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Use of Backward Masking Test for the Study of Visual Information Processing in Healthy Subjects and Schizophrenic Patients

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Abstract—The study of 14 healthy subjects and 15 schizophrenic patients was conducted under visual backward masking conditions. Sensory thresholds were identified using the method of constant stimuli. A special modification of the backward masking technique with lateralized presentation of test and masking stimuli was used to study the lateral characteristics of visual attention. It was found that the thresholds of letter stimulus identification were significantly higher in patients with schizophrenia than in healthy subjects. Only in patients the asymmetry of visual perception was revealed with the higher recognition thresholds in the left visual hemifield. The overall data analysis suggests an association between increased recognition thresholds in schizophrenic patients and changes in the interruption mechanism functioning at the neocortex level.

Keywords: backward masking, the method of constant stimuli, schizophrenia

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The backward masking (BM) phenomenon consists in that, during sequential presentation of two stimuli with a short interstimulus interval, the second stimulus (which is called the masking stimulus) impairs the perception of the first stimulus (which is called the test stimulus) [1].

The study of BM with varying the characteristics of the test and masking stimuli, as well as the intervals between them, has shown that the most sensitive parameter is the interval between the presentation onset of the test and masking stimuli. This parameter has been called SOA (stimulus onset asynchrony), and its leading role for masking strength, the SOA law [2–4].

Over the last fifty years, backward masking has become one of the leading methodological approaches to studying the spatial and temporal characteristics of visual perception and attention [5–7].

Schizophrenia is traditionally related with fundamental attention disorders. The manifestation of these disorders in schizophrenic patients consists in difficulties in processing information presented sequentially and at a high rate, as in the situation of backward masking. The studies of BM in schizophrenic patients conducted to date revealed a significant decrease in task performance parameters compared to the norm. In particular, it was shown that (1) an impairment (compared to the norm) of test stimulus perception under backward masking conditions in schizophrenic patients is permanent rather than episodic and is observed for 18 months and longer [8]; (2) lengthening of the SOA required for test stimulus recognition was observed in both schizophrenic patients subjected to pharmacological therapy and in patients who were not given psychoactive drugs [9, 10]; (3) impaired perception is observed not only in schizophrenic patients, but also their close relatives [9, 11, 12]. Analysis of the results allows a suggestion that low backward masking task performance values in schizophrenia may be regarded as a probable endophenotype, i.e., the genotype marker [13, 14]. The search for gene markers that are simultaneously the product of the genotype and environmental influences rather than for specific genes seems to be useful for studying a polygenic disease such as schizophrenia [13, 15, 16]. Apart from investigational tasks, the study of endophenotypes is of interest for the development of early diagnostic laboratory systems.

Interhemispheric asymmetry disorders are known to play an important role in the pathogenesis of schizophrenia [17]. However, the lateral features of backward masking test performance in schizophrenic patients remain virtually unexplored. In order to fill the gap in our knowledge, gaining practical experience in a special modification of the backward masking technique using the most sensitive method for measuring perceptive thresholds, i.e., the method of constant stimuli, seems to be promising [18].

Thus, the aim of the study was to optimize the technique of measuring perceptive thresholds under backward masking conditions that enables subtle differences in recognition of visual stimuli in the left and

right visual hemifields to be revealed, as well as to investigate lateral features of visual perception and attention in health and in schizophrenia.

METHODS

The selection criterion for enrolment of the subjects in the study using the backward masking technique was 100% binocular vision or absolutely corrected eyesight.

Thirty-five right-handed men took part in the study. Fourteen mentally healthy subjects and 15 patients with the paranoid form of schizophrenia (index F20.006 according to ICD-10) with the prevalence of productive symptomatology managed to perform the test. The patients did not receive psychopharmacotherapy in the course of the study and for three days before it.

The age of healthy subjects varied between 21.3 and 27.1 years (the mean value was 24.3 years). The age of schizophrenic patients was in the range from 23.1 to 46.0 years (the mean value was 34.9 years). Due to the significant age differences between the two groups of subjects, age was considered as a covariate in statistical analysis.

Before the study, all the subjects signed a letter of informed consent.

Stimulus information was presented on a LED display (based on red light-emitting diodes), which was at a distance of 180 cm from the subject's eyes (eccentricity, 6°), with a fixation point in the form of a green light-emitting diode being placed at the center. The experiment was controlled with a personal computer.

