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Sensorimotor and Cognitive Laterality Profiles

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Abstract—Different types of functional asymmetries, which form individual laterality profiles, were compared with the use of a battery of sensorimotor and cognitive laterality tests (TOPOS), the Benziger thinking style assessment (BTSA) test, the Cattell 17PF test, and psychosemantic multidimensional scaling. The proportion of men was shown to be higher among individuals with the left-side, symmetrical, and intersecting motor laterality profiles. Men with a dominant left leg or without asymmetry in the profile were more frequent than women, whereas women prevailed among persons with a dominant left eye. Different laterality profiles were obtained for different factors of the Cattell test. Comparison of the sensorimotor laterality and the BTSA data showed that more than half of persons with the left-hemispheric sensorimotor profile prefer right-hemispheric cognitive strategies. The results suggest that lateralities of different types may be nonuniform.

Hemispheric localization of the functions of the human brain has for many years been one of the most important branches of modern neurophysiology and related sciences. It is remarkable, however, that, as early as in 1844, Wigan [1] not only suggested independent, or individual, work of the right and left brain hemispheres but also described in detail their features and even cognitive types characteristic of each hemisphere. It is a striking fact that neither this interesting work, nor the studies of the renowned British neurologists Jackson [2] (1868) and Wilks [3] (1872), nor the investigations of the Russian researchers Manaseina [4] (1883) and Astvatsaturov [5] (1923) had any influence on the ideas of the hemispheric organization of higher functions of the brain, whereas Broca's and Wernicke's discoveries gained wide scientific recognition for many decades. The evolution of various asymmetries in animals facilitated their environmental adaptation, and formation of the functional asymmetry of the brain has provided, in a similar way, for the development of crucial human-specific features such as speech (with corresponding cognitive possibilities). It is difficult to overestimate the role of the cerebral asymmetry in adaptation to anthropogenic factors of the physical and information environment, which is continuously increasing in complexity [6].

The avalanche of works on the functional mapping of the brain, i.e., the recording of neuronal activity during mental performance, shows that virtually the whole brain is involved in the activity: for example, visual areas are activated during reading and motor areas during sound production, along with speech centers traditionally known as responsible for verbal functions. It is quite clear that regions associated with attention, memory, and emotions are also activated, along with many subcortical structures. A great amount of factual evidence for hemispheric specificity has been accumulated using different models, for example, by studying patients with commissurotomy, focal pathology, or mental disorders of different origins [7–12]. Development of noninvasive methods of brain investigation has yielded a wealth of evidence concerning the healthy human brain of right- and left-handers and subjects of both genders and of different ages, including newborns and fetuses examined in the prenatal period. Neuroscience invokes genetic, morphometric, and neurochemical data. In parallel, the importance of knowledge accumulated by sciences traditionally involved in anthropological investigations proper, such as linguistics, cognitive and cross-cultural psychology, and neuropsychology, as well as in aspects of artificial intelligence such as cognitive and sensory functions, has been realized [13–19]. There are also many concepts attempting to systematize empirical data.

Paradigms prevailing during certain periods—from purely localizationist theories, with the areas responsible for mental arithmetic or singing being found in the brain cortex, to ideas of dynamic localization, with almost the whole brain being considered to be involved in all intricate functions—alternated depending on the state of scientific knowledge. To date, the question has been poorly clarified and the above paradigms still coexist or alternate.

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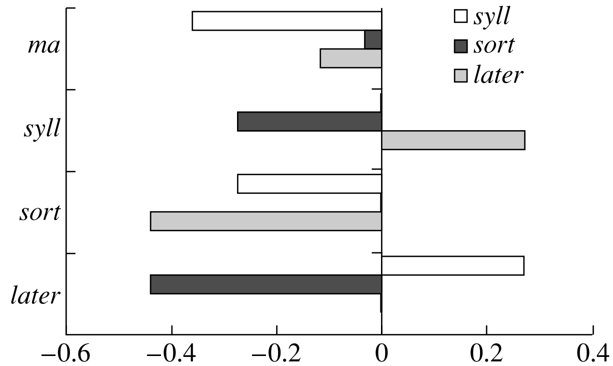
The general principles of the brain functioning are still indefinite in large measure despite the undeniable breakthroughs and discoveries of the 20th century and increasingly sophisticated techniques [20, 21]. The questions of how speech performance redistributes the activity of neuronal assemblies, how and why new functional connections are formed, and in what ways incoming information and genetic factors affect the development of language competence have been the most actively discussed in recent years.

