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The influence of geomagnetic disturbances on parameters of acupuncture points, EEG, HRV, hormone, immunity and metabolism of a persons with hypertension

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Abstract

Background and aim. Back in 1990, Limansky YP hypothesized acupuncture points (AP) as polymodal receptors of the ecoceptive sensitivity system. In the process of hypothesis development in 2003 an existence of separate functional system of regulation of electromagnetic balance of organism has been substantiated. Recently, our research group found that disturbances of the geomagnetic field (GMF) cause a significant immediate modulating effects on the APs and parameters of neuro-endocrine immune complex. On the other hand, it was shown that the latter as well as metabolic parameters are closely related to the level of blood pressure. Based on the above, we hypothesized that individuals with hypertension, responders and non-responders to GMF changes, differ among themselves in the constellation of neural, endocrine, immune, metabolic and AP parameters. The purpose of this study is to test this hypothesis.

Methods. The object of the study was database of 19 men (37-69 y) and 17 women (33-76 y) with hypertension (Mean±SD: BPs 150±15 mmHg; BPd 87±10 mmHg). Retrospectively, was recorded the geomagnetic Ap-Index and Kp-Index, on the day of testing and during the previous 7 days, using a publicly available information resource https://www.spaceweatherlive.com. The object of the analyses was blood pressure (BP), acupuncture points (AP), EEG, HRV, endocrine, immune and metabolic parameters.

Results. Using the cluster analysis method, two groups of individuals with the same hypertension were identified, which manifested itself against the background of significantly different levels of Ap- and Kp-Indexes on the day of testing and during the previous two days, characteristic of a calm or slightly disturbed (for 14 men and 13 women) and significantly disturbed (for 5 men and 4 women) geomagnetic field (GMF), respectively. Screening revealed that significantly disturbed GMF is accompanied by left-sided asymmetry of AP MC(AVL) electrical conductivity as well as beta and alpha rhythms in contrast to their symmetry against the background of calm or slightly disturbed GMF. Regarding quantitative parameters, the first cluster is accompanied, firstly, by reduced levels of monocytes, triiodothyronine, testosterone, atherogenicity, heart rate, and Baevskiy's Stress Index, in contrast to their normal or elevated levels in the second cluster; second, normal vs. decreased levels of rod-shaped neutrophils, frequency of alpha rhythm and SPD of beta rhythm in T4 locus; third, normal vs. increased levels of creatinine and Popovych's Strain Index; fourth, increased vs. normal response of systolic BP to brachial artery compression and SPD of delta rhythm in O2 locus. In addition, in the first cluster 23 EEG parameters were found to be decreased or normal vs. normal or increased in the second cluster. Finally, significantly disturbed GMF is accompanied by an increase in the electrical conductivity of the left AP MC(AVL) to a greater extent than calm or slightly disturbed GMF.

Conclusion. In individuals with hypertension, regardless of sex and age, disturbances of the geomagnetic field, even without reaching the storm level, are accompanied by significant modulating, mainly downregulating, effects on recorded parameters of EEG, HRV, immunity and metabolism, apparently through acupuncture points as polymodal receptors of the ecoceptive sensitivity system.

Keywords: Earth magnetic field, geomagnetic Ap and Kp-indexes, acupuncture points, EEG, HRV, immunity, metabolites, hypertension, relationships, humans.

