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PERSPECTIVE APPLICATION OF SIMULTANEOUS EEG RECORDING AND fMRI EXAMINATION IN AVIATION MEDICINE

PERSPEKTYWY ZASTOSOWANIA JEDNOCZASOWYCH BADAŃ EEG I fMRI W MEDYCYNIE LOTNICZEJ

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ABSTRACT: Introduction. *In this paper we present task load induced brain functional changes evaluated by the simultaneous measurement of both bioelectrical activity (EEG) and MRI due to multiple responses evoked in time and space in healthy humans. The stability of individual EEG patterns compared for dynamic changes during and post effect of high frequency magnetic stimulation of nervous system was investigated. Simultaneous fMRI and EEG studies provide a new diagnostic possibilities and new area of scientific research in neurophysiology. Both anatomical and functional data can be generated for each subject, making structural identification of active regions possible. With these techniques, we are beginning to learn how brain structure varies among individuals and how it is related to different behavior.* ***Methods.*** *EEG signals from 64 electrodes were recorded using Curry 7.0 system during*

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MRI examination in Philips Achieva 1.5 T scanner. Additionally, the EEG cap has electrodes for recording vertical oculographic signal (VOEG) and one channel of ECG. During recording visual and auditory stimulation were applied. ***Results.*** *Using artifact rejection procedures, gradient and balistocardiographic artifacts have been removed. The filtered signals were analyzed using spectral analysis and Independent Component Analysis. Structural neuroimages and maps of brain electrical activity in common coordinates have been analyzed.* ***Conclusion.*** *Protocol of the study enables verification the hypothesis regarding influence of the PM/MRI on the spontaneous resting and reresting EEG for evaluation of various connectivity between functionally different regions. Our preliminary experiences with this method indicate that this methodology could allow us to solve the problems described in our previous papers such as microstate conscious deficits, and pseudo-seizure activity in healthy subjects. Including extended structural and functional examinations using these techniques into the procedures of candidates selections in aviation medicine might be of great importance for flight safety*
KEY WORDS: *Neuroimaging, fMRI, functional EEG, ICA artifacts rejection, aviation medicine*

STRESZCZENIE: Wstęp. *W artykule omówiono pilotażowe badania dotyczące zmian aktywności bioelektrycznej mózgu w polu magnetycznym skanera MRI w zapisach EEG rejestrowanych w skanerze. Analiza dotyczy zmian wzorca sygnału EEG przed w czasie i po ekspozycji zmiennego pola magnetycznego dla oceny jego wpływu na centralny układ nerwowy. Jednocześne badania fMRI i EEG stwarzają możliwość prowadzenia badań w kierunku łączenia różnych technik neuroobrazowania. Jednocześnie uzyskiwane obrazy strukturalne i czynnościowe pozwalają na identyfikację aktywowanych struktur oraz ocenę międzyosobniczego zróżnicowania obrazów strukturalnych i czynnościowych.* ***Metody.*** *Zapis EEG z 64 elektrod rejestrowany był w systemie Curry 7.0, w czasie badania MRI w skanerze Philips Achieva 1.5 T. Dodatkowo rejestrowany był sygnał okulograficzny (VOEG) i jeden kanał zapisu EKG. W czasie rejestracji stosowana była stymulacja wzrokowa i słuchowa.* ***Wyniki.*** *Po zastosowaniu procedur eliminacji artefaktów pola magnetycznego i balistokardio-graficznych sygnał EEG w kolejnych etapach badania był analizowany metodami analizy spektralnej i ICA. Oceniano również obrazy strukturalne i mapy aktywności bioelektrycznej mózgu.* ***Wnioski.*** *Wstępna ocena pilotażowych badań wskazuje na ich przydatność w badaniach nad wpływem pola magnetycznego na zapis EEG, a ocena zapisów spoczynkowych i po ustaniu działania pola może być przydatna w ocenie połączeń między różnymi funkcjonalnie regionami mózgu.*