All these circumstances should be taken into account during interpretation of the results of experimental studies of various laterality profiles in individuals, groups, or even populations [6] because it is well known that questionnaires and examination techniques may yield poorly comparable (if not opposite) results. It is noteworthy that Luria's concept of the partial dominance of functions triggered and justified investigations of this problem [22]. Multiple studies have revealed that subjects with different sensorimotor dominances differ in some features such as emotional personality characteristics, cognitive styles, and adaptive abilities [23–27]. However, a correlation between the laterality and individual psychological features was not observed in some works [28].

In recent years, the problem of asymmetry of cerebral functions has been substantially revised. Some items that determine the subject of investigation in this field remain unclear. It is of prime importance to determine which kind of asymmetry is assessed, in particular, in psychophysical and neuropsychological tests. Asymmetry can be central (cortical) or related to the sensory input; cortical, subcortical, structural, chemical, or functional; motor, sensory, or mental; individual or population; inborn or formed under the effect of ontogenetic, social, and/or cultural factors; stable or voluntarily controlled dynamic; and/or specifically human or shared with other biological species.

It has been experimentally proved that asymmetry of functions is characteristic of all levels of signal processing: from the sensory level [29–31] to the level of the most intricate cognitive tasks [12, 32–36]. Accumulation of necessary genetic, morphometric, and neurochemical evidence is increasing the number of factors relevant for the formation of brain asymmetry. The evidence in the literature and the results of our investigations show that not only the organization of the test procedure and material but also the processing and interpretation of data crucially depend on a wide spectrum of biological and nonbiological factors such as the gender, endocrine state, motivation, cognitive style, knowledge of languages, and cultural type of a subject. There is evidence that both normal and pathological functional activities of the brain are subject to diurnal fluctuations, and the periods of activity of the right and left hemispheres do not coincide. It has also been shown that a low productivity of the healthy left hemisphere correlates with fatigue and drowsiness, especially as concerns the sensory sphere [37]. Evidently, these and other dynamic factors (for example, the endocrine state, especially in women [38]) should be taken into account during testing.

The interesting problem of the distribution and features of left-handedness can be considered in this respect. According to data in the literature, the proportion of left-handers varies from 8.4 to 9.4% in a population (9.34% in France, 9.38% in Belgium, and 9.3% in Canada) [6, 39]. According to our investigations, the male populations of northwest Russia and Bulgaria have substantially higher proportions of left-handers than the female populations (7.5–8.5 and 5%, respectively) [39]. Similar data have been obtained in Spain (7.89% left-handers among men and 4.38% among women), Italy (8.28 and 5.06%), and Brazil (8.5 and 5.3%) but not in France (8.72 and 9.84%, respectively). The proportion of men with a dominant left leg is substantially higher than that of women. Symmetrical or diagonal hand–leg laterality profiles are more frequent in men. The proportion of individuals with a dominant left eye is 21–23% in southern Europe and 32% in northern Europe. In the total Mediterranean population, the proportion of women with a dominant left eye (23.6%) is higher than that of men (21%). Individual cognitive styles, associated with asymmetry, are actively discussed as significant for the organization of education and the orientation of the corresponding domains of artificial intelligence (construction of expert systems and knowledge bases, simulation of cognitive processes, and distance education); such projects have even been actualized in recent years [15, 18, 40–42]. The achievements of neuroscience have been insufficiently taken into account in construction of intelligence systems, which should, by definition, simulate the psychophysiological processes underlying human cognitive activity. Most systems based on knowledge imitate the left-hemispheric human cognitive activity, which is characterized by an exhaustive search of logical variants representing a system of formal rules applicable to the facts known in a given field. However, expert performance in any field (especially in a "soft" subject area) is based to a greater extent on vivid intuition and imaginative thinking, aggregating personal experience in task solving [19, 42]. Despite a certain level of progress in studying and developing formal mathematical procedures and software for representation of intuitive knowledge, the role and weight of such knowledge remain an open question and require special investigation. Our studies testify with high reliability that preliminary testing aimed at determining the laterality, in particular, the cognitive profile, substantially increases the productivity and rate of learning and working efficiency, as well as decreases the probability of stress and maladaptation. The same refers in full measure to the problem of occupational selection. Practically convenient testing and adequate assessment of its results are necessary to approach the question of association of hemispheric functional specialization



Correlations between the data obtained with laterality questionnaires and estimation of the metaphoric character of the configuration of psychosemantic stimuli. Designations: *syll*, score on the questionnaire of syllogisms; *sort*, score on a subset of sorting tests for cerebral asymmetry; *later*, score on the laterality test.

with individual, professional, and cross-cultural features of information processing.