1. Introduction

The Earth's magnetic field is influenced by its interaction with solar winds and other external events. When the solar winds are especially active, this can create geomagnetic disturbances that influence the underlying ionosphere resulting in "space weather" that impacts electric currents, plasmas, and even fields in Earth's magnetosphere. Simply put, the Earth's geomagnetic field (GMF) is the magnetic field surrounding the Earth [Finlay CC et al., 2010; Siscoe GL, 1975; Hathaway DH, 2015; Mitsutake G et al., 2005; Zenchenko TA & Breus TK, 2021]. The main component of this field is due to the circulation of Earth's molten Iron core and Earth's rotation. It is sometimes referred to as the main field with an average value that ranges from about 25 μT to 65 μT depending on geographic location [Finlay CC et al., 2010]. The field's magnitude changes slowly largely dependent on internal Earth-bound processes. However, external sources can affect this field causing rapidly changing magnitudes that constitute **geomagnetic disturbances**. One such external source is attributed to changes in solar activity and solar wind via charged particle interaction with the main field including solar coronal mass ejections [Siscoe GL, 1975]. Solar activity varies according to an approximate 11-year cycle that depends on variations in the Sun's magnetic field [Hathaway DH, 2015]. When the Sun's magnetic field is at its maximum intensity and well organized, it contains the Sun's plasma in regions close to the Sun's surface. Over time, the field becomes less organized, and its ability to keep the high-energy plasma near the Sun's surface weakens. As a consequence, radiation in the form of bright Solar flares may occur, sometimes associated with huge amounts of high-energy, high-speed charged particles that represent coronal mass ejections. When these disturbances occur, the terms **geomagnetic storm, substorm, or pulsations** may apply. If the changes induced in the GMF are sufficiently large, the term geomagnetic storm applies and is one type of disturbance thought to affect biological processes, even though the resultant change in the GMF may be of the order of 5%. In addition to these externally induced transient field changes, there are coexisting field changes mainly due to lightning radiant energy resulting in Schumann resonances [Mitsutake G et al., 2005]. The term heliobiology has also been used to describe possible space weather effects of solar and geomagnetic processes [Zenchenko TA & Breus TK, 2021].

Mechanisms by which any of the various field alterations affect biological processes are mostly speculative with multiple hypotheses suggested. As a very broad summary of three possible groupings, there are (1) mechanisms triggered by rapid changes in the GMF, (2) mechanisms associated with resonant interactions triggered by electromagnetic fluctuations of various frequencies, and (3) mechanisms that trigger biological changes from space weather-induced changes in climatological parameters [review: Mayrovitz HN, 2023].

Studies that attempt to correlate a physiological or pathophysiological effect with changes in the GMF require a quantitative estimate of the magnitude of the field change. For this purpose, several parametric indices are available that are derived from measurements of the actual GMF and its temporal variations. The status of the GMF is often characterized by two planetary indices of geomagnetic activity (GMA) identified as Kp and Ap, both measured and reported in units of magnetic field strength and usually expressed in nT [Matzka J et al., 2021].

The **planetary index Kp** is calculated in a three-hour interval as the mean of K-indices determined at 13 worldwide geomagnetic observatories located between 44° and 60° North and South geomagnetic latitudes. Ap is the overall daily index of geomagnetic activity determined as the mean of eight three-hour values from the same observatories sometimes referred to as k-sum. The diurnal variation of the naturally occurring, time-varying magnetic field is measured by each local geomagnetic observatory as the K index. The value of the Kp index is used as a measure of the planetary GMF effect that includes all currents and magnetic deviations they produce on the ground. Kp quantifies disturbances in the Earth's magnetic field on a scale of 0-9, with ≤2 indicating low GMA and ≥5 indicating a geomagnetic storm [Rangarajan GK & Barreto LM, 1999; Tan Y et al., 2018; Wang JJ et al., 2023]. These are logarithmic ratings that are related to the absolute change in the Earth's magnetic field, although attempts have been made to extrapolate the global Kp values to the local situation [Segarra A & Curto JJ, 2015]. GMA can also be measured using the **Ap index** which is defined as the earliest occurring maximum 24-hour GMA value obtained by computing an eight-point running average of successive three-hour Ap indices during a geomagnetic storm event and is uniquely associated with the storm event.

