

Geomagnetic Storms and their Influence on the Human Brain Functional State

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Abstract. An investigation of the influence of geomagnetic storms of various intensities on healthy adults' human brain activity and its functional state was conducted. Results of electroencephalogram (EEG) investigations were used as the most objective method reflecting functional state of the human brain. Studies on the influence of geomagnetic storms on the human brain functional state of healthy adult women patients (permanent group) in states of relaxation, photo-stimulation and hyper-ventilation have revealed a negative influence of severe geomagnetic storms on functional state of the human brain. As a rule, during periods of strong geomagnetic disturbances, indisposition, weakness and presence of indistinct localized headaches were recorded for majority of patients. Complex of nonspecific shifts on EEG reflects disorganization of functional activity of cortex of large hemispheres of the human brain at geomagnetically disturbed days, which is likely connected with dysfunction of integrative subcortical systems, with disbalance of its ascending synchronizing and desynchronizing influences. Imbalance of activating and deactivating mechanisms including dysfunctions of ergo- and tropho-tropic over-segmentary centers was registered. Strengthening cortical connections in the right cortical hemisphere and their short circuit on temporal sections during geomagnetically disturbed days were observed, while, in geomagnetically quiet days, a profile of correlation interrelations reflected weak internal- and inter-hemispheric connections. The threshold of convulsive (spasmodic) readiness of the human brain is reduced, which is especially dangerous for risk group persons. It is established that, in general, weak and moderate geomagnetic storms exert stimulating influence while strong disturbances of geomagnetic conditions activate braking (inhibiting) processes.

Keywords: Space weather, geomagnetic storms, human brain, electroencephalogram, nervous system.

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1. Introduction. Space Weather and human physiological state

The geosphere is very sensitive to solar activity, to changes in this activity and their manifestations on the Earth. Conditions on the Sun and in the solar wind, magnetosphere, ionosphere and thermosphere (i.e., so called Space Weather) can influence not only the performance and reliability of space-borne and ground-based technological systems, but can endanger human life and health^{1, 2}. Therefore, it is very important to get more and better knowledge about solar and geomagnetic storms and their potential impacts, in order to decrease or minimize these disturbance factors³.

The biological and systems ecological are significantly exposed to the influence of solar and geomagnetic activities; they play very important role in our daily life. One of the main targets of negative influence of the geomagnetic storms on health state is the human nervous system. The results of the detailed studies, which are published in^{4 - 10}, show that during the periods of strong geomagnetic disturbances, the number of hospitalized patients with nervous diseases notably increases, the cases of myocardial infarcts and cerebral insults, different paroxysmal conditions, nervous disturbance disorders and suicidal attempts become more frequent, the psycho-neurological diseases become aggravated and so on. At the same time, some reports show comparatively positive influences of heliogeophysical conditions on the human health state. For the persons, suffering from epilepsy, a reduction of frequency of epileptic attacks and improvement of general health state were detected during increases the level of geomagnetic field disturbances. Researches, conducted simultaneously at different geographical regions of the globe, revealed that during geomagnetic storms some monotype changes in the health state of mentally ill patients take place. It is curious that with an increase of disturbance of geomagnetic field, the number of epileptic attacks decreases.

During high solar activity periods, the predominance of maniacal phases in patients suffering from manic-depressive psychosis is of frequent and short-duration nature. When there is stabilization in the geomagnetic conditions, the maniacal phase is replaced by the depressive stage.

Neuropsychological data, reflecting functional state of the human brain during geomagnetic disturbances, is not less contradictory. Long-duration (about 72 hours) irradiation of animals by electromagnetic flux resulted in 89 % of cases in the expressed changes of bioelectric activity of the brain. The depression of the alpha-activity in all leads of the brain fields, displacement of dominant frequency band of the electroencephalogram (EEG) activity in hippocampal sections, in tonsil-like complex and in septum in the theta-range (4–7 Hz) were observed. In the cortex and reticular formation of mesencephalon, despite of the decrease of general specific weight, the dominance of EEG-activity in the alpha-range (8–13 Hz) took place. The frequency of EEG-activity in all leads reliably increased, which was testified by increasing of specific weight of activity in beta-range (15–20 Hz) and by decreasing of differences between dominant rhythms.