In this work, we posed the problem of the development of a software for testing and analyzing laterality characteristics and subsequent use of the data in research and applied intelligence systems with the aim of studying the correlations between various asymmetries and other individual features.

METHODS

We examined 465 healthy men and women of different occupations. The following original and common tests were used.

The tool for psychophysiological survey (TOPOS) is a battery of laterality sensorimotor and cognitive questionnaires and includes questions assessing the hand, leg, eye, and ear dominances and various sorting tasks ("the fourth item is out"; syllogistic tasks; and understanding grammatical and lexical constructs, metaphors, and idioms) [40, 41].

A special software developed for laterality testing consists of two modules.

The module TOPOS/1, with a graphic interface, is designed for testing proper and importing its results into a database. The module provides the possibility of working with sensorimotor questionnaires revealing the dominant hand, leg, eye, and/or ear; a database containing information about the respondents and their responses; a drag-and-drop test, which allows sorting and pooling of objects displayed visually (lexical, syntactic, metaphoric, and third-item-out tasks); and syllogistic tasks.

The module TOPOS/2 is designed for data processing and interpretation of the results. The laterality sensorimotor questionnaire provides five answers to select from: "Always right," "Frequently right," "Either," "Frequently left," and "Always left." The answers "Always right/left" correspond to a score of 1; "Frequently right/left," 0.5; and "Either," 0. The right or left preference is determined from the total score. Cognitive laterality (*f*1) and generalized (*f*3) scales serve for interpretation of the results of testing. Each question of the test has a weighting coefficient; the algorithm of calculation of the general laterality coefficient was developed by test standardization with a representative sample and adjustment of raw estimates. The current version of the system uses the Piton language of scenarios as a means of task formulation in the above modules. Estimation of the other test components is based on our previous data on the specificity of particular responses for the predominant involvement of the right or the left hemisphere into a given task [8, 12, 32, 36].

The Benziger thinking style assessment (BTSA) test is used for determining the cognitive style in terms of hemispheric dominance [43, 44]. In this test, the subject is presented with 30 statements associated, predominantly, with the work of the left hemisphere (for example, "I think logically," "I understand technology," or "I can use money in a proper way") and 30 right-hemispheric statements (such as "I understand the language of facial expressions, gestures, and postures," "I am frequently guided by intuition," or "I like doing several things at the same time"). The subject is asked to select statements that characterize him or her best. The prevalence of a certain cognitive style is inferred from the sum of the corresponding scores as proposed by Benziger.

The Cattell 16PF test is used as a 17PF version, validated for Russian-speaking samples [45].

Psychosemantic examination consists in modeling subjective systems of meanings by means of multidimensional scaling. The system Medis [46, 47], which we developed on the basis of published works [48–50], is used as a software tool.

Historically, two major, partly overlapping approaches to psychosemantic problems can be discerned, i.e., Kelly's theory of personal constructs [51] and the repertory grid test, based on this theory, and multidimensional scaling [52–57].

As in the repertory grid technique, a list of stimuli (elements and/or constructs) is initial in our test. A certain text description (definition) of a notion or an object can serve as a stimulus. As distinct from the repertory grid technique, no distinction is made between elements and constructs; some stimuli are simply declared elements and others, constructs. As a consequence, constructs are monopolar in the Medis system.

During the estimation of differences (or similarities), scores of the categories selected by a subject are put down in a data matrix, which consists of two parts, a distance matrix and an estimation grid. The distance matrix contains estimates of element–element differences and is symmetrical (triangular). The estimation grid contains estimates of element–construct similarities and is rectangular.