Naturally occurring geomagnetic disturbances are thought to be associated with biological and clinical events [Kuzmenko NV et al., 2019]. Solar flares and solar activity generate magnetic storms, which through modulation of the solar wind, cause geomagnetic anomalies in the Earth's environment impacting living organisms [Kuzmenko NV et al., 2019; Podolská K, 2018; Gmitrov J & Gmitrova A, 2004]. During storms, changes in the magnetic field, particularly small pulsations of the magnetic field accompanying the geomagnetic storm, have been reported to affect human health adversely, with the heart and cardiovascular system being the main targets [Kleimenova NG et al., 2007]. Cardiovascular exacerbations have been reported to correlate with high negative values of the interplanetary magnetic field component and the geomagnetic disturbances they induce. Cardiovascular-related changes reported range from changes in blood's properties including red cells [Gurfinkel YI et al., 2000], and white cells [Tracy SM et al., 2022] to changes in blood pressure (BP) [Dimitrova S et al., 2004]. An indication of the possible impact on BP in hypertension is suggested by the reported increase of 12% in ambulance calls for hypertension-related matters [Vencloviene J et al., 2015]. A summary of some of the main contributors to changes in the GMF is schematized in Fig. 1.

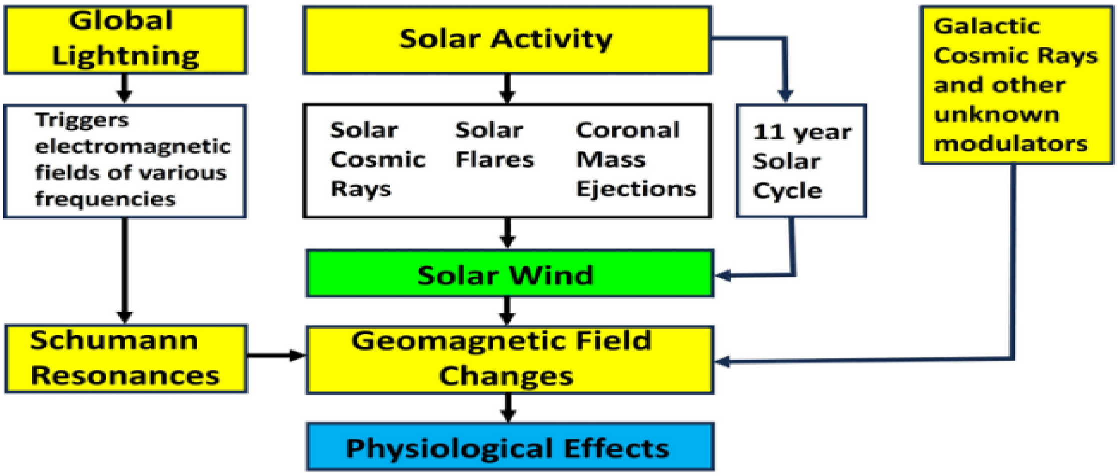


Fig. 1. Some main contributors to changes in the geomagnetic field (GMF).

The schematized version of the processes impacting the GMF from solar and other sources is an overview and not meant to be fully inclusive of all processes that might alter the GMF. The coupling mechanisms between changes in the GMF and associated physiological effects are unresolved. The physiological effect of interest in this study is the effect on blood pressure [Mayrovitz HN, 2023].

The preponderance of the reported evidence is consistent with the concept that space weather and related events that cause sufficiently large changes in the geomagnetic field (GMF) can impact BP. The associated BP change in most but not all cases is one in which both systolic blood pressure (SBP) and diastolic blood pressure increase, with SBP appearing to be more consistently involved. The magnitude of the reported BP increase ranges from about 3 to 8 mmHg depending on the intensity of the geomagnetic activity. The initiation of these BP changes has been variably reported to occur shortly before the GMF change or in synchrony with the abrupt change in the GMF. Such GMF-linked BP changes are not present in all persons and there appears to be increased sensitivity in women and in persons with co-existing hypertension. The utility of these findings in assessing or treating persons with known or suspected hypertension remains to be determined via future research. Further, research directed at determining the factors that determine responders from non-responders to GMF changes is warranted [review: Mayrovitz HN, 2023].