It should be noted, that during strong geomagnetic disturbances, the tolerance to mental and physical stresses is decreased; there appears a danger of disorders for the people whose professional work is connected to high-level responsibility, like surgeons, dispatchers, drivers, pilots, etc. The changes of geomagnetic conditions affect, first, the activity of regulating systems which are related to high cortical mechanisms of regulation and sub-cortical integrative apparatuses responsible for the organization of routine activity of organism and for adaptation to environment changes.

Disturbances of the geomagnetic field, as any stress factor, influences first the central nervous system being the sensitive screen, and perceiving even weak disturbance fluctuations (oscillations) in the environment^{11, 12}. Investigation of bioelectric activity of the human brain, which reflects a continuum of functional conditions, according to the paper¹³, is an adequate method for research of a condition of cerebral cortex of the big hemispheres and cortico-subcortical interrelations.

Not only the central, but also the vegetative nervous system of human being is very sensitive (responsive) to the geomagnetic disturbances¹⁴. It is established that during weak and moderate magnetic storms, a tone strengthens in the field of sympathetic part (section) of a vegetative nervous system. Only in some cases and, most often for the men, the strengthening (amplification) of tone of the parasympathetic section of a vegetative nervous system is observed¹⁴.

Based on EEG researches, it is established that the nervous system of patients responds on geomagnetic disturbances by a diphasic reaction¹⁵. During days with geomagnetic storms, the generalized reduction of indexes of spatial synchronization of EEG is marked. On the contrary, a general increase is registered on the next day in contrasted long-lived quiet period.

An investigation of examined patient's blood also gave interesting results. The blood viscosity during geomagnetic storms increases sharply (in some cases almost twice), the erythrocytes become adhesive, and the blood stream slows down. Therefore, it is demonstrated that the magnetic storms increase the risk of morbidity in the cardiovascular system^{9,10}. Geomagnetic storms cause cardiac rhythm problems for cosmonauts during extreme conditions in the orbital station¹⁶.

According to the relevant investigations, an influence of electromagnetic fields on the human brain has a large polymorph character. In some cases, the changes have a predominance of slow rhythms, in other cases, on the contrary, there is a predominance of fast waves or general depression of bioelectrical activity.

Nevertheless, there is an evidence that the human nervous system is a target and/or messenger at effecting fluctuations of the geomagnetic field on human physiological states and, particularly, on the human brain's functional state. Therefore, in our research works the EEG investigations are used as the most objective and practical method reflecting functional states of the human brain.

In spite of the increasing interest of scientists from different fields of science in the helio-medicine, many problems in this discipline either are elucidated insufficiently and sometimes with contradictory results, or, remain absent. Only few papers are dedicated to the analysis of possible influence of the Space Weather (especially geomagnetic disturbances) on the bioelectric activity of human brain by help of EEG (for example, see papers¹⁷⁻¹⁹).

In this original research paper we have studied the possible influence of solar and geomagnetic storms of various strengths and some very intense (severe) geomagnetic storms caused by the violent Sun-Earth connection events (such as which had a place in October-November 2003) on the human brain activity and its functional state. Daily monitoring of Space Weather conditions (parameters) and available solar-geophysical data, using Internet contacts and resources (US National Aeronautics and Space Administration (NASA), the European Space Agency (ESA), US National Oceanic and Atmospheric Administration's Space Environment Center (SEC NOAA) and SPIDR, Russian Space Weather Initiatives (RSWI), the Institute of Terrestrial Magnetism, the Ionosphere and Radio-wave Propagation (IZMIRAN, Russian Academy of Sciences) and other services) for the considered periods and region were provided, after analysis, by the Shamakhy Astrophysical Observatory Azerbaijan National Academy of Sciences (ANAS) and were used in our continuous experiments. Special attention was paid to the stormy days of July 2000, April 2001, October-November 2003, November 2004, January 2005, etc. Particularly, one of the major and severe geomagnetic super-storms of the current Solar Cycle 23 in October-November 2003 gave a unique chance to Azerbaijani researchers to study in details an impact of extreme Space Weather events on the human brain functional state. We have coordinated activities of astrophysicists and specialists on brain physiology, and were able to conduct high-level experiments within a joint research program on the considered subject which started several years ago. A special attention was paid to the days of risk, namely from 14 October to 21 November

2003 with maximums at 29-30 October and 4 November. The relevant information about these events for the public was published in daily Space Weather Prognosis column provided by famous Azerbaijani newspaper "Zerkalo" in Russian.