The ACHS (Application Constructor for Human Studies) programming environment, with tools for prompt formulation of questionnaires and tests with an IBM-compatible PC, was developed with the aim of automating the procedure of such multifactor testing. ACHS uses the interpreter Arity Prolog 5.1, whose set of primitives was expanded to include subprograms written in the C/C++ language and allowing access to an outer database (Paradox, dBase), mathematical statistics, and a user interface. This version of the ACHS system makes it possible to input verbal texts in the interactive mode and to describe the procedures of their decoding and interpretation. To operate this system, a user does not need to know programming languages.

The software tool set TRIVIUM was developed to generate intelligent systems of data interpretation for multifactor questionnaires. Interpretation implies construction of a verbal portrait of the respondent on the basis of analysis of the factors available with subsequent translation of factor values into a corresponding description. Factors are analyzed with the use of the available database, which determines the rules of construction of the respondent portrait. The following requirements were imposed upon the software tool set. The basic variant should have tools for operation with question–response questionnaires of all types. The system should have tools for interactive visual editing of questionnaires, test scales, and rules for calculation of raw scores. The system should have tools for automatic interpretation of testing results for each respondent according to expert rules. The system should have tools for on-line testing of respondents through the Internet. The system should have a friendly interface intuitively clear to a nonprogrammer. There should be means to restrict access to the questionnaire and respondent databases.

Multidimensional scaling includes a class of statistical methods applicable for easy-to-grasp representation of data when only one relationship between elements of the data array is known, i.e., a similarity or difference expressed as a certain integral measure. It is usually assumed (or specified by the character of the objects to be scaled) that the major part of an operationally significant difference between objects is actually due to a few factors (latent constructs), the nature and meaning of which are hidden from direct determination because of either task intricacy or data noisiness. To identify these factors, it is proposed to approximate the set of individual differences between objects by a certain geometric model, in which each object is assigned to a point in a Euclidean space with a number of dimensions much lower than the number of objects and a difference between objects corresponds to a distance between points.

With such a model, the interpretation of the Euclidean axes in the space of scaled objects may prompt some preliminary suggestions about the nature of the real latent constructs that determine the similarities and

Table 1. An example of data obtained for one subject (Part *A*) and (Part *B*) the resulting matrix of coefficients of correlation for the Cattell test and the laterality questionnaire

Part *A*

	A	*B*	…	*Q*4	*Later*	*Sort*	*Syll*	*Ma*
Subject 1	7	5	…	11	–50	–20	40	4

Part *B*

	later	*sort*	*syll*	*ma*
later	1	–0.446	0.263	–0.124
sort	–0.446	1	–0.282	–0.037
syll	0.263	–0.282	1	–0.367
MD	0.221	–0.229	0.078	–0.06
A	0.37	–0.431	0.102	0.122
B	0.161	–0.223	0.008	0.062
C	0.02	–0.176	0.131	–0.024
E	–0.23	0.292	–0.094	0.03
F	–0.03	–0.177	0.031	0.037
G	0.409	–0.351	–0.068	0.038
H	–0.097	–0.269	–0.022	–0.286
I	–0.219	0.244	0.264	–0.452
L	0.015	–0.058	–0.223	0.388
M	–0.229	0.295	0.13	0.061
N	–0.141	0.079	–0.022	0.254
O	–0.057	–0.151	–0.199	0.038
*Q*1	–0.418	0.379	–0.223	0.038
*Q*2	–0.096	–0.072	0.159	–0.017
*Q*3	0.261	–0.294	0.099	0.115
*Q*4	0.17	–0.162	0.241	–0.147
ma	–0.124	–0.037	–0.367	1

Notes: Here and in Table 2, *A*–*Q*4, factors of the Cattell 17LF test; *Later*, score on the laterality test; *Sort*, score on a subset of sorting tests for cerebral asymmetry; *Syll*, score on the syllogistic questionnaire; *Ma*, estimate of the metaphoric character of the results of psychosemantic testing.