Earlier researchers of Truskavetsian Scientific School of Balneology proposed the concept of **tensioregulome** [Popovych IL et al., 2022] by analogy with the metabolome and the microbiome. The forward stepwise program identified 26 tensioregulome parameters as characteristic of quantitative-qualitative BP clusters: 10 EEG, 6 metabolic, 6 immune, testosterone, cortisol, sympathetic tone as well as sex. The accuracy of patient classification is 98,9%. Another 25 parameters were found to be characteristic, but were outside the discriminant model, including 11 EEG, 2 HRV, 5 metabolic, 4 immune, bacteriuria, body mass index, and age [Kozyankina NV et al., 2020; 2021; 2022; 2022a; 2024; Kozyankina NV & Popovych IL, 2024].

Back in 1990, Limansky YP [1990] hypothesized acupuncture points (AP) as polymodal receptors of the ecoceptive sensitivity system. In the process of hypothesis development an existence of separate functional system of regulation of electromagnetic balance of organism has been substantiated and a working conception of light therapy has been formulated [Gulyar SA & Limansky YP, 2003]. Inspired by this hypothesis, members of our group recorded the electrical conductivity of 9 pairs of APs as well as EEG, HRV, endocrine and immune parameters of 21 men (24-63 y) and 20 women (30-72 y) twice with an interval of 4 days. Retrospectively recorded the geomagnetic Ap-Index on the day of testing and during the previous 7 days. During the week, the average level of Ap-index ranged from 7 to 13 nT. Maximum coefficients of multiple correlation with APs parameters were detected for Ap-index on 6th day before (R=0,552) and on the day of testing (R=0,470). The canonical correlation between Ap-indexes for 7 days before and on the day of testing, and the APs parameters was 0,661; the EEG parameters - 0,886; HRV&Hormonal parameters - 0,766; immunity parameters - 0,921 (Fig. 2) [Tserkovniuk RG et al., 2021; 2021a; 2021b; 2024].

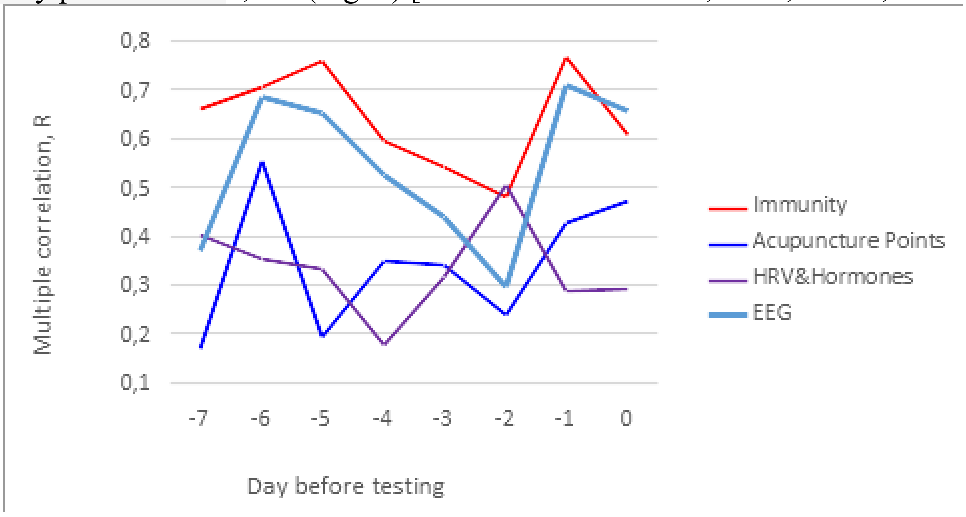


Fig. 2. Patterns of coefficients of multiple correlation R between Ap-Indexes and acupuncture points as well as neuro-endocrine-immune complex parameters [Tserkovniuk RG et al., 2021]

In turn, the immune parameters closely related to the EEG parameters (R=0,944) as well as to the HRV&Hormonal parameters (R=0,714). This is consistent with the concept of a neuro-endocrine-immune network/complex [Besedovsky H & del Rey A, 1996; Gozhenko AI et al., 2019; 2021; Popovych IL et al., 2022a; Kozyankina NV et al., 2024].

