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The Phenomenon of Indirect Learning: Brain Mechanisms and Models

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Abstract

We studied an artificially constructed isomorphism between denotative (color) and lexical (geometric shapes) spaces and revealed the dynamics of formation of color-semantic representations in the process of indirect learning. We have detected the component of evoked potential (EP), which describes its changes from trial to trial in the process of learning; it significantly correlates with the value and direction of the errors. The results confirm the role of the brain structures that control movement (globus pallidus, caudate nucleus) in problems reconfiguring the system of relations between the sensory attributes of the reception of sign (visual cortex), and attributes of denotatum stored in memory (frontal cortex and parahippocampal gyrus) that occur during the formation of concepts.

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1. Introduction

Complete acquisition of knowledge requires, above all, learning in symbolic form a system of generalizations which are the main content of knowledge. Not only a sign (concept) should get its denotative function (fixing correspondence between sign and denotatum), but there is a certain structure of the whole integrated system of signs (signs should get their significative meaning), i.e connections and mutual relations of signs must match the natural connection of objects in the real world.

For a long time the prevailed understanding of the mechanism of concept formation was limited to the process of establishing links between different brain areas or to association of the two impressions of the sign and the denotatum. However, the use of special method to deploy the process of concept formation by Ach, L.S. Vygotsky and L.S. Sakharov [1], [2] showed that the formation of concepts has always productive rather than

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reproductive character. Experimental investigation of integral human conceptual systems is possible by the development of special methods for constructing semantic spaces, whose structure (dimensions, metrics, basic axis of the space as system attributes, position of points-concepts in the system of axes) models the structure of the relevant subjective representations. Establishment of relations between the denotative (perceptual) and lexical (semantic) spaces at different stages of formation of the sign system allows us to investigate the mechanisms of semantic coding more effictively [3], [4], [5], [6], [7], [8], [9]. The formation of the semantic space can also proceed on the basis of purely verbal associations, such as the color representations blind people [10], and people with impaired color vision in the natural language learning [11], [12]. Study of verbal and nonverbal forms of human communication, the communication systems of animals [13], [14] suggest that human language as a flexible semiotic system of consciousness and communication must include and use at the new level, some more archaic elements of semiosis and in particular the phenomenon of the sound symbolism or, more precisely, the modeling of the external world by means of the vocal apparatus.

Researches in this direction which considering brain mechanisms of coding [15] allowed us to formulate an assumptions that at certain level of language development transformed the process of the concept formation (sign system) in the process of finding and establishing regular correspondence (agreement) between two integrated systems of signs (displayed by two local analyzers).This refers to general perceptual attributes of whole set of denotations and general perceptual characteristics of the set of objects that become signs. The test person on the basis of the experience of individual pairwise associations denotation - sign detects the general conformity (isomorphism) of two sets altogether. He trying to define the rule of transformation (of the conversion) for attributes system to another one (in the model of such a transformation can be formally reduced to the axis-rotation of one space with limited dimension in an axis-system of another, if these spaces are isomorphic). This mechanism underlies the particular type of learning, which can be called indirect or "paradoxical" in classical model of associanism. The phenomenon of indirect learning appears when one can find a pair of objects that have never been associated in the experience of the subject as pair sign-denotatum, however the linkage between this objects was formed indirectly through the formation of a general compliance between systems of attributes. The presence of the phenomenon of indirect learning with artificial concepts material has been experimentally demonstrated in humans [16]. The special technique of a quantitative assessment of character and size of mistakes was for this purpose developed. It was confirmed experimentally that the mechanism of this type of learning is to establishing by subject the general compliance of the two local systems of attributes on the basis of trial and error and that such compliance is achieved by rotating the axes of one space of attributes relative to other one. As a result, errors in tests on individual pairs of incentives are not random, their value and tendency is directly correlated with the size of the rotation angle of the basis of space in the given trial.

We aimed to identify the dynamic formation of semantic representations of color by human and tracking the corresponding dynamics of brain activity during indirect learning in the conditions of artificially constructed (iso) morphism between denotative (color) and lexical (geometric shapes) spaces.