Single letters of the Russian alphabet were used as test stimuli; rectangular graphic drawings that could not be verbalized, as masking stimuli. The angular size of the letters was 1.1° × 1.6°; line thickness, 15′; the angular size of the masking rectangle, 2.5° × 3.2°. The distance between the test stimuli and the fixation point was 19 cm. Masking stimuli were presented at the same place as test stimuli. Luminosity near the screen was 0.11 lx ± 20%. The test stimulus exposure time was 25 ms, and the masking stimulus exposure time was 200 ms. Letter brightness was so selected that in the absence of a masking stimulus the subjects could read them in 100% of cases. The stimulus afterglow time was 1 ms.

Before the beginning of the study, each subject was given an instruction: "Rivet your eyes on the green point at the center of the screen. You will be shown letters either on the right or on the left of this point (in random order). In each trial, you will have to name the letter you have seen disregarding the drawing following this letter. Even if you have doubt about your answer, you have to make a guess what letter you have seen."

The subject was then shown a sheet of paper with a set of eight Russian letters to be presented (K, M, H, O, П, P, C, and T). It was important for the subject to know these letters; only in this case were we sure that the random recognition probability was equal to 1/8 and not to 1/20 or 1/33. After presentation of the instruction, the subject was allowed to adapt himself to darkness for 5 min.

At the beginning of the study, the subject was presented a familiarization series, in which each of the eight letters was presented once in the left and right visual hemifield. Note that the interval between the test stimulus onset and the masking stimulus onset was equal to 400 ms; the masking effect was equal to zero, which allowed the subject to see how the test and the masking stimuli appear on the screen.

The set of intervals between the test stimulus presentation onset and the masking stimulus presentation onset (SOA) used in the experiment was selected individually for each subject. The individual SOA set was obtained so that each of the test stimuli could be recognized with a probability exceeding the random recognition level (12.5%) but not reaching 100%. Note that, at this minimal SOA, the recognition probability slightly exceeded the random level, and at the maximal SOA, the stimuli were recognized with a probability of 80–90%. The remaining three intervals lay between these two SOA. For example, in subject K., the recognition probability at SOA = 30 ms was 16.7%; at SOA = 70 ms, 87.5%; the remaining three SOA were between 30 and 70 ms. Thus, the experiment used the following five intervals (SOA): 30, 40, 50, 60, and 70 ms. For subject M., a set of five SOA appeared to be different: 40, 50, 60, 70, and 80 ms. For patient R., with his stimulus perception impediment, longer intervals of 40, 55, 70, 85, and 100 ms had to be used.

The main investigation phase included six experimental units of 40 trials each. Thus, the total number of trials was 240, 48 trials for each SOA. Within one SOA, stimuli were presented 24 times in the left visual hemifield and 24 times in the right hemifield.

The procedure used by us complied with the requirements of the method of standard stimuli, one of the classical methods for measuring sensory thresholds [18].

At the first analysis step, the percentage of correct answers was calculated for each SOA separately for the left and the right visual hemifields. The percentage of correct answers is an experimental estimate of the stimulus recognition probability (P) under preset conditions (at a specified SOA and in a given visual field).

At the second step, the results obtained were processed using the method of normal interpolation [18]. The assumption (confirmed experimentally) that the data obtained using the method of constant stimuli must be described with normal distribution underlies this mode of calculation [18].

The method of normal interpolation is usually implemented by conversion of the recognition probabilities (P) to the normalized deviation values (z).

The main advantage of transition from the P values to the z values is that, if the function $P = f(\text{SOA})$ is known to be nonlinear, the function $z = f(\text{SOA})$ is linear or so close to it that it can be regarded as linear with no significant error. In this case, experimental data processing is considerably simplified.

At the next processing step, approximation of the experimental points of the straight line was carried out in normal coordinates (the z normalized deviation values were plotted along the ordinate) using the least square method [19].

As a result of data processing using the normal interpolation method, the transfer from the correct answer probability values (P) to the normalized deviation values (z) was performed and, using the least squares method, the straight lines approximating the experimental results were constructed. Two straight lines were obtained for each subject: one for the stimuli presented in the left visual hemifield; the other, for the stimuli in the right visual hemifield (Fig. 1).

At the third step, the threshold values for the left and right visual hemifields were calculated. In the process, we used the advantage of the method of constant stimuli over the other threshold methods (minimal changes, mean error). This advantage consists in the possibility of measuring the threshold values at any stimulus recognition probability, beginning with a random one ($P = 0.125$) up to complete recognition ($P = 1.00$). For each such a probability, it is possible to find the SOA value (in milliseconds) in the left and right visual hemifields. Lower SOA values correspond to low thresholds of stimulus perception, i.e., to higher sensitivity[1].