Research Aim, Research Hypotheses, and Research Questions.

Based on the above, we hypothesized that individuals with hypertension, responders and non-responders to GMF changes, differ among themselves in the constellation of neural, endocrine, immune, metabolic and AP parameters.

Research Aim. The aim of this study is to investigate the influence of geomagnetic disturbances on parameters of acupuncture points, electroencephalogram (EEG), heart rate variability (HRV), hormonal status, immunity, and metabolism in persons with hypertension, and to determine whether individuals with hypertension who differ in sensitivity to geomagnetic field (GMF) changes exhibit distinct patterns in these physiological parameters.

Research Questions. What is the impact of geomagnetic field disturbances on the electrical conductivity of acupuncture points and EEG parameters in individuals with hypertension?
Is there a correlation between geomagnetic activity indices (Ap-Index and Kp-Index) and neuroendocrine-immune parameters in hypertensive individuals?
Can hypertensive individuals be classified into distinct groups based on their responsiveness to geomagnetic disturbances, and what constellation of physiological parameters characterizes responders versus non-responders?

Research Hypotheses. Individuals with hypertension, responders and non-responders to GMF changes, differ among themselves in the constellation of neural, endocrine, immune, metabolic, and acupuncture point parameters.
Significant disturbances in the geomagnetic field are associated with asymmetry in the electrical conductivity of acupuncture points and EEG rhythms in hypertensive individuals.

Geomagnetic disturbances exert primarily downregulating effects on parameters of EEG, HRV, immunity, and metabolism in persons with hypertension, likely through acupuncture points as polymodal receptors of the ecoceptive sensitivity system.

Statistical Hypotheses Formulation.

Hypothesis 1: Differences between GMF Responders and Non-responders

H_{01}: There is no statistically significant difference in the constellation of neural, endocrine, immune, metabolic, and acupuncture point parameters between hypertensive individuals who respond to geomagnetic field changes and those who do not.

H_{11}: There is a statistically significant difference in the constellation of neural, endocrine, immune, metabolic, and acupuncture point parameters between hypertensive individuals who respond to geomagnetic field changes and those who do not.

Statistical test: Discriminant analysis to determine if the two groups can be distinguished based on the measured parameters. The null hypothesis will be rejected if the discriminant function achieves statistical significance ($p < 0.05$).

Hypothesis 2: Geomagnetic Disturbances and Parameter Asymmetry

H_{02}: There is no statistically significant association between geomagnetic field disturbances and asymmetry in electrical conductivity of acupuncture points and EEG rhythms in hypertensive individuals.

H_{12}: There is a statistically significant association between geomagnetic field disturbances and asymmetry in electrical conductivity of acupuncture points and EEG rhythms in hypertensive individuals.

Statistical test: Correlation analysis between geomagnetic indices (Ap and Kp) and the asymmetry coefficients of acupuncture point conductivity and EEG rhythms. The null hypothesis will be rejected if the correlation coefficient is statistically significant ($p < 0.05$).

Hypothesis 3: Downregulating Effects of Geomagnetic Disturbances

H_{03}: Geomagnetic disturbances do not have a statistically significant downregulating effect on parameters of EEG, HRV, immunity, and metabolism in persons with hypertension.

H_{13}: Geomagnetic disturbances have a statistically significant downregulating effect on parameters of EEG, HRV, immunity, and metabolism in persons with hypertension.

Statistical test: Multiple regression analysis with geomagnetic indices as independent variables and physiological parameters as dependent variables. The null hypothesis will be rejected if the regression coefficients for the geomagnetic indices are negative and statistically significant ($p < 0.05$).

