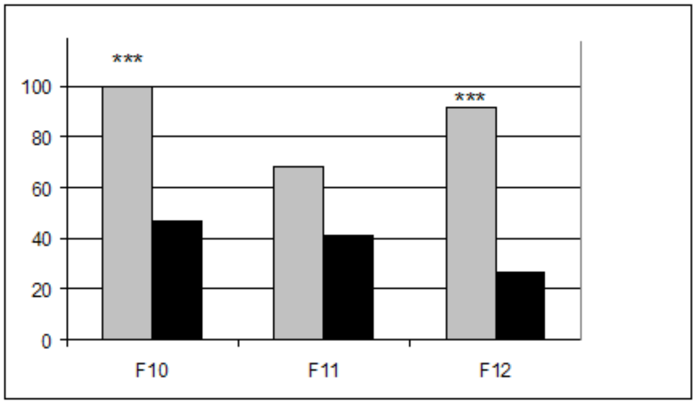

Fig. 7. The proportions (in %) of EX (grey columns) and CoEX (black columns) mice in three selected generations, who solved successfully the "puzzle-box" stage, where the plug had to be removed. *** – significantly different from the score for CoEX group (φ – method of Fisher for alternative proportions).

A B

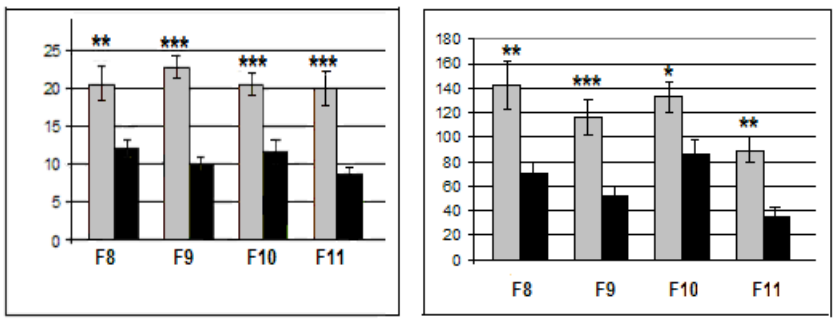

Fig. 8. Neophagia test indices in EX (grey columns) and CoEX (black columns) male mice in F8 - F11. The higher the columns, the lower the index of hyponeophagia. A – number of approaches (ordinate) to the cup with a small pieces of cheese (new food). B – time *sec, ordinate) occupied by eating. *, **, *** – significantly different from the respective values for CoEX mice, p<0.05, 0.01,), 001, respectively.

Thus, the results of the selection experiment demonstrated at this stage that extrapolation ability as a cognitive trait should be regarded as a result of "positive" cooperation among many factors. This consideration is in accordance with the data obtained in experiments with mice carrying Rb (8, 17) 1Iem, i.e., it agrees with the correlations of extrapolation task success with decreased fear and elevated exploration intensity. Thus, animals (without a highly developed brain, like mice) are able *to anticipate* the achievement of a certain goal, although this may not be equally successful in all individuals. Both genotypic and environmental factors obviously influence the phenotypic expression of these complicated behavioural features, although usually it is not possible to distinguish the true origin of intraspecies variability and trait instability.

4 Concluding Remarks

Mice are able to foresee the achievement of goals in the nearest future, i.e. to anticipate future events (and adjust their behaviour respectively). The experimental results described in this paper demonstrate that this anticipatory capacity, analyzed in the form of elementary logical task performance, is influenced by fear-anxiety motivation, reaction to novelty and, perhaps, by other behavioral factors. In order to behave according to the elementary logical requirements of the presented task, an animal has to possess a whole complex of various traits. For successful anticipation, the phenotype should exhibit a certain balance among them. As selection experiments for higher cognitive traits (reasoning ability) have to our knowledge never been done before, our data demonstrates for the first time that, in spite of the complicated patterns of selection results, anticipatory behavior and capacities are also under genetic control.

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References

1. Antle M. C. , Silver R.: Neural Basis of Timing and Anticipatory Behaviors. Eur. J. Neurosci., Vol. 30, pp. 1643–1649, (2009)
2. Poletaeva I. I. & Zorina Z. A. (eds.): The Development of Behavior: Its Normal and Abnormal Aspects. To the 100 Anniversary of L.V. Krushinsky. LRS Publ. House, (2013) (In Russian)
3. Krushinsky L.V.: Experimental Studies of Elementary Reasoning. Evolutionary, Physiological and Genetic Aspects of Behavior. Oxonian Press, New Dehli, (1990)
4. Poletaeva I.I. In: E.Alleva et al. (eds), Behavioral Brain Research in Naturalistic and Semi-Naturalistic Settings, Kluwer Academic Publishers. 375-393, (1995)
5. Acosta-Galvan G., Yi C.-X., van der Vliet J., Jhamandas J. H., Panula P.I, Angeles-Castellanos M., del Carmen Basualdo M., Escobar C., Buijs R. M.: Hypothalamic Dorsomedial Nucleus and the Suprachiasmatic Nucleus Determine Intensity of Food Anticipatory Behavior. PNAS, Vol. 10, pp. 5813–5818, (2011)
6. Challet E., Mendoza J., Dardente H., Pevet P.: Neurogenetics of Food Anticipation. Eur. J. Neurosci., Vol. 30, pp. 1676–1687, (2009)
7. Poletaeva I. I., Popova N. V., Romanova L. G.: Genetic Aspects of Animal Reasoning. Behavior Genetics, Vol. 23, pp. 467-475, (1993) doi:10.1007/BF01067982
8. Leitinger B., Poletaeva I. I., Wolfer D. P., Lipp H. P.: Swimming Navigation, Open-Field Activity, and Extrapolation Behavior of Two Inbred Mouse Strains with Robertsonian Translocation of Chromosomes 8 and 17. Behav Genet., Vol. 24, pp. 273-284, (1994)
9. Poletaeva I.I., Salimov R.M.: A Factor Analysis of Behavioral Organization in Mice. Zh. Vyssh. Nerv. Deiat., Vol. 42, pp. 314-324, (1992) (in Russian)
10. Poletaeva I. I., Romanova L. G.: Chromosomal Mutations and Mouse Ability to Extrapolate the Direction of Stimulus Movement. In: Poletaeva I.I., Zorina Z.A.(eds)). The Development of Behavior: Its Normal and Abnormal Aspects. To the 100 Anniversary of L.V. Krushinsky. LRS Publ. House, pp. 217-238, (2013) (in Russian)
11. Perepelkina O. V., Markina N. V., Golibrodo V. A., Lil'p I. G., Poletaeva I. I.: Selection of Mice for High Level of Extrapolation Capacity with Concommitant Low Anxiety. Zh. Vyssh. Nerv. Deiat., Vol. 61, pp. 742-749, (2011) (in Russian)
12. Perepelkina O.V., Golibrodo V.A., Lilp I.G., Poletaeva I.I.: Selection of Laboratory Mice for the High Scores of Logic Task Solutions: The Correlated Changes in Behavior. Advances in Bioscience and Biotechnology.. Vol. 5, pp. 294-300, (2014) http://dx.doi.org/10.4236/abb.2014.54036
13. Galsworthy M.J., Paya-Cano J.L., Liu L., Monleon S., Gregoryan G., Fernandes C., Schalkwyk L.C., Plomin R.: Assessing Reliability, Heritability and General Cognitive Ability in a Battery of Cognitive Tasks for Laboratory Mice. Behav. Genet., Vol. 35, pp. 675–692, (2005)