We have studied the influence of geomagnetic storms on the human brain functional state of healthy adult women patients (permanent group) in states of relaxation, during photo-stimulation and in hyper-ventilation. Results of EEG investigations were used for reflecting functional state of the human brain. A parallel registration of the electrocardiogram (ECG) was also conducted. Comparison of data for October-November 2003 with other data obtained during a long-time period experiments for relatively geomagnetically quiet and moderately disturbed days as well as interpretation of the obtained results were carried out.

2. Experimental methods

Data record of bioelectric activity of the human brain was made with the help of the computerized electroencephalograph, which is the multi-channel (16 channels) digital recorder intended for polygraph registration of the physiological characteristics. The digital data was recorded on the hard disk, which was subsequently subjected to reviewing and analyzing qualitatively and quantitatively.

27 healthy female persons (permanent group), aged between 20 and 40 years old, issued from the same geographical area, were chosen for a long-term investigations during geomagnetically quiet (favorable) days, at days with weakly-disturbed, and strongly-disturbed (unfavorable) geomagnetic conditions. All female patients were examined in the inter-menstrual period.

Daily changes of meteorological situation during the experiments were also taken into account. In order to avoid psychological effects prior to experiments, the persons under test were not familiarized about Space Weather conditions before and during experiments. The experiments were conducted in isolated rooms (to minimize effects of environment and artificial fields) and in hospital conditions.

Registration of spontaneous EEG by a mono-polar way from 16 standard leads arranged pursuant to the international system of "10-20" and a parallel registration of the electrocardiogram (ECG) was conducted. The experiments were carried out in the standard system from forehead (frontal), central, parietal, occipital and temporal areas of both hemispheres of the human brain.

Investigations were carried out for quiet and active awakers in conditions with open and closed eyes, in the states of relax, in photo-stimulation and in the process of a hyperventilation. The native records of EEG, which were obtained at different functional conditions, as well as the relevant data and registered curves were stored on disks. Later on, after removal of artefact segments, they were subjected to the computer analysis using the special software. Spectral and amplitude mapping, correlation and periodical-metric analyses were carried out. Frequency and amplitude cartograms, obtained for different functional conditions, reflect features of the human brain functioning at comparatively quiet days and at days with strong geomagnetic storm.

Experiments were conducted taking into account solar and geomagnetic storms during above-mentioned days. As the most widely-used parameters of the geomagnetic activity for biomedical problems, the A_p -index and Dst -index, were used in our researches alongside other Space Weather parameters.

3. Results and discussions

Results of our investigations have revealed that during severe geomagnetic storms the large majority of patients under test expressed indisposition, weakness and/or presence of indistinct localized headaches. In most cases, bioelectric activity of the human brain was characterized by reduction of frequencies of a dominating rhythm, amplification (strengthening) of expressiveness of slow-wave component (mainly, a theta-rhythm) and increase in amplitude of activity (Figures 1.1 and 1.2). We have observed the forms of waves with pointed outlines and strengthening of process of synchronization of activity.

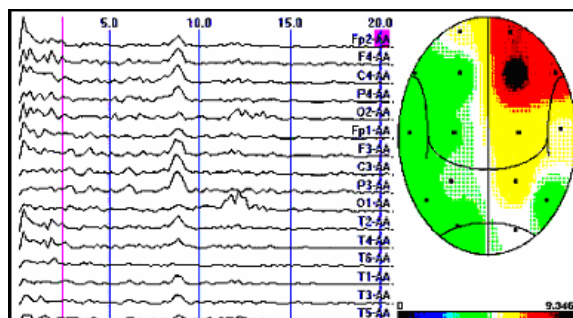


Fig.1.1. Typical frequency histogram and frequency cartogram during the major geomagnetic storms

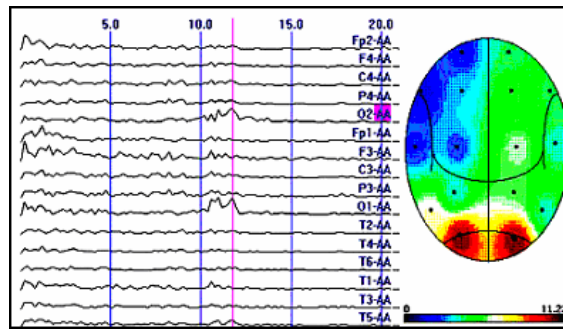


Fig.1.2. Typical frequency histogram and frequency cartogram at the comparatively geomagnetically quiet conditions

Flashes of pointed and sharp alpha- and theta-waves, having right cerebral hemisphere's accent (stress), were registered during experiments. Typical pictures are provided in Figures 2.1 and 2.2. Smoothing of interzonal distinctions was observed as well. For a part of examinees diffuse synchronization was traced on frequency ranges of alpha-1 and alpha-2 rhythms. Reactivity of dominating activity was weakened, and reactions of adopting a rhythm were observed on lower frequencies of the alpha-range.