2. Methods

Subjects. 5 healthy right-handed subjects (mean age 20.2 +/- 5.1 years old) with normal color vision.

Equipment. We used a computerized system with 21-channel electroencephalograph "NeuroKM" and the system Presentation for displaying of stimuli. Data analysis was carried out in the system BrainSys, use special tools to separate the signal from the noise (MFS) [17] and factor analysis of the EP changes relative to the mean, cerebral localization based on equivalent electrical dipoles was carried out in the program BrainLoc.

Procedure and stimulus. The methodology was a modification of the double stimulation by Vygotsky and Sakharov. Use two samples of stimuli created in a special way, which were subjectively specified in the preliminary experiments. Received stimuli formed ordered sequences on the ground of two specific subjectively perceived attributes. As signifieds we used color stimuli (presented on computer screen) which formed a continuum of changes in hue from green to red (including yellows) and in saturation (subjective color intensity), i.e. these stimuli constitute a subset of the four-dimensional variety of possible color changes. As stimulus-signs we used double figures - external and internal flat figure, both varied independently from the circle to the triangle with smooth transitions of a form. In the associative experiment were chosen 12 concrete stimuli-signs (concrete double figures) and they were given for correspondence 12 colors so that the change in the external shape from the circle to the triangle in accuracy (in regard to quantitative proportions) coincided with changes in color hue (from red to green), and the changes in internal shape coincided with changes in saturation (circle – the color is most saturated, color shade is defined by an external figure, triangle - white). The subject passed learning and test series several times (to complete acquisition of the material). In a learning series in a random order paired combinations of 10 signs and the corresponding designations (3 times for each pair) visually were presented. In a test series signs-stimuli (on 3 times for each sign; random order; 12 stimuli were used, i.e. were displayed 2 new signs had not associated in training) were shown. After each presentation the test-person had click with a mouse cursor on the designated shade of color on a palette, which is representing gradually all possible shades of color (for a horizontal: from green to red through yellow) and saturations (for a vertical: white downwards) which fully displayed the whole sample of designated stimuli in this experiment. Every choice of the test-person has been registered in the cursor position coordinates. They are then compared with the coordinates of the given (target) stimuli and the error was calculated as the difference between the chosen and the correct coordinates (separately for vertical and horizontal).

3. Results

As the result we obtained learning curves which were similar for the stimuli associated and not associated in learning series. The further analysis of the errors and analysis of the brain activity was performed separately for each subject. For each test were obtained averaged over all stimuli evoked potentials (EP) by the stimulus-sign. Then we discovered how the EP-curve in process concept formation changes. It was found that such changes occur in almost the entire time interval after the presentation of stimulus-sign. Examples of changes in the EP for one of the subjects (Sle), with the largest number of tests are shown in Fig. 1

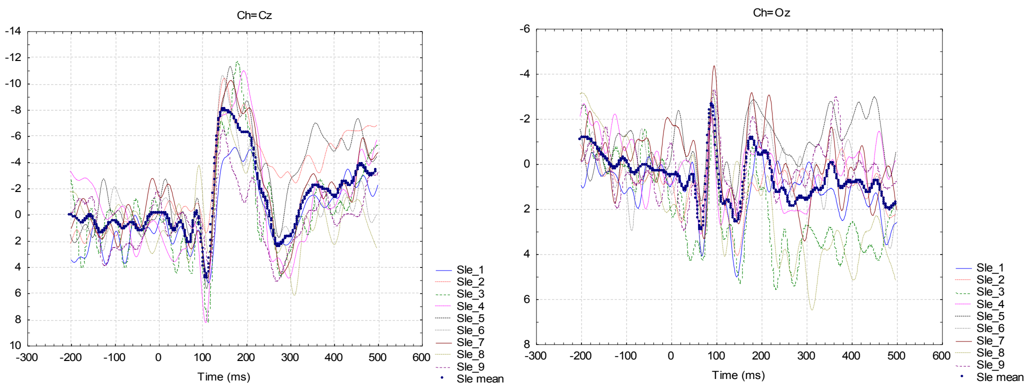

Fig. 1. Example of visual evoked potentials by stimulus-sign during test series (1-9) in the formation of concepts (with two-parameter differences between stimuli) for two channels of 21 for examinee Sle. Marker isolated on average for all samples the EP. Average on all tests of VP is outlined.

