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Improvement of the technology of fMRI experiments in the concealed information paradigm

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ABSTRACT

This work is a continuation of research on the creation of a forensic method for MRI diagnostics of hidden information in a person. The article presents some results of the first (technological) stage of these studies, during which the method of fMRI experiments was improved by using an MRI compatible polygraph (MRICP) within the framework of the information concealment paradigm. Numerous experiments show: the efficiency of MRICP during fMRI procedure; the usefulness of the methodological technique created through the use of MRICP that have improved the performance of fMRI experiments; prospects of application of certain tests (in compliance with the strict requirements of forensic science) in the context of the fMRI study.

INTRODUCTION

Psychophysiological studies using a polygraph (SUP) in order to diagnose person's hidden information has existed since the 1930s and are currently used in about a hundred countries. Despite the long history of SUP, the brain processes that make it possible for a person to reveal information about hidden events in the past have not been studied enough, although by today about two dozens of so called "polygraph theories" has been proposed, trying to explain the work of the brain during the SUP [1]. Therefore, revealing of neurocognitive mechanisms underlying the forensic diagnosis of a person's hidden information during the SUP is important.

At the beginning of the XXI century, the first studies were conducted on the possibility of using functional magnetic resonance imaging (fMRI) to diagnose information about hidden events of the past in a person [2, 3, etc.]. It was believed that fMRI would allow to visualize the diagnostic process and bring closer the creation of a scientifically based theory of SUP. The results of such fMRI studies were promising, and within five years in the United States two companies were established that provided services on a commercial basis to detect a person's hidden information using fMRI (in American terminology – "fMRI based lie detection").

However, hopes for rapid success from the use of fMRI were not justified. Scientists have criticized the work carried out by these American companies, and meta-analyses of the results of scientific research in recent years have shown that to create a practically useful method of fMRI diagnostics of hidden information (fMRI diagnostics), a special technology for conducting fMRI research must be developed. And now "most publications report only group analyses, which makes them poorly suited to answering this question" [4, p. 125] about the forensic use of neuroimaging.

Although fMRI based lie detection has been commercialized and is used by some organizations for real-world applications, research on this topic began as a form of basic science with the goal of identifying the neural systems involved in deception.

When conducting research on the "fMRI based lie detection", foreign experts usually use many tens of stimuli during tests and, in an effort to do the test quickly, present stimuli to the subjects at intervals of less than 10 seconds [5]. Foreign experts perform experiments on small groups of subjects (sometimes – on 3 people [6]), and the subjects give answers by pressing buttons [5, 7].

In our opinion, these and many other experiments were conducted without taking into account the strict methodological requirements for the "fMRI based lie detection" that criminalistics has established for its methods, and applied research on fMRI diagnostics is not given enough attention.

Research on the creation of a complex of fMRI diagnostics was started at the National Research Center "Kurchatov Institute" (NRC "Kurchatov Institute") in 2018 [8]. When conducting forensic research using fMRI, it was hypothesized about the possibility of improving the accuracy of fMRI data by monitoring behavior of subjects and their response to various influences: the control was proposed to be carried out by using simultaneous registration of fMRI and vegetative reactions (VR) of a person.

To test the hypothesis that it is possible to improve the quality of fMRI data, a prototype of a computer MRI compatible polygraph (MRICP) was created at the NRC "Kurchatov Institute". This device made it possible to observe in real time the fast-flowing VR of a person that arose in response to the action of external or internal factors, including the stimuli presented to the person. For the purposes of fMRI quality control, we used VR parameters that are traditionally used in criminology for the diagnosis of hidden information in humans, namely, the amplitude and/or frequency characteristics of the respiratory system, the cardiovascular system, and the human skin galvanic response (GSR) [9]. MRICP helped to bring the new technology of fMRI diagnosis to the existing technologies of SUP.

Research on creating a complex of MRI diagnostics includes two components:

- a "technological" stage aimed at developing methodological and technical means to control the response of a person to various stimuli during fMRI research, and
- a "research" stage aimed at detecting areas and neural networks of the brain ("markers") that indicate the concealment of information by a person.

This article describes the results of the "technological" stage of the research.

Taking into account the requirements of forensic diagnostics, the concealed information paradigm was chosen as the methodological basis for experiments.

To test the usefulness of using MRICP during fMRI and to develop methodological tools for conducting fMRI-experiments, tests were selected that are widely used in forensic practice for SUP. In particular, the test with a concealed name (TCN), the silent response test (SRT) and the "guilty knowledge" test (GKT) were selected as tests of the concealed information paradigm.

During experiments, it was found that MRICP allowed to see the response of each person during fMRI and thus to divide people into groups with a high and low degree of physiological response to the stimuli presented to them [10].

The use of these tests and the monitoring (with the help of MRICP) of the dynamics of a person's response to perceived stimuli together opened up new opportunities for studying neurocognitive processes, including for the purpose of diagnosing a person's hidden information. And as will be shown below, the "technological" stage of the improvement process has created conditions for improving the quality of fMRI data registration.

METHODS

During the "technological" stage on the creation of a complex of fMRI-diagnostics, the above mentioned hypothesis was studied in experiments on healthy volunteers, 21-35 y. o. in the fMRI procedure using MRICP and a set of tests borrowed from criminalistics – TCN, SRT and GKT, respectively, on 73, 12 and 49 subjects.

Permission to conduct the fMRI experiments was obtained from the ethics committee of NRC "Kurchatov Institute".