Metoda jednoczesnych badań fMRI i EEG może mieć istotne znaczenie dla rozwiązywania niezwykle ważnych dla medycyny lotniczej problemów, którymi zajmujemy się od wielu lat, przejściowego upośledzenia funkcji poznawczych oraz występowania czynności rzekomo napadowej u ludzi zdrowych. Zastosowanie tej metody w badaniach kandydatów do zawodów lotniczych może mieć istotne znaczenie dla podwyższenia poziomu bezpieczeństwa
SŁOWA KLUCZOWE: *neuroobrazowanie, fMRI, EEG czynnościowa, ICA, medycyna lotnicza*

Introduction

Compilation of structural and functional neuroimages is a new trend in the examination of central nervous system [3,8]. Neuroimaging using high-tech equipment enables simultaneous insight into brain structure and its functions. The most important events in the development of new concepts and technologies leading to the present capabilities were: X-ray imaging Computer Tomography, Magnetic Resonance Imaging (MRI), and functional magnetic resonance fMRI. Along this line in the field of neurophysiology a method of brain electrical activity mapping (BEAM) proposed by Duffy in 1989 has been developed [7]. Multichannel EEG recordings allow to visualize distribution of brain electrical potentials on the scalp surface. Application of this method enables topolocalisation of recorded potentials.

Mapping of brain potentials converts results of EEG studies to a form that can be compared with results of structural studies by overlapping of EEG maps with structural images obtained with various techniques, such as: CT, MRI, PET or SPECT. Such a possibility was very important step forward to comprehensive evaluation of brain morphology and function [18,20].

Functional magnetic resonance imaging (fMRI) provides new possibilities of simultaneous examination of brain structure and function [12]. The principle of this method is to identify the changes of the blood flow in various brain structures during given task. The structures activated during the task are supplied with oxygen and blood flow increases in this area. Oxyhemoglobin has different magnetic properties that allow to distinguish structures supplied by oxygen. Hemoglobin is used in this method as a natural contrast. Principle of fMRI is BOLD (blood oxygenation level dependent) [21].

Indeed, electrochemical processes underlying the brain activity manifesting themselves in the form of brain waves can be investigated by combined fMRI and EEG techniques. Scalp EEG reflects the brain electrical activity, particularly postsynaptic potentials in the cerebral cortex. Brain functional imaging (fMRI) detects hemodynamic changes in the brain through the BOLD effect. Therefore, EEG-fMRI enables direct correlation of these different measures of brain activity and increases their reliability [14,15].

EEG and fMRI methods have different time and spatial resolutions. In fMRI time resolution is comparable with the heart rate, i.e. in range of seconds whereas time resolution of EEG mapping may be 1 ms or even better. In contrast, spatial resolution of fMRI is around 1-5 mm in comparison to that of EEG being around 1 cm.

Simultaneous fMRI and EEG studies provide a new diagnostic possibilities and new area of the scientific research in neurophysiology. Both anatomical and functional data can be generated for each subject, making structural identification of active regions possible. With these techniques, we are beginning to learn how brain structure varies among individuals. Simultaneous fMRI and EEG examinations provide an unique possibility to learn how brain functional structure varies among individuals and how it is related to different behavior.

Another issue that open new perspectives in basic sciences is the new possibility of multichannel EEG recording in the magnetic field both constant and alternating. The MRI environment introduces several different types of EEG artifact such as gradient artifact and the cardiac pulse related artifact usually referred to as ballistocardiogram. Amplitude of MR image acquisition artifact is several orders of magnitudes larger than EEG signal and balistocardiographic artifact. Nevertheless, these artifacts are relatively reproducible and therefore can be removed from EEG recording by signal processing. In some procedures the gradient artifacts are reduced using interleaved recording pattern. The systems designed for EEG recording in MRI scanner provide advanced methods for artifacts rejection that allow to obtain good quality EEG signal.