Table 2. Results of subsample comparison with Student's *t*-test

Factor	*pole-A*	*pole-B*	*P*	M_A	σ_A	N_A	M_B	σ_B	N_B
I	male	female	0.004	6.39	2.35	23	8.44	1.46	16
L	male	female	0.029	5.43	2.06	23	4.13	1.2	16
*Q*1	male	female	0.037	7.57	2.09	23	6.13	2	16
*Q*2	male	female	0.020	4.87	2.22	23	6.56	2.03	16
later	MDh	MDl	0.033	76.57	24.51	7	19	39.6	2
sort	MDh	MDl	0.038	–20	2.52	7	–11	9.9	2
MD	MDh	MDl	0	10.29	0.49	7	4	0	2
N	MDh	MDl	0.045	4.29	2.06	7	8	0	2
A	Ah	Al	0	9.9	0.79	20	4.2	0.84	5
sort	Ah	Al	0.001	–18.85	6.08	20	–6.8	7.73	5
*Q*2	Ah	Al	0.002	5.05	2.04	20	8.4	1.14	5
B	Ah	Al	0.033	5.3	1.56	20	3.6	1.14	5
I	Ah	Al	0.037	6.3	2.25	20	8.8	2.28	5
later	Ah	Al	0.044	87.1	46.05	20	36	56.34	5
F	Ah	Al	0.054	6.6	2.56	20	4	2.55	5
B	Bh	Bl	0	6.32	0.58	19	2	0	3
*Q*3	Bh	Bl	0.011	7.89	2.13	19	4.33	1.15	3
G	Bh	Bl	0.017	8.42	1.17	19	6.33	2.08	3
later	Bh	Bl	0.037	67.95	57.89	19	–11.33	50.64	3
E	Bh	Bl	0.032	6.74	1.63	19	4.33	2.08	3
E	Eh	El	0	8.44	0.73	9	3.63	0.74	8
F	Eh	El	0.010	7.22	2.33	9	4.75	0.46	8
O	Eh	El	0.010	4.33	1.66	9	6.63	1.51	8
later	Eh	El	0.030	45.56	54.81	9	97.12	27.98	8
H	Eh	El	0.030	8.89	2.03	9	6.75	1.58	8
G	Gh	Gl	0	9.13	0.9	24	4	0	1
sort	Gh	Gl	0.002	–17.67	5.71	24	3	0	1
later	Gh	Gl	0.007	85.67	42.77	24	–44	0	1
L	Gh	Gl	0.030	4.67	1.55	24	1	0	1
*Q*3	Gh	Gl	0.036	7.46	1.96	24	3	0	1
I	Ih	Il	0	9.22	1	18	3.25	1.5	4
ma	Ih	Il	0.001	0.22	0.65	18	2.25	1.71	4
I	Lh	Ll	0.048	5.5	0.58	4	7.68	2.03	19
L	Lh	Ll	0	8.5	0.58	4	3.42	0.9	19
ma	Lh	Ll	0.012	2.75	1.89	4	0.68	1.25	19
*Q*3	Lh	Ll	0.048	5	1.41	4	7.47	2.25	19
N	Nh	Nl	0	8.57	0.79	7	3.13	1.06	15
MD	Nh	Nl	0.019	6	1.91	7	8.07	1.71	15
ma	Nh	Nl	0.050	1.86	1.77	7	0.53	1.19	15
*Q*3	Q3h	Q3l	0	9.27	1.28	15	3.33	0.58	3
*Q*1	Q3h	Q3l	0.016	6.93	1.71	15	9.67	0.58	3
G	Q3h	Q3l	0.024	8.4	1.68	15	5.67	2.08	3
sort	Q3h	Q3l	0.040	–16.87	9.39	15	–3.67	9.07	3

Notes: *Factor*, factor whose numerical characteristics are presented (classification is made only by gender and Cattell's factors); *pole-X*, a parameter of sample classification and its polarity ($X = A$ or B); *P*, probability of the equality of the values of the variable *Factor* in the two subsamples (low *P* suggests that the subsamples differ significantly in the corresponding *Factor*); M_X, mean *Factor* for sample *X*; σ_X, variance of *Factor* for sample *X*; N_X, size of sample *X*. For convenience, some factors are characterized qualitatively as *h*, high, or *l*, low. For example, *Xh* stands for a high value of the factor *X* and *Xl*, for a low value of the factor *X*.

differences between the given objects. Note that a hypothesis concerning the meaning of latent constructs and resulting from interpretation of multidimensional scaling data should be independently verified by some methods adequate to the specificity of a given object domain.

The result of operation of such an algorithm is a certain configuration, i.e., a set of coordinates of the points representing the scaling objects. The scaling is aimed at positioning the points in such a way as to best match the geometric distances between the points with the initial differences between the objects.