Experiments at the NRC "Kurchatov Institute" have shown:

1. The selected tests (TCN, SRT and GKT) can be successfully applied during fMRI procedure in accordance with the strict requirements of forensic science. Each test lasted 7-8 minutes, contained 25-30 stimuli, of which 5-6 were significant, and the subjects gave in the tests not motor, but speech responses. At the same time, the tests provided the necessary amount of fMRI data to solve the research tasks.
2. 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 acquired 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.

At the initial stage of experiments, fMRI data were acquired with the following parameters: 30 slices, TR = 2000 ms, TE = 25 ms, slice thickness = 3 mm, flip 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 stereotactic 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)).

To increase the volume of fMRI data and the sensitivity of the technique, it was considered appropriate to switch from classical scanning sequences (TR = 2000 MS) to ultra-fast ones (TR = 1110 MS). Fig.1. shows the group statistical maps obtained when analyzing the TCN for (a) the classical sequence (TR = 2000 ms), and (b) the ultrafast one (TR = 1110 ms).

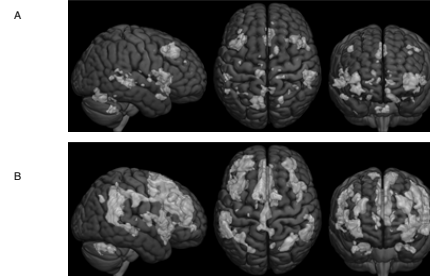


Fig. 1. Group statistical maps drawn on a three-dimensional translucent model of the human brain: (a) TR = 2000 ms; (b) TR = 1110 ms.

The ultra-fast sequences allow the signal to be excited and picked up from multiple slices simultaneously, significantly increasing the signal-to-noise ratio.

3. The use of MRICP allowed us to monitor the real-time dynamics of physiological reactions of subjects to different influences, and record artifacts, the neglect of which would worsen the correctness of the recorded fMRI data, during fMRI procedure. For example, one of the artifacts is "physiological noise", during which the correct registration of fMRI data is impossible (Fig. 2)

Often, during experiments, there were spontaneous reactions to stimuli that were not marked as significant for a particular person under the conditions of the test (Fig. 3).

The use of MRICP made it possible to create a method for rejecting artifacts: fMRI data that were registered when spontaneous reactions or "physiological noises" appeared were excluded from the entire collection of fMRI-data obtained during a specific test. When using the rejection technique, a rule was introduced: a fifth part of the total fMRI data was always excluded ("noised" by artifacts data).

RESULTS

Summing up the results of the "technological" stage, we can state that the selected tests (TCN, SRT and GKT) are a reliable methodological basis for further research on fMRI-diagnostics.

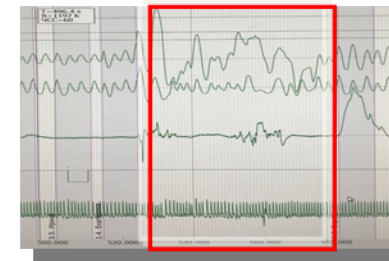


Fig. 2. "Physiological noise" during TCN.

The figure shows a fragment of the experiment (marked with a red border), during which the subject suddenly began to take deep breaths (on the polygram – the first and second graphs from above) and move his hand, which was reflected in the graph of GSR (the third graph from above).

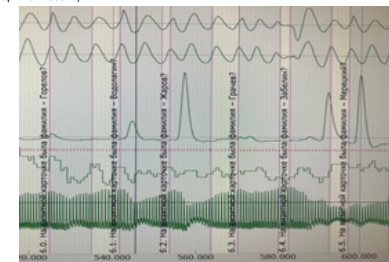


Fig. 3. Spontaneous reaction to an insignificant stimulus in the GKT.

During the sixth presentation of the GKT, the subject had spontaneous reactions in the GSR and photoplethysmogram (on the polygram, respectively, the third and fifth graph from above) to the 2nd (insignificant) stimulus, which are almost equal in magnitude to similar reactions to the 5th (significant) stimulus.

Experiments based on TCN, SRT and GKT have clearly shown the effectiveness of the transition from classical ultra-fast scanning sequences. Representative samples of the same size showed a tenfold increase in detected statistically significant voxels when using an ultrafast sequence compared to the classical one.

The use of MRICP and the developed method of rejecting artifacts during MRI, combined with the transition to ultra-fast scanning sequences, allowed, on the one hand, to improve the quality of recorded fMRI data transmitted to subsequent processing, and, on the other, to increase the number of voxels allocated as a result of such processing. So, experiments performed on 104 healthy men at TR = 2000 ms and TR = 1110 ms confirmed the effectiveness of using the method of rejecting artifacts. This technique helped to increase the number of statistically significant voxels (Student statistics p<0.001) by 52% and 17%, respectively, while the volume of fMRI data was reduced by 20%.

At present, almost all of our neurocognitive experiments are conducted with the mandatory use of MRICP to control the quality of fMRI data registration.

Taking into account the fact that the main physiological process in the rejection of artifacts was the dynamics of GSR, and this improved the quality of selection of active brain zones, it seems correct to study the detected dependence in depth.

CONCLUSIONS

The results presented in the article show the prospects for continuing experimental work on creating fMRI diagnostics. In the future, the developed set of methodological and technical tools will be supplemented by methods of objective quantitative assessment of physiological data recorded by the MRICP.

ACKNOWLEDGMENTS & REFERENCES

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