High temporal resolution of EEG causes brain mapping concern not only localization but also temporal dynamics of neuronal activation [4]. Temporal characteristics of brain electrical activity are rhythmic oscillation in different frequency ranges and periods of transient EEG. Periods of stable electric field configuration are called microstates [16,19]. EEG recording allows to study changes of EEG pattern in magnetic field and changes of the electrical activity correlation with hemodynamic [2,10,13]. Goldman et al. [9] have shown that fMRI signal negatively correlated with alpha activity recorded from occipital cortex. This suggests that generation of high amplitude rhythms might not require increased blood supply.

EEG recordings in MRI scanner free from artifacts enable to study the essential changes of EEG signals pattern in comparison with EEG ambulatory recording. This is a crucial problem which we will deal with in our study.

METHOD

EEG recording during fMRI examination. EEG signals from 64 electrodes were on-line recorded, using Curry 7.0 system during MRI examination in Philips Achieva 1.5 T scanner. Additionally, the EEG cap has electrodes for recording vertical oculographic signal (VOEG) and one channel of ECG. During recording visual and auditory stimulation were applied, using NNL (Nordic Neuro Lab) system for stimulation in MRI scanner. Fig. 1 shows the starting up of examination.

The spontaneous EEG activity was recorded before fMRI sequence whereas stimulations were applied during this sequence. Visual stimuli were applied, using goggles seen in Fig.1 and auditory stimuli by headphones that protect also against the noise produced during scanning process.

Fig. 1. Starting up of the examination EEG recording in the MRI scanner.
Ryc. 1. Rejestracja EEG w skanerze MRI.

Patient's movement had to be restricted to ensure the quality of collected data in both techniques i.e. BOLG signal and EEG signals. Movement artifacts can change the contrast of the BOLD image and also make it difficult to average over repeated trials. The sponges between headphones and the coil were used to limit head movement and additionally to attenuate a noise.

The examination protocol consists of:

- EEG recording outside the scanner, ambulatory examination,
- EEG recording in the scanner during rest before starting scanning,
- EEG recording during fMRI high frequency sequences,
- EEG recording in constant magnetic field.

The procedures of artifact rejection available in Curry 7.0 system were applied that allowed rejection of both gradient (high frequency) and balistocardiographic artifacts. The filtered signals were analyzed using spectral analysis and Independent Component Analysis ICA). The Curry 7.0 system allows an integration of structural neuroimages and maps of brain electrical activity in common coordinates as well as superposition of images of both techniques.

In current study, we focused on the analysis of EEG signals recorded according to above schedule rather than on fMRI images. In what follows some issues regarding the analysis of EEG signals recorded in MRI scanner are presented.

Results

EEG signal processing. EEG signal recorded in MRI scanner during fMRI examination is shown in Fig. 2. Artifacts of magnetic field are seen as over clamping signals.

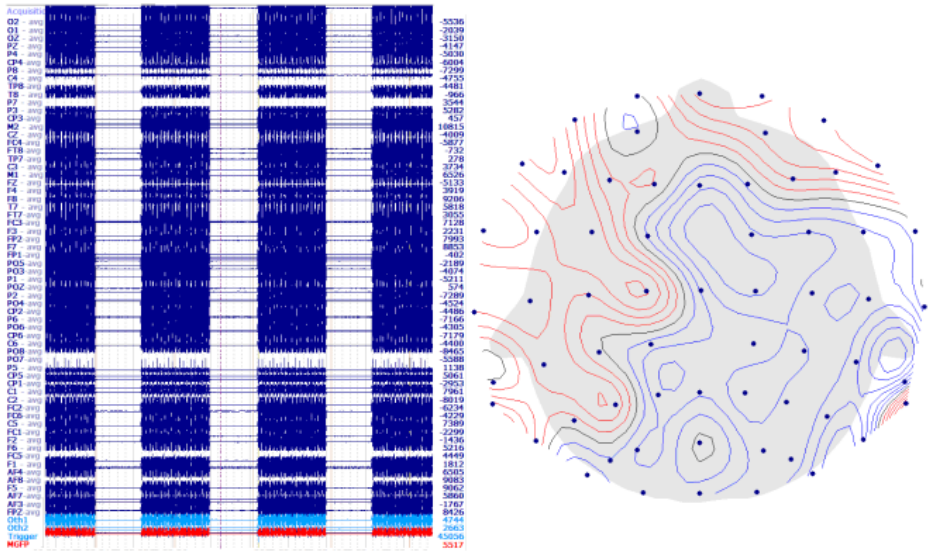


Fig. 2. EEG record with magnetic field artifacts over clamping EEG signal. On the right a map of EEG activity in between sequences.