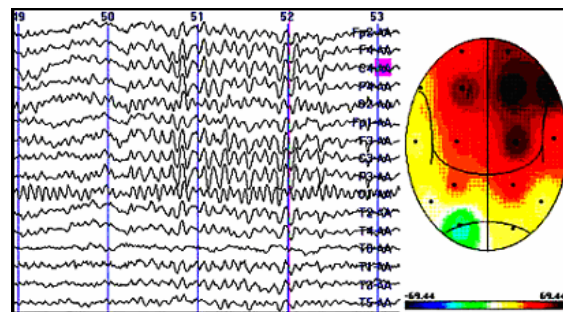


Fig.2.1. Example of EEG and total (summary) amplitude cartogram during the major geomagnetic storms

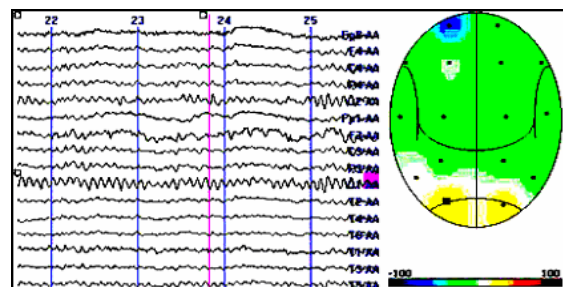


Fig.2.2. Example of EEG and total (summary) amplitude cartogram at the comparatively geomagnetically quiet conditions

During the hyperventilation process observable flashes of both pointed and sharp alpha- and theta-rhythms were amplified, and their amplitudes were increased as well. Figure of correlation interrelations, inherent to various functional conditions, was broken (Figures 3.1 and 3.2). Inter-hemispheric asymmetry was revealed. The leading role in interrelations had temporal area of the right cerebral hemisphere. Activation of rostral-temporal and caudal-temporal connections (links) of the right hemisphere was marked.

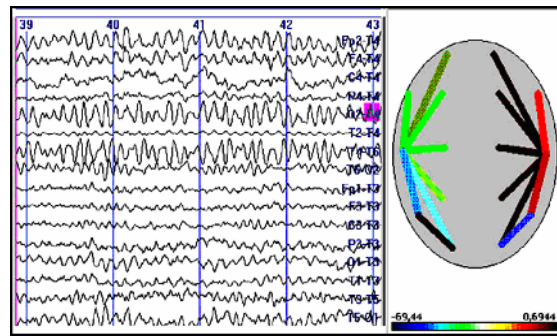


Fig.4.1. Typical EEG and correlogram during the major geomagnetic storms

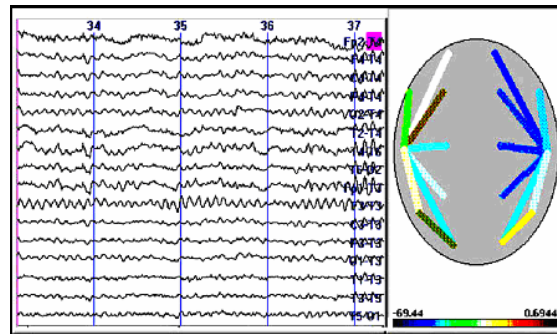


Fig.4.2. Typical EEG and correlogram at the comparatively geomagnetically quiet conditions

The obtained results prove the significant changes in activity of the human brain during the days with severe geomagnetic storms, reflecting infringement of functions on both central integrative mechanisms and local processes of brain regulation.

It is well known that the most sensitive sections of the human brain, being influenced by negative factors of an environment, are hypothalamus and cerebral cortex of the big hemispheres of the human brain²⁰. The increase of representativity of theta- and alpha-rythms, which carry flash-like character, testifies on dysfunction of mesodiencephalic sections within the limits of which hypothalamic nucleus are located. Considering hypothalamus as a leading part of nonspecific systems of the human brain^{21,22} and as responsible for neuroendocrinal and vegetative regulation, it should be noted that strong geomagnetic disturbances infringe normal activity of this structure, causing imbalance in ergo- and tropho-tropic interrelations.