The corresponding mathematical problem can be formulated and solved in more than one manner. First, a condition can be laid down that the numerical values of differences be in a literal sense equal to distances between the points in the configuration. To find the configuration that meets the condition best, it is possible to apply the well-known method of principal components. This variant of scaling is traditionally called metric.

It is clear that the main assumption of the method is too artificial for a majority of psychosemantic tasks. Subjective estimates of differences do not fit the inequality triangle or even weaker metric axioms [55]. In this connection, several nonmetric methods have been proposed, which take into account the features of subjective scaling [56]. As distinct from the metric solution, the nonmetric solution is not single. It is possible to move (sometimes appreciably) the points in the configuration without changing its general correspondence to the initial data (in terms of rank order of differences). It is important that two seemingly different nonmetric solutions that represent the rank order of differences with equal accuracy are equivalent in terms of information content.

RESULTS AND DISCUSSION

Data of the Cattell test and the laterality questionnaire battery obtained for each subject formed a row in the resulting data matrix (Table 1), which was subjected to factor analysis and analysis of sample means. Subsamples were formed on the basis of gender and polar values of numerical parameters given in Table 1.

The most important (for the interpretation) correlations between the data of the laterality questionnaires and the estimates of the metaphoric character of the psychosemantic stimuli configuration are shown in the figure. It can be seen that high estimates of the metaphoric character correlate with the right-hemispheric type of thinking according to the results of the syllogistic test (*Syll*). The results of comparison of the subsamples by Student's *t*-test are presented in Table 2, where the subsamples are arbitrarily denoted *A* and *B*. The following conclusions can be drawn from the data.

The number of men is higher among individuals with the left-side, symmetrical, and intersecting motor laterality profiles. Men with a dominant left leg or with the absence of asymmetry are more frequent than women. There are more women with a dominant left eye than men. The factors *L* (trustfulness and egocentrism) and *Q*1 (analytical and critical thinking) are higher and the factor *O* (anxiety and sense of guilt) is lower in men than in women. Men and women do not differ significantly in the efficiency of solving syllogisms and sorting. Subjects with a high factor *A* (sociability and openness) show significantly higher factors *B* (quick-wittedness), *F* (expressiveness and impulsivity), *H* (adventurism), *Q*2 (independence of thought), and *Q*3 (self-control). The strongest differences were revealed for the factor *F*; i.e., open subjects are more impulsive (though the author of the test considered all factors to be independent). Subjects with a high factor *E* (dominance and leadership) are more frequently left-handers. Subjects with a high factor *G* (honesty and industriousness) are less efficient in sorting; i.e., they are more frequently right-hemispheric. Subjects with a high factor *M* (creativity and bohemian features) have higher indices of formal solving of syllogisms; i.e., they are more frequently left-hemispheric. Subjects with a high factor *N* (experience and insight) have a lower laterality; i.e., they are more frequently right-hemispheric.

We compared the data obtained with the laterality questionnaire and the BTSA test for 64 subjects. The results coincided in 41 ± 3% of cases ($P < 0.01$). Only three subjects (5%) were left-sided by the laterality questionnaire, whereas a predominantly right-hemispheric type was revealed in 35 subjects (55%). Analysis of the gender-related data showed that the results of the tests coincided in 43 ± 5% of men ($P < 0.05$) and in 40 ± 3% of women ($P < 0.05$).

These data testify that more than half of persons with left-hemispheric sensorimotor dominances prefer, predominantly, the right-hemispheric cognitive style.

CONCLUSIONS

Thus, the human population is heterogeneous, and cognitive style (increasingly associated with laterality profiles) has taken its place on the list of categories describing this heterogeneity. Despite the fact that the percent of left-handed persons is several tens of times less than that of right-handers in the population of European Russia, the proportion of people with the right-hemispheric cognitive style is approximately equal to that of people with the left-hemispheric style. It is thought that persons with the right-hemispheric types of reactions are more frequent among women than among men, but such a trend was not revealed in our study. Comparison of the sensorimotor and cognitive characteristics of functional asymmetry of the brain showed that right-handed persons do not necessary use the left-hemispheric cognitive style. As for left-handed persons, the question remains open, in particular, because ontogenesis proceeds under the pressure of the social environment, which shifts hemispheric asymmetry towards the left-hemispheric pole both in the sensorimotor and in the cognitive sphere.

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