At the fourth step, statistical data processing was carried out: the SOA obtained in healthy subjects and in schizophrenic patients were compared at the same stimulus recognition probabilities. The SOA values were measured at the test stimulus recognition probabilities 0.20; 0.30; 0.40; 0.50; and 0.60. However, since the most significant data were obtained at probabilities of 0.30 and 0.50, the results obtained only at these threshold values are presented. For these probabilities of stimulus recognition, which was carried out separately in the normal and schizophrenia groups, the SOA values were also compared separately in the left and right visual hemifields.

[1] Presentation of the test and masking stimuli, calculation of the percentage of correct answers for each SOA (separately for the left and right visual hemifields), processing the results using the method of normal interpolation, and calculation of the threshold values for each visual hemifield were carried out using specially designed software packages that were subject to state registration (V.Yu. Novototskii-Vlasov, A.V. Kirenskaya, V.V. Myamlin. Certificate of state registration of software for electronic computer no. 2014611941 of February 13, 2014).

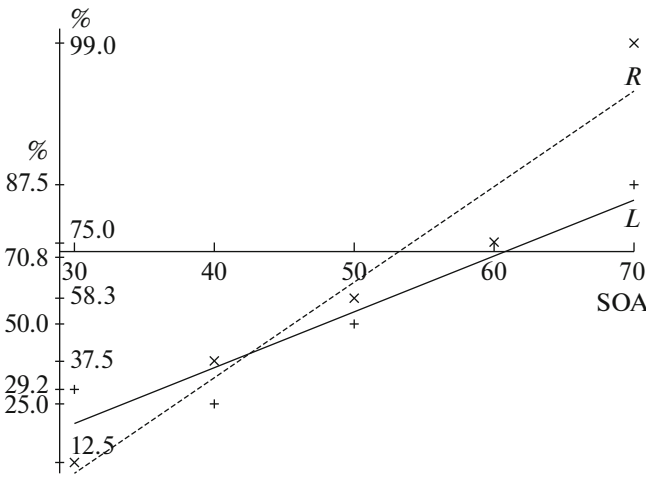

Fig. 1. An example of approximation of the study results (subject V., the normal group). Solid line, the approximation straight line for the left visual hemifield; broken line, for the right visual hemifield. +, experimental points on stimulus presentation in the left visual hemifield (L); ×, in the right visual hemifield (R). Abscissa, the SOA (the interval between the test and the masking stimulus onset, ms) values. The ordinate scale is linear by the normalized values (z) and nonlinear by the correct answer probability values (P).

RESULTS

This study showed that the threshold values in healthy subjects were significantly lower than in schizophrenic patients with both stimulus recognition probabilities.

The test stimulus recognition probability of 0.30. As seen from the histogram of SOA distribution (Fig. 2a), with a recognition probability of 0.30 in the left visual hemifield in the normal group, SOA duration varied between 5 and 42 ms; in the schizophrenia group, between 22 and 90 ms. The most frequently occurring value was 35 ms in both mentally healthy individuals (50% of cases) and in schizophrenic patients (40% of cases). The average SOA value in the schizophrenia group was 46.7 ± 5.2 ms and significantly ($p < 0.01$) exceeded the average values in the normal group (29.1 ± 2.6 ms) (table).

Close results were obtained for the right visual hemifield at a recognition probability of 0.30 (Fig. 2b). In healthy subjects, the SOA values varied between 11 and 39 ms, with the most frequently occurring values 25 ms (57% of cases). The average SOA value in the normal group was 28.8 ± 1.9 ms. In the schizophrenia group, SOA were recorded in the 19–71-ms range, with three SOA values 25, 35, and 45 ms occurring equally frequently (Fig. 2b). The average SOA value in the schizophrenia group was 50.0 ± 4.5 ms, which was significantly higher than in the normal group ($p < 0.05$).

