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Study of neurocognitive mechanisms in the concealed information paradigm

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ABSTRACT

This work is a continuation of a research aimed at creating a forensic method for MRI diagnostics of hidden information in person. The article presents some results of the research in the paradigm of information concealment, during which the activity of brain structures in experiments with tests used in criminology was studied using fMRI and MRI compatible polygraph (MRiCP). In a group analysis of the experimental data obtained in the block design, brain zones are shown that are active in concealing personally significant and situationally significant information. Assumptions are made about possible differences in the functioning of neural networks involved in the implementation of concealment of information of these two types.

INTRODUCTION

Study using a polygraph (SUP) is the most widespread method of forensic direction in applied psychophysiology.

Many countries around the world use polygraph in law enforcement practice, but in the early 1980s, US Congress experts expressed the opinion that "the basic theory of polygraph testing is only partially developed. The testing process is complex and not amenable to easy understanding. A stronger theoretical base is needed for the entire range of polygraph applications. Basic polygraph research should consider the latest research from the fields of psychology, physiology, and medicine; comparison among question techniques; and measures of physiological response" [1].

Decades have passed, but the question of the theory of polygraph testing in the United States remains open to this day, and according to the American Polygraph Association (APA), the probability of a correct result when conducting SUP during investigations is in the range of 0.89–0.91 [2].

The development of science led to introduction of new methods of experimental research into psychophysiology, and some of them, researchers tried to use for the purpose of detecting concealed information in a person, thereby creating an alternative to SUP. In particular, in 2001 the first experiments were conducted in which functional magnetic resonance imaging (fMRI) was used to detect concealed information in a person [3]. Scientists declared – "we examine directly the organ that produces lies, the brain... (and) this neurobiologically based strategy relies on identifying specific patterns of neural activation that underlie deception" [4].

fMRI research on the subject of detecting hidden information in a person has borrowed some elements of the SUP technology, was conducted mainly in the differentiation of deception paradigm, but significant progress in the scientifically based application of fMRI in forensic practice has not yet been achieved. Therefore, conducting further research in the field of forensic fMRI and improving the existing technology of SUP is relevant both in Russia and abroad.

Research on the complex of fMRI diagnostics was started at the National Research Center "Kurchatov Institute" (NRC "Kurchatov Institute") in 2018 [5], and for such studies, in particular, a prototype of a computer MRI compatible polygraph (MRiCP) was created. Taking into account the requirements of forensic diagnostics, the concealed information paradigm, was chosen as the methodological basis for research [6]. Within this paradigm, two widely used criminalistics tests were selected and the study of neural networks involved in concealing personally significant and situationally significant information was started. For the methodological correctness of diagnostics of concealed information, a series of preliminary experiments were conducted, during which the possibility of measuring the dynamics of person response to the stimuli of selected tests perceived by them during fMRI was studied [7, 8].

METHODS

23 men aged from 21 to 23 years old took part in experiments to create a system of MRI diagnostics of hidden information in a person. In each of the fMRI experiments, MRiCP was used to control the dynamics of the response of the studied person. Permission to conduct the fMRI experiments was obtained from the ethics committee of NRC "Kurchatov Institute".

Experiments were aimed at neuroimaging of the process of concealing information by a person, and the possibility of detecting differences in the activity of brain structures when hiding personally significant and situationally significant information was studied. In order to increase the motivation of participants in the study, a monetary reward was provided for strict compliance with the necessary instructions of the experimenter and the successful conduct of the experiment.

As a methodological tool that simulates the concealment of personally significant information, the test with a concealed name (TCN) of the SUP technology was used, during which the person under study (the subject) hid from the polygraph examiner his own name, presented in a row with five other names. The sets of names were presented to all subjects during the TCN five times. The series of names for each of the five repetitions began with the same name, and it had the number "0". All other names (including the name of the subject) were given in a random order that was unknown to the subject, and he was asked a question – "Your passport name is...?". Hiding their name in a row of other names, the subjects answered all questions – "no". The experimenter asked questions with intervals of about 20 s and with the obligatory account of the current dynamics of physiological parameters of a subject, simultaneously recorded by MRiCP. In order to increase concentration during the test, the subject after the TCN was asked how many times his name was sounded.