For the same test-person were analyzed the errors in the trials. It was shown that all the alteration of errors (by two registered parameters) in 9 trials are for 69.2% described by two factors and the location of variables (trials) in this space can be described by the angle of rotation in the plane (the corresponding figures are attached). Then we verified the assumption that style of mistakes alteration in these trials can find reflection in alteration of EP registered in each test (trial). For this purpose the analysis of EP change relatively the mean was carried out. It is shown that all system of changes of this EP set is described for 70.8% by three factors one of which correlates with the size and trend of a mistake in the same trials ($r = -0.7593$; $p = 0.0176$). The other EP components reflecting other processes of brain activity at performance by the person of activity by determination of value of learned designation weren't considered yet. The other EP components reflecting processes of the brain activity during definition of the denotatus by subject weren't considered yet. As a result of equivalent areas of EP localization (with high reliability at CD>.95), which are interesting within a goal of this project, we managed to find dynamic system of brain structures activation connected with it. Localization reflects only the size and the trend of mistakes.

It was shown that in the time interval 50-170 ms after the presentation of the visual stimulus-sign the activity of the left frontal cortex: Brodman Area (BA) 10, right medial (BA 6) and occipital cortex (BA 17, 18, 19, 7, it is clear as we used visual stimulation), as well as the left parahippocampal gyrus, changes. In the interval 170-270 ms changes in the activity are associated with the right frontal (BA 8 and 9) and left parietal (BA 40) cortex areas, subcortical nucleus areas such as globus pallidus and the «head» of the caudate nucleus and the right hippocampus. In the interval 270-350 ms the change in activity is also associated with frontal (BA10) and occipital (BA 19, 18, 31) cortex.

Were detected also significant individual features of the concept formation, which become apparent in learning strategies (choice of hypotheses relative to the principles of the stimulus-sign and stimulus-denotatus accardance) and in of the EP curve and, likely, in the brain processes that ensure, on the one hand, the current activity of test-person such as perception, evaluation, and task execution, and, on the other hand, the control and restructuring of systems for the assessment of stimuli from sample to sample concept formation. Therefore, as the methodical basis for integration of different test-person data isn't developed yet, we have to content us with the analysis of individual cases that is, nevertheless, much more correct than the analysis of the data average within examinees.

4. Discussion and conclusions

Deep physiological mechanisms of all forms of semantic coding at the highest human level probably have to rely on phylogenetically more ancient structures which development in animals served as the precondition for development of these mechanisms in humans. Thus in the study of the mechanisms of integration and reintegration of visual and auditory information relative to the estimation of the pray position by the owl were obtained the data which are well corresponding with received results [18], [19], [20], [21], [22]. It was shown that in inferior colliculi of the corpora quadrigemina of a owl's brain on a basis to combinations of two criteria (allocated by the distinct neural canals) forms the detector map of acoustical space and arise the isomorphic correspondence between the position of the aim and a geometrical place of the corresponding neuron-detector, i.e. take place coding by channel number [22].

This map is projected onto the visual tagmentum and forms there a bimodal map (geometrically ordered bimodal neurons-detectors). Further, this map is projected onto the motor cortex that is necessary for owl to turning the head. In ontogenesis, including the artificial distortion of the visual information by special "glasses" it is possible to reconfigure the map of auditory space under the influence of the visual system.

These experimental data allow us not only to describe quantitatively, but also to confirm the mechanism of the process of indirect learning. Obtained results confirm the role of the brain structures that control movement (globus pallidus, caudate nucleus) in tasks of reconfiguring in the system of correspondences between the sensory attributes of sign representing (visual cortex) and the attributes of the stored in memory denotatus (frontal cortex and parahippocampal gyrus) that occur as a result of the concept formation. This comply with the hypothesis of the brain mechanisms of concept formation, offering by the conceptual model [23], in which the idea of a primacy of motor integration of analyzers, and also formation of a hierarchical taxonomy and the organization of feedback of different level was nominated to the forefront.

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