The test stimulus recognition probability of 0.50. As seen from Fig. 3a, with a test stimulus recognition

Age-related intergroup differences in the recognition thresholds. Covariance analysis data

Recognition probability, P	Visual field	Recognition thresholds, ms		Significance of differences, p
		norm	schizophrenic patients	
0.30	Left	29.1 ± 5.49	46.8 ± 5.26	0.042
0.30	Right	29.5 ± 4.59	40.3 ± 4.39	0.132
0.50	Left	41.9 ± 7.19	65.8 ± 6.89	0.037
0.50	Right	420 ± 5.26	56.3 ± 5.00	0.081

probability of 0.50 in the left visual hemifield in the normal group, the SOA values varied between 29 and 49 ms, with 45 ms being the most frequently occurring SOA value (57% of cases). The average SOA value was 41.3 ± 1.9 ms. In the schizophrenia group, the SOA values varied in the range were from 35 to 135 ms. Note that SOA equal to 45 ms occurred most frequently as in the normal group, but only in 27% of cases. The average SOA value in the schizophrenia group constituted 66.4 ± 7.3 ms being significantly higher than in the normal group ($p < 0.01$).

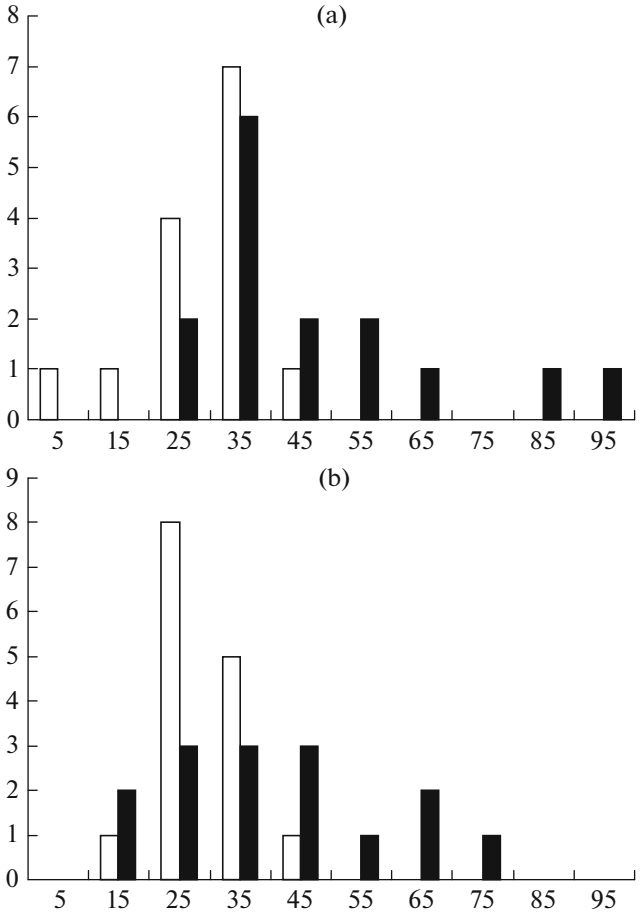

Fig. 2. Histogram of distribution of the SOA interval values in the (a) left and (b) right visual hemifields at a test stimulus recognition probability of $P = 0.30$. Abscissa: the threshold interval values (ms); ordinate: the number of patients with this threshold interval. White bars, healthy subjects; black bars, schizophrenic patients.

In the right visual hemifield (Fig. 3b) with a recognition probability of 0.50, the SOA values in the normal group varied between 31 and 56 ms, with the average value being 40.4 ± 1.9 ms. The most frequently occurring SOA value (57% of cases) was 35 ms. In the schizophrenia group, the minimal SOA value was also 31 ms; the maximal value, 95 ms, with the average value being 57.7 ± 5.2 ms ($p < 0.01$ compared to the norm).

Asymmetry of the right and left visual hemifields. No significant differences were revealed between the SOA values in mentally healthy individuals in the left and right visual hemifields ($p = 0.84$ at a recognition probability of 0.30 and $p = 0.57$ at a recognition probability of 0.50).

In schizophrenic patients (Fig. 4), at a stimulus recognition probability of 0.50, the SOA value in the right visual hemifield (57.7 ± 5.2 ms) was considerably lower than the corresponding value in the left visual hemifield (66.4 ± 7.3 ms). The comparison of means showed the significance of differences at a trend level ($p = 0.057$).

Comparison of the two groups of subjects with regard to age difference. Since the average age of schizophrenic patients exceeded the same parameter value in the normal group by 10 years, we performed an additional statistical analysis in which age was taken into account as a covariate (table). According to the data shown in the table, in this analysis variant, the recognition thresholds in the normal group were significantly lower than in the group of schizophrenic patients only when stimuli were presented in the left visual hemifield. In the case of stimulus presentation in the right visual hemifield, the intergroup differences did not attain the level of significance.

DISCUSSION

This study showed that, under BM conditions, the letter stimulus recognition thresholds in schizophrenic patients were significantly higher than in healthy subjects, which agrees with the results of the earlier investigations [8–10, 14].