As a methodological tool that simulates the concealment of situationally significant information, the "guilty knowledge" test (GKT) was borrowed from the SUP technology. Before performing the GKT, the subject randomly selected one of five business cards, copied it on a piece of paper, and memorized the name and place of work of the person indicated on this business card. The subject was instructed to hide the signs of the selected business card (family name and place of work) from the experimenter who registered fMRI and MRiCP data. Before beginning the GKT, lying in the tomograph chamber, the subject always read what he wrote on a piece of paper, and refreshed his memory with the signs of a business card. The family (F) from the business card was presented to the subject during the test four times, and the place of work (W) – two times. The signs of the selected business card were presented in the following order: F – W – F – F – W – F. Thus, the signs of a business card were presented to all subjects during the GKT six times. Each of the six repetitions began by the signs of a business card that was not among the five business cards that were offered to choose from, and these signs had the number "0". All the signs of the five business cards were set in a random order unknown to the subject, and they were asked by the question – "Did you have the last name on your business card...?". "The person with the business card works in ...?". Hiding the signs of the chosen business card among other family names and places of work, the subjects answered all questions – "no". The experimenter asked questions with intervals of about 20 s and with the obligatory account of the current dynamics of physiological parameters of a subject, simultaneously recorded by MRiCP. In order to increase concentration during the test, the subject after the GKT was asked, how many times the family name and place of work of the person on the business card were sounded during the test.

Thus, the TCN and GKT lasted, respectively, 6–7 and 8–9 minutes and contained 25 and 30 stimuli, in response to which the experimenter registered fMRI and MRiCP data. Between the TCN and GKT the experimenter made another test lasting 11–12 minutes, which is not considered in the article, and between all tests, the experimenter made intervals of 5–8 minutes, during which the instructions for the next test were discussed.

The MRI data was acquired using a 3 T SIEMENS Magnetom Verio MR scanner. The T1-weighted sagittal three-dimensional magnetization-prepared rapid gradient-echo sequence was applied with the following imaging parameters: 176 slices, TR = 1900 ms, TE = 2.19 ms, slice thickness = 1 mm, flip angle = 9°, inversion time = 900 ms, FOV = 250 mm x 218 mm².

Preliminary studies [8] showed the feasibility of using ultra-fast scanning sequences for obtaining fMRI data at TR = 1110 ms with the following parameters: 51 slices, TE = 25 ms, slice thickness = 2 mm, rotation angle = 90°, FOV = 192 x 192 mm². Functional and structural MRI data were processed using the SPM8 software package (available at <http://www.fil.ion.ucl.ac.uk/spm/software/spm8/>). After converting DICOM files to NIFTI format, all images were manually centered to anterior commissure. The EPI images were corrected for magnetic field inhomogeneity using the FieldMap toolbox for SPM8. Then, the fMRI data signals were temporally corrected. The need to apply this correction is explained by the use of an event-related scheme of the experiment. Anatomical and functional data were normalized in the ICBM stereotaxic reference system. T1 images were divided into 3 tissue maps (gray, white matter, and cerebrospinal fluid). Functional data was smoothed using a 6x6x6 mm³ FWHM Gaussian filter. Statistical analysis was performed using the Student t-statistics ($p < 0.05$ with correction for multiple comparisons (FWE)).

Cross-platform CONN software based on Matlab was used to calculate, display and analyze functional connectivity based on fMRI data. In this paper, 132 regions included in the CONN Atlas were used as regions of interest. After data preprocessing, the first-level connectivity assessment (individual), second-level random effects analysis, and hypothesis testing (group assessment) were performed. The Pearson correlation was chosen as the functional connectivity metric. Of the 23 subjects, a group of 17 subjects (the "best" group) was identified, in which a high degree of vegetative reactions to information hidden in the TCN and GKT was detected with the help of MRiCP. fMRI data was analyzed both for the entire sample of subjects and separately for the "best" group.

FINDING #1

Recent meta-analyses, with all the variability of experiments conducted in the differentiation of deception paradigm and concealed information paradigm, agree that the front-parietal areas of the brain are involved in the implementation of lies and concealment of information [9]. According to foreign experts, "these regions include the anterior cingulate and surrounding medial prefrontal cortex; the ventrolateral prefrontal and insular cortex, bilaterally; portions of the left precentral, middle, and superior frontal gyrus; and the inferior parietal lobular and supramarginal cortex, bilaterally" [10].

Experiments performed at the NRC "Kurchatov Institute" established consistency between the results obtained and the conclusions of foreign meta-analyses: the concealment of personally significant and situationally information by the subjects during the TCN and GKT revealed high activity of the same zones – frontal pole (bilaterally), insular cortex (bilaterally), and so on.