Ryc. 2. Zapis EEG z artefaktami przełączania gradientów, które powodują przesterowanie sygnału. Po prawej stronie mapa sygnału w czasie między kolejnymi sekwencjami.

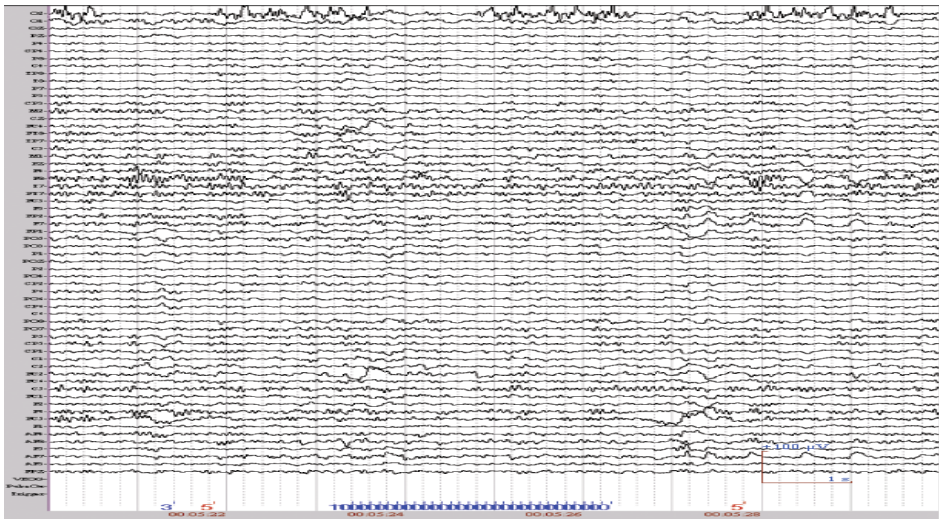


Fig. 3. EEG record during fMRI examination after filtration. Markers 5 indicate the start of sequence. Marker 3 indicates visual stimulus and markers 10 series of auditory stimuli.

Ryc. 3. Zapis EEG w czasie badania fMRI po filtracji. Markery 5 oznaczają początek sekwencji, marker 3 oznacza bodziec wzrokowy, a marker 10 serię bodźców słuchowych.