In addition, the experimental procedure of backward masking test performance enabled significant

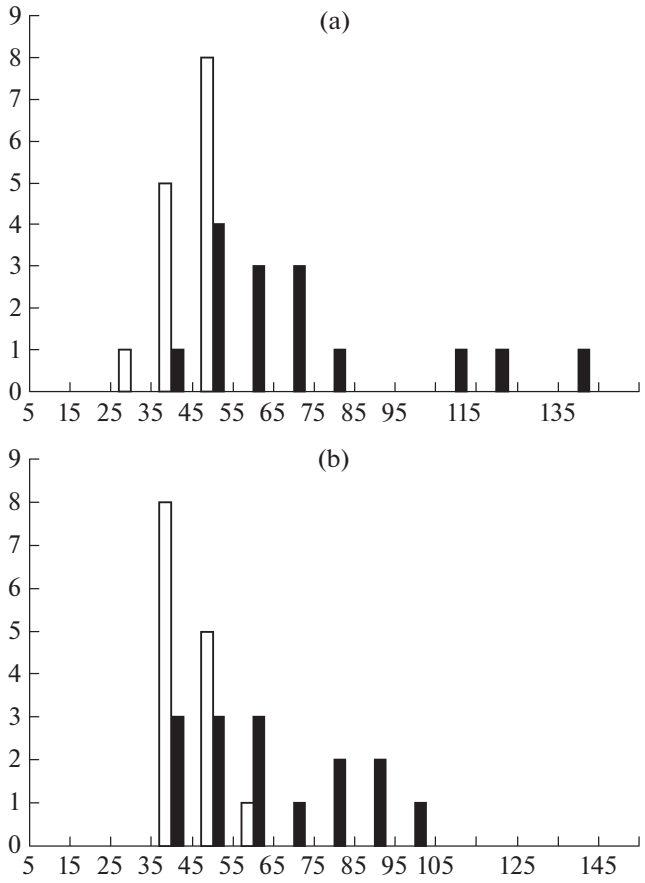

Fig. 3. Histogram of distribution of the SOA interval values in the (a) left and (b) right visual hemifields at a test stimulus recognition probability of $P = 0.50$. For designations, see Fig. 2.

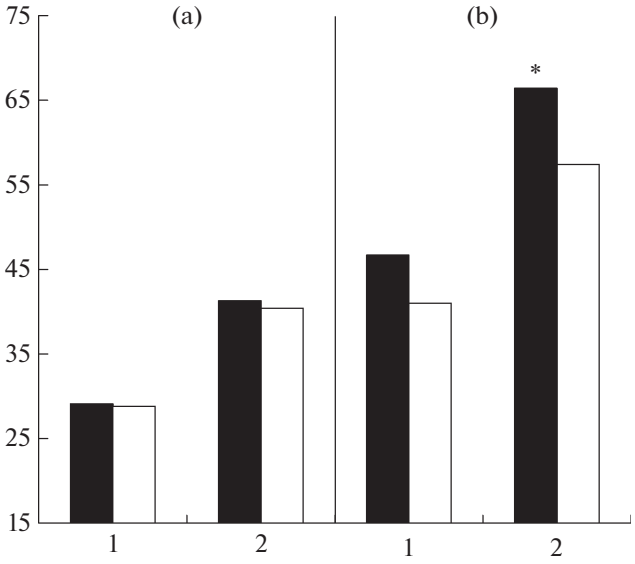

Fig. 4. SOA interval values in the left and right visual hemifields in (a) healthy subjects and (b) schizophrenic patients. Designations: black bars—the left visual hemifield, white bars—the right visual hemifield. *1*, stimulus recognition probability $P = 0.30$; *2*, stimulus recognition probability $P = 0.50$.

differences in the recognition thresholds between the normal and schizophrenia groups to be revealed only in the left visual hemifield. Analysis of asymmetry of the right and left visual hemifields revealed distinct asymmetry in letter stimulus recognition in the left and right visual hemifields only in schizophrenic patients; in healthy subjects, significant asymmetry in test stimulus recognition was absent.

The accumulated knowledge of the specific features of the mechanism of action of backward masking allows us to determine more accurately the information processing levels at which disorders are observed in schizophrenia.