Group analysis of fMRI data of fragments showed that the activity of many areas of the brain structures during TCN consistently exceeded the activity of the same structures during GKT (at $p < 0.05$, adjusted for the expected proportion of false deviations – FDR). At the same time, in some zones – (CONN Atlas) angular gyrus_r, paracingulate gyrus_L, precuneus, thalamus (bilaterally) – the number of detected statistically significant voxels in GKT was 50–150% higher than in TCN (Fig. 1). The cross sections show a high similarity in spatial localization of the detected zones and a greater activation in the regions described above – thalamus (bilaterally), precuneus and angular gyrus_r.

An evaluation of fMRI data obtained in response to the presentation of insignificant stimuli in the TCN and GKT found that they do not form a single set, although they are insignificant in their tests. It turned out that insignificant stimuli in the TCN caused significantly more activity of brain structures, than insignificant ones in the GKT.

The subjects who took part in the study were undergoing MRI for the first time and, although they gave their voluntary consent to participate in the experiments, nevertheless, according to their questions, they experienced some mental stress at the beginning of the experiment; this may explain the discovered feature of responding to insignificant stimuli of the TCN and GKT. Probably, the difference in response is a neurocognitive reflection of a phenomenon often observed in the practice of SUP, when the dynamics of vegetative reactions in the first test (i.e., in the first 10–15 minutes of testing) significantly differs from their dynamics in subsequent tests, during which the subject adapts to the conditions of the study and his psychophysiological state is stabilized.

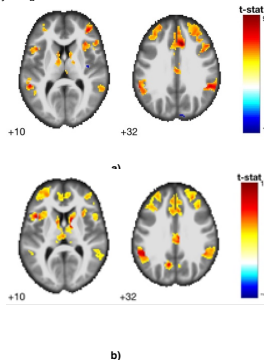


Fig. 1. Group statistical maps of activity of brain zones at the level $z = 10; 32$ in MNI space when performing: a) TCN and b) GKT.

FINDING #2

To identify the neural networks involved in the process of hiding information, based on fMRI data from a group of 23 subjects, an analysis of the functional connectivity of brain zones was performed when performing the TCN and GKT (Fig. 2).

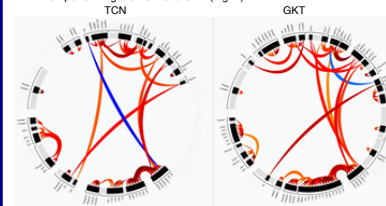


Fig. 2. Analysis of functional connectivity of brain areas during the test with a concealed name and the "guilty knowledge" test: a group of 23 subjects.

FINDING #3

In order to identify the dominant connections, an analysis of the functional connectivity of brain areas was performed separately for the subjects from the "best" group (Fig. 3).

The selection of this group showed that with the general trend of increased activity of neurostructures in the TCN compared to the activity of the same structures in the GKT, the activity of zones – (Atlas CONN) angular gyrus (bilaterally), paracingulate gyrus_L, precuneus, thalamus (bilaterally), caudate (bilaterally) – became more pronounced: the number of identified statistically significant voxels in GKT was 50–300% higher than in TCN.

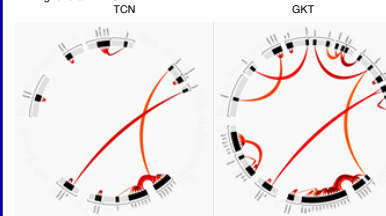


Fig. 3. Analysis of functional connectivity of brain areas during the test with a concealed name and the "guilty knowledge" test: 17 subjects – the "best" group.

The results of the analysis of functional connectivity of the brain areas of the subjects (Fig. 2 and 3) show a great similarity of neural networks involved in concealing personally significant and situationally significant information.

Apparently, special attention should be paid to the activity of the cerebellum, which foreign experts only casually mentioned in some articles: the activity of the cerebellum is consistently observed in the TCN and GKT, and in some areas of this brain structure, the activity in the GKT was 80% greater than in the TCN.

CONCLUSIONS

The data presented above are preliminary and require confirmation. At the same time, they indicate the need for further study of the activity of brain structures when using forensic tests of the concealed information paradigm. In particular, it is necessary to study the influence of the position of a particular test among other methodical tools used in the experiment on the configuration and activity of neural networks. It can also be assumed that a possible marker of hidden information will not be a single set of neural networks, but the redistribution of activity in a number of sensitive areas of the brain; this is indicated by the results of experiments.

ACKNOWLEDGMENTS & REFERENCES

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