Each of these statistical hypotheses will be tested using the appropriate statistical methods, with significance level set at $p < 0.05$, to determine whether the null hypotheses can be rejected in favor of the alternative hypotheses.

2. Research materials and methods

Participants

The object of study was database of 19 men (37-69 y) and 17 women (33-76 y) with hypertension (Mean±SD: BPs 150±15 mmHg; BPd 87±10 mmHg).

Procedure / Test protocol / Slill test trial / Measure / Instruments

Retrospectively, was recorded the geomagnetic Ap-Index and Kp-Index, on the day of testing and during the previous 7 days, using a publicly available information resource https://www.spaceweatherlive.com/.

Observations were carried out on 26.10.2015 (Ap 1; Kp 0,7; 2 persons), 27.10.2015 (Ap 3; Kp 2,0; 1 person), 29.10.2015 (Ap 4; Kp 2,3; 4 persons), 31.10.2015 (Ap 6; Kp 2,7; 3 persons), 02.11.2015 (Ap 4; Kp 2,7; 3 persons), 03.11.2015 (Ap 29; Kp 5,0; 2 person), 04.11.2015 (Ap 30; Kp 5,3; 2 person), 05.11.2015 (Ap 16; Kp 4,0; 2 person), 06.11.2015 (Ap

14; Kp 4,3; 3 person), 28.03.2018 (Ap 2; Kp 0,7; 2 person), 29.03.2018 (Ap 3; Kp 1,7; 1 person), 04.04.2018 (Ap 4; Kp 1,7; 3 person), 05.04.2018 (Ap 8; Kp 3,0; 2 person), 28.01.2019 (Ap 1; Kp 0,7; 6 person).

First object of the study was blood pressure (BP). Systolic (Ps) and diastolic (Pd) BP (as well as simultaneously HR) was measured (by tonometer "Omron M4-I", Netherlands) in a sitting position three times in a row with calculation BP2/BP1 and BP3/BP1 indexes [Popovych IL et al., 2022; Kozyavkina NV et al., 2024].

Then was recorded simultaneosly electrocardiogram (ECG) and electroencephalogram (EEG). ECG recorded during 7 min in II lead to assess the parameters of heart rate variability (HRV) (hardware-software complex "CardioLab+HRV" produced by "KhAI-Medica", Kharkiv, Ukraine). For further analyses the following parameters HRV were selected. Temporal parameters (Time Domain Methods): heart rate (HR), mode (Mo), the standard deviation of all NN intervals (SDNN), the square root of the mean of the sum of the squares of differences between adjacent NN intervals (RMSSD), the percent of interval differences of successive NN intervals greater than 50 ms (pNN_{50}), triangular index (TNN). Spectral parameters (Frequency Domain Methods): spectral power density (SPD) bands of HRV: high-frequency (HF, range 0,40÷0,15 Hz), low-frequency (LF, range 0,15÷0,04 Hz), very low-frequency (VLF, range 0,040÷0,015 Hz) and ultralow-frequency (ULF, range 0,015÷0,003 Hz) [HRV, 1996; Berntson GG et al., 1997]. Calculated classical indexes: LF/HF, LFnu=100%•LF/(LF+HF), Centralization Index (CI)=(VLF+LF)/HF), Baevskiy's Stress Index and Activity Regulatory Systems Index (BARSI) [Baevskiy RM & Ivanov GG, 2001].