The dysfunction, registered on EEG and reflecting ascending sendings, undoubtedly affects descending directions as well, causing complex vegetative complaints observed in the majority of examinees. At the same time, it must be noted that, pointed and sharp flashes of theta- and alpha-range which are observed on some tested persons in the days with severe geomagnetic storms, testify on the paroxysmal character of the infringements, specifying on reduction in a threshold of convulsive (spasmodic) readiness mesodiencephalic formations with followed corresponding clinical-neuropsychological consequences.

Observed right cerebral hemisphere accent (stress) of changes testifies the greater "interest" of right hemisphere. According to the paper²³, activation of the right hemisphere is accompanied by negative tinge of emotional reactions. Outgoing from this fact, it is possible to assume that during very strong disturbances of geomagnetic conditions the negative emotional background of the person is amplified. This assumption is also proven by results of the correlation analysis specified on strengthening cortical connections in the right cortical hemisphere and their short circuit on temporal sections, while, in geomagnetically quiet days, a profile of correlation interrelations has reflected weak internal- and inter-hemispheric connections.

Thus, results of our researches prove the negative influence of the very strong geomagnetic storms on the functional state of the human brain. Normal functioning of integrative nonspecific systems, located within the limits of limbic-reticular complex and responsible for creation of the corresponding level of wakefulness, which is directed on realization of optimum current activity of an organism, is broken. Imbalance of activating and deactivating mechanisms arises including also dysfunctions of ergo- and tropho-tropic over-segmentary centers.

The threshold of convulsive (spasmodic) readiness of the human brain is reduced which is especially dangerous for the persons of high risk and, as a result, this fact should be taken into account for preventive measures and therapy of paroxysmal conditions.

4. CONCLUSIONS

The obtained results allowed concluding that the disturbances of geomagnetic conditions can negatively influence the human organism, having an effect on functional activity of a brain and changing its background state. There are significant changes in the functional activity of the human brain during the days with severe geomagnetic storms, which reflect infringement of functions in both central integrative mechanisms, and local processes of the human brain regulations.

It is established that, together with the detected specific changes, the complex of nonspecific shifts on the EEG reflects disorganization of functional activity of the cortex of large hemispheres of the human brain at geomagnetically disturbed days, which is most likely connected with dysfunction of integrative subcortical systems, with disbalance of its ascending synchronizing and desynchronizing influences. The disbalance of these mechanisms infringes the optimal functioning of the integrated brain, disorders normal level of corticosubcortical correlations, which, in turn, finally affects *emotional* and *ideational* activities.

As a rule, during periods of severe geomagnetic disturbances, *indisposition*, *weakness* and *presence of indistinct localized headaches* were recorded for the major part of the patients under test.

In most cases bioelectric activity of the human brain was characterized by the slow-down of frequencies of dominating rhythm, by the strengthening of expressiveness of a slow-wave component (mainly a theta-rhythm) and by an increase in amplitude of activity. The form of waves had the pointed (sharp) shape and amplification of process of synchronization of the activity as well as smoothing inter-zonal distinctions were observed.

For the part of examined patients, a diffuse synchronization was traced on frequency ranges of an alpha-rhythm (clearly expressed in the occipital sections and in the temporal areas). Reactance of activity was weakened, reactions of mastering of a rhythm were observed on lower frequencies of an alpha-rhythm range. Flashes of both pointed and sharp alpha and theta-rhythms, exceeding on amplitude a background, were observed during hyperventilation process.

Picture of correlation relations inherent to various functional states was infringed and inter-parencephalon (inter-hemispheric) asymmetry was marked. Temporal area of the *right cerebral hemisphere* (parencephalon) had a leading role in interrelations. Activation of rostral-temporal and caudal-temporal links of the right hemisphere was marked.

During strong disturbances of geomagnetic conditions, the *negative emotional background* of the person is amplified. Strengthening cortical connections in the *right cortical hemisphere* and their short circuit on temporal sections during geomagnetically disturbed days were observed, while, in geomagnetically quiet days, a profile of correlation interrelations reflected weak internal- and inter-hemispheric connections. The *threshold of convulsive (spasmodic) readiness* of the human brain is reduced.

It is established that weak and moderate geomagnetic storms exert stimulating influence while the strong disturbances of the geomagnetic conditions activate braking (inhibiting) processes.

Complex and synchronic investigation of geomagnetic storms' effects on human brain in different latitudinal and longitudinal areas of the globe could give more detailed and interesting results which are very important for understanding the influence mechanisms and preventive measures.

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