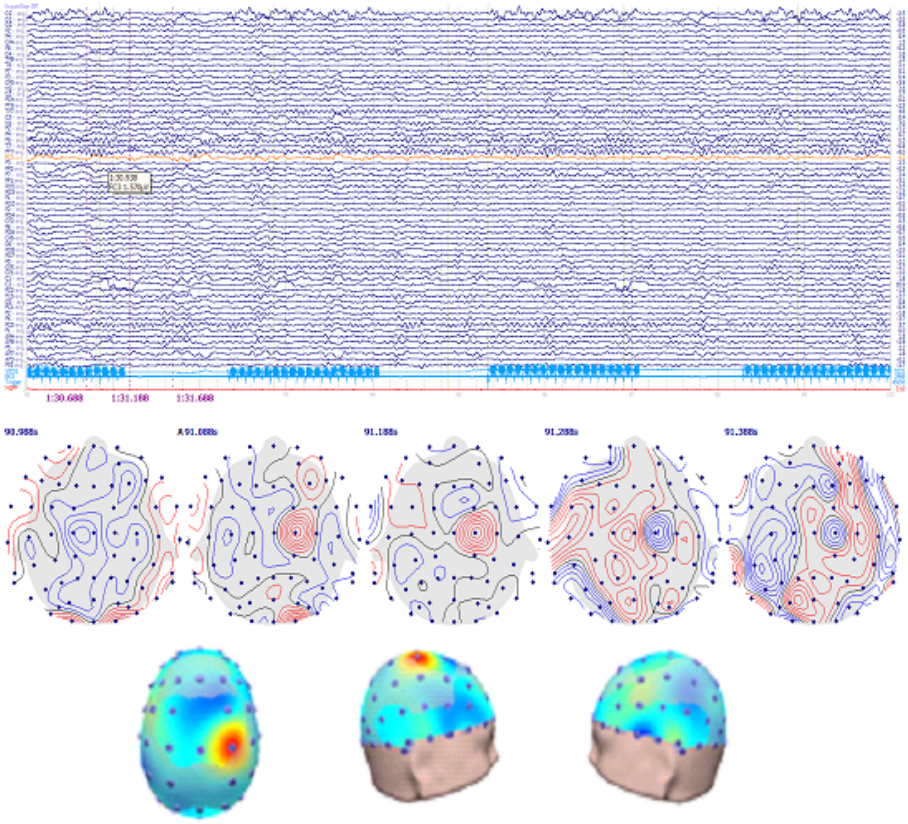


Fig. 4. EEG signals free of artifacts with markers of stimuli shown at the top. 2D and 3D maps of the activity at the bottom indicate dipole constellation that reveal inverse polarization in consecutive maps.

Ryc. 4. Zapis EEG bez artefaktów z zaznaczonymi markerami bodźców. Na mapach 2D i 3D widoczne są konstelacje o zmiennej polaryzacji na kolejnych mapach.

Application of the procedures for artifact rejection available in Curry 7 allowed effective removing of artifacts as presented in Fig. 3. Fig. 4 EEG record with markers of stimuli at the top. A the bottom maps of EEG activity after reconstruction are presented on 3D maps.

Fig. 5 shows continuous EEG record with visual markers indicated by arrows and bars. Stimuli are not directly related to the gradient. For three signal segments of 2 seconds before consecutive stimuli the alpha and beta activity index was calculated. Results are given in Tab. 1. The results are not statistically significant due to the small number of samples, however, it is worth noticing simultaneous decreasing frequency in alpha band and increasing in beta band. These trends may be related to the attention process [1,11].

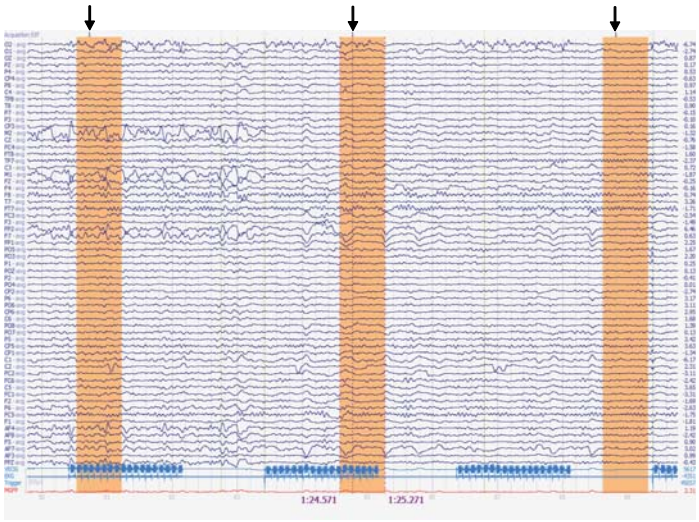


Fig. 5. EEG record after filtration shows visual stimuli in relation to fMRI sequences. Bars mark signal segments before and after stimulus.
Ryc. 5. Zapis EEG z zaznaczonymi bodźcami wzrokowymi. Markerami w postaci pasów zaznaczony jest segment analizy przed i po bodźcu.