There are two the most probable backward masking mechanisms: integration and interruption [3, 20]. The former consists in that the masking stimulus seems to be fused with the test stimulus, and they are processed by the visual system as a whole. In this case, the shorter the interval between stimulus presentations, the more the perception of each separate stimulus is deteriorated and, consequently, the poorer the test stimulus recognition is. The interruption mechanism implies that the masking stimulus interrupts the processing of test stimulus–related information. The integration mechanism involves peripheral processes of information processing; the interruption mechanism, the central processes.

Our study has shown that, in schizophrenic patients, the interval between the test and masking stimulus presentation onset necessary for recognizing the test stimulus is considerably prolonged in both the left and right visual hemifields. There is good reason to believe that this prolongation is linked to the interruption mechanism acting at the level of the cerebral hemisphere cortex. The results of clinical and physiological investigations give evidence of the intactness of simple visual and motor reactions and a delay in motor responses to more complicated cognitive tests in schizophrenic patients [21], which allows us to speak about delayed central processes in schizophrenia. Thus, it may be suggested that the test signal processing time is lengthened in schizophrenic patients compared to normal individuals; therefore, a longer SOA interval is required for its recognition.

It is quite possible that the mechanism of disturbed visual information processing in schizophrenic patients described by Strelets et al. [22] might also act under backward masking conditions. This mechanism manifests itself in the deficit of automatic sensory processing of stimulus-related information, which reduces the recognition time and, as a consequence, interferes with the completeness and accuracy of sensory analysis. Our findings allow a suggestion that

patients require less time for information processing at the early stages. As a result of such a low-quality analysis, they need additional time (compared to the norm) for stimulus recognition at the later stages, which causes the sensory visual thresholds to increase.

When analyzing the letter stimulus recognition asymmetry revealed in schizophrenic patients, we think it important to note that it was observed under moderate masking conditions with a stimulus recognition probability of 0.50, but not under intense masking conditions, when the recognition probability was equal to 0.30. This also agrees with the suggestion that the masking effect was mainly determined by the interruption mechanism.

According to the data obtained, patients recognized the test stimuli (letters) better in the right visual field, i.e., when the information about them arrived first to the left hemisphere. The asymmetry revealed in our study is consistent with certain saccade characteristics data obtained by Slavutskaya et al. Analysis of the asymmetry of latent saccade periods during the performance of different experimental tasks (antisaccades, direct attention saccades, memory-guided saccades, double step) showed that, in mentally healthy individuals, the latent period for saccades to the left is shorter than for saccades to the right [23, 24]. In contrast, saccades to the left were performed slower by schizophrenic patients than saccades to the right. In the authors' opinion, this fact is indicative of marked dysfunction of the right hemisphere and the spatial attention system closely connected with the right hemisphere in schizophrenia.

Our data also agree with the results of the studies of ambiguous visual image perception using positron emission tomography [25], which revealed schizophrenic patients to have right hemispheric activation deficit compared to normal subjects. It was suggested that the impairment of backward masking test performance in schizophrenia may be due to disruption of the lateralization processes necessary for processing integral visual stimuli.

It should be taken into account that we studied patients with paranoid schizophrenia. According to current wiews, there is a relationship between schizophrenic syndromes and the balance of interhemispheric activation. Note that increased activation of the left hemisphere and decreased activation of the right hemisphere are associated with the prevalence of the positive symptoms inherent in paranoid patients [26]. These conceptions are confirmed by the results of analysis of interhemispheric asymmetry at the level of cerebral activation when antisaccades and saccades to visual stimulus were performed (by the amplitude of a conditionally negative wave), according to which a substantial shift in the activation balance towards the left hemisphere compared to the norm and right hemispheric inhibition were observed in patients with paranoid schizophrenia [27]. However, the studies of Slavutskaya et al., as well as Hellige [23–25], were conducted with no regard to psychopathological symptomatology. Thus, further studies are necessary to investigate the interrelationships between interhemispheric asymmetry disorders under backward masking conditions and the clinical syndrome in schizophrenic patients.

CONCLUSIONS

(1) Under backward masking conditions, the visual recognition thresholds in schizophrenic patients were significantly higher than in mentally healthy individuals, with significant differences in the left visual hemifield.

(2) The asymmetry of visual perception was revealed in schizophrenic patients during backward masking, the thresholds of test stimulus (letters) recognition being higher in the left visual hemifield compared to the right one.

(3) The asymmetry of visual perception in patients was revealed under moderate masking conditions (with a stimulus recognition probability of 0.50), which allows us to suggest correlation between the increase in the recognition thresholds in schizophrenia and changes in the interruption mechanism functioning at the neocortex level.

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