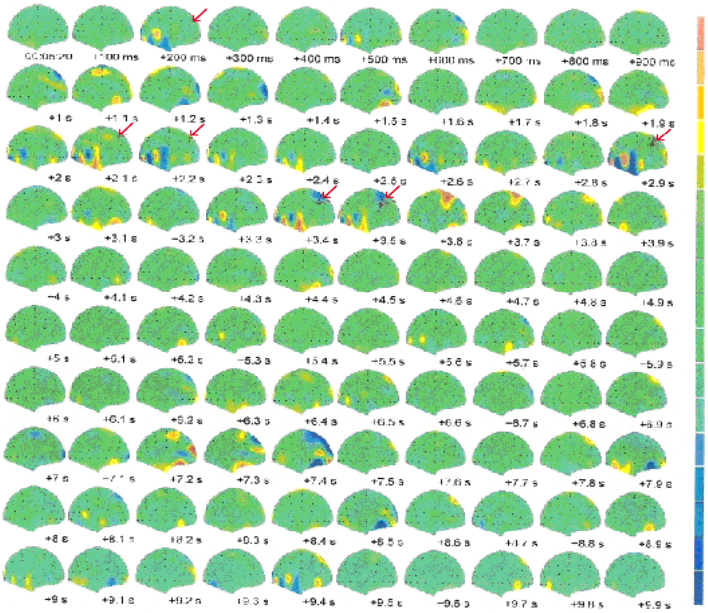
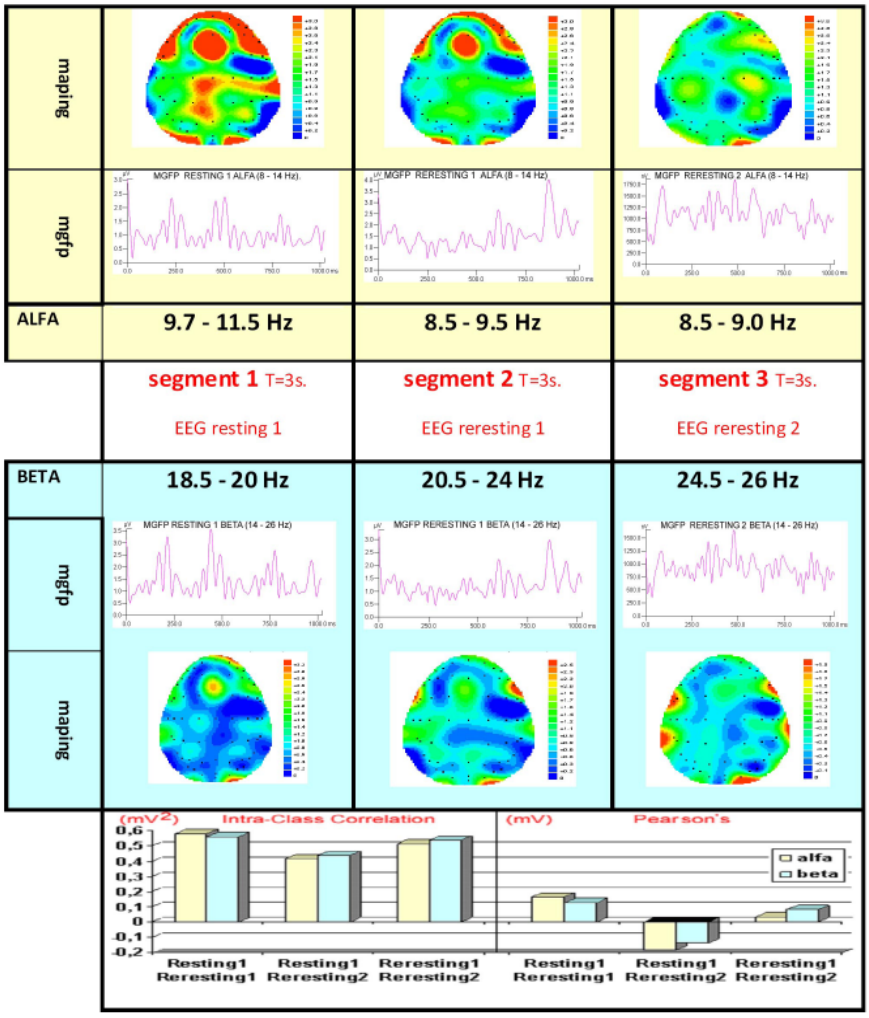


Fig. 6. Spatial-temporal distribution of spontaneous stimulated bioelectrical activity during MRI. Arrows indicate bipolar constellations in temporal and occipital regions.
Ryc. 6. Seria map aktywności bioelektrycznej mózgu w czasie badania MRI. Strzałki wskazują konstelacje bipolarne w okolicy skroniowo-potylicznej.

Tab. 1. Comparison MGFP and alpha/beta index of EEG signal during fMRI study.

Tab. 1. Porównanie wartości energetycznej (MGFP) oraz rozkładu indexu EEG alfa/beta w przestrzeni mózgu (mapping) w czasie badania fMRI.



Discussion

Results of the preliminary recording of multichannel EEG signals in MRI scanner during fMRI examination illustrate, how comprehensive examination of both structural and functional neuroimaging enables the topolocalization of brain electrical activity sources and therefore allows to study the relationships between structure and function. This method provide new possibility to study both metabolic and hemodynamic correlates of electrical activity in the brain and therefore to get the knowledge about functional anatomy. This advantage may be useful in the aviation

medicine in a course of initial examinations of candidates. The fMRI and EEG examinations allow to solve the crucial problem often met in aviation medicine, i.e. how variations of the norm observed in the brain structure as well as in EEG activity in healthy people might impact functions of the central nervous system. The most important issues to be considered are pattern of reactivity to multimodal stimulation, making decision, attention, visuospatial cognitive tasks, etc. Results of these examinations extend the knowledge regarding psychophysiological candidates suitability to this profession.

The German Air Force decided to screen every applicant during initial examination by cranial MRI to rule out relevant intracranial abnormalities. As reported [24], during a two-year scanning in more than one thousand and seven hundred candidates only about 80% had normal results, 9% had variations of the norm, 8.4% had findings of unknown significance (e.g. arachnoid cysts, white matter lesions, etc.) and 0.7% had definite abnormal findings (arteriovenous malformations, cavernomas, tumors).

In our EEG studies in aviation medicine we have found abnormalities in about 2% of candidates [5,6]. The only way of verification in such cases is comprehensive analysis of relationships between electromagnetic and hemodynamic signals and possible morphological changes of brain. Combined supervision with fMRI, EEG and neuropsychological testing provide high probability of the abnormal findings detection.

The rare findings of abnormalities or evident pathological changes do not diminish, however, the importance of cranial screening, using advanced methods [17,24]. Extended procedures increase the value of the initial examination resulting in more appropriate candidates selection and therefore in increasing flight safety. Regarding economy, costs of including extended structural and functional examinations into the procedures of candidates selections are low as compared with the overall costs for pilot education and training. The results provided significant contribution to flight safety since candidates of great risks can be excluded and those with borderline findings can be limited in their deployment [24].

The above is applicable to both morphological and functional examinations using fMRI and simultaneous EEG examinations. Moreover, EEG recording in magnetic field provide an unique possibility of studying the influence of constant as well as alternating magnetic field on neuronal activity. This enables to extend the knowledge on this phenomenon that may be of an importance in aviation medicine [22].

Conclusions

The program of EEG recording in MRI scanner enables verification of the hypothesis regarding impact of the PM/MRI on the spontaneous resting and retesting EEG for evaluation of various connectivity between functionally different regions.

Our preliminary experiences with this method indicate that this method could allow us to solve the problems described in our previous papers such as microstate conscious deficits [25], and pseudo-seizure activity in healthy subjects [5]. Including extended structural and functional examinations with these techniques into the procedures of candidates selections in aviation medicine might be of great importance for flight safety.

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