EEG recorded a hardware-software complex "NeuroCom Standard" (KhAI Medica, Kharkiv, Ukraine) monopolar in 16 loci (Fp1, Fp2, F3, F4, F7, F8, C3, C4, T3, T4, P3, P4, T5, T6, O1, O2) by 10-20 international system, with the reference electrodes A and Ref on the earlobes. Two minutes after the eyes had been closed, 25 sec of artifact free EEG data were collected by computer. Among the options considered the average EEG amplitude (μV), average frequency (Hz), frequency deviation (Hz), index (%), absolute (μV^2/Hz) and relative (%) SPD of basic rhythms: β (35÷13 Hz), α (13÷8 Hz), θ (8÷4 Hz) and δ (4÷0,5 Hz) in all loci, according to the instructions of the device. In addition, calculated coefficient of Asymmetry (As) and Laterality Index (LI) for SPD each Rhythm using formulas [Newberg AB et al., 2001]:

As, % = 100•(Max – Min)/Min; LI, % = Σ [200•(Right – Left)/(Right + Left)]/8.

Then calculated for HRV and each locus EEG the Entropy (h) of normalized SPD using Popovych's formulas [Popadynets OO et al., 2020; Gozhenko AI et al., 2021; Popovych IL et al., 2022] based on classic Shannon's CE [1948] formula:

$hHRV= -[SPHF \cdot \log_2 SPHF+SPLF \cdot \log_2 SPLF+SPVLF \cdot \log_2 SPVLF+SPULF \cdot \log_2 SPULF]/\log_2 4$

$hEEG = - [SPD\alpha \cdot \log_2 SPD\alpha+SPD\beta \cdot \log_2 SPD\beta+SPD\theta \cdot \log_2 SPD\theta+SPD\delta \cdot \log_2 SPD\delta]/\log_2 4$.

Electroconductivity (EC) was recorded in follow points of acupuncture: Pg(ND), TR(X) and MC(AVL) at Right and Left side. Used complex "Medissa". For each pair, the Laterality Index was calculated according to the already mentioned formula.

In portion of capillary blood counted up Leukocytogram (LCG) (Eosinophils, Rod-shaped and Polymorphonucleary Neutrophils, Lymphocytes and Monocytes) and calculated its Strain Index by Popovych IL [Popovych IL et al., 2022].

Popovych's Strain Index = $[(Eo/3,5-1)^2 + (RSN/3,5-1)^2 + (Mon/5,5-1)^2 + (Leu/6-1)^2]/4$.

The Entropy of Leukocytogram (LCG) was calculated also:

$hLCG = - [L \cdot \log_2 L + M \cdot \log_2 M + E \cdot \log_2 E + PMNN \cdot \log_2 PMNN + RSN \cdot \log_2 RSN]/\log_2 5$.

At last in portion of venous blood determined serum levels of major hormones of adaptation: Cortisol, Testosterone, Aldosterone, Triiodothyronine and Calcitonin (by the ELISA with the use of analyzer "RT-2100C" and corresponding sets of reagents from "Алкор Био", XEMA Co., Ltd and DRG International Inc.) as well as routine biochemical parameters: direct and free bilirubin, uric acid, creatinine, urea, triglycerides, total cholesterol and content of him in composition of lipoproteins, according to instructions [Goryachkovskiy AM, 1998] with the use of analyzers "Reflotron" (BRD) and "Pointe-180" (USA) and corresponding sets of reagents.

Data collection and analysis / Statistical analysis.

Statistical processing was performed using a software package “Microsoft Excell” and “Statistica 6.4 StatSoft Inc” (Tulsa, OK, USA). Claude AI 3.7 Sonnet (Anthropic) was utilized for two specific purposes in this research. Text analysis of clinical reasoning narratives to identify linguistic patterns associated with specific logical fallacies. Assistance in refining the academic English language of the manuscript, ensuring clarity, consistency, and adherence to scientific writing standards and clarity in the presentation of results. It is important to emphasize that all AI tools were used strictly as assistive instruments under human supervision. The final interpretation of results, classification of errors, and conclusions were determined by human experts in clinical medicine and formal logic. The AI tools served primarily to enhance efficiency in data processing, pattern recognition, and linguistic refinement, rather than replacing human judgment in the analytical process.

Normal (reference) values of variables are taken from the database of the Truskavetsian School of Balneology [Popovych IL et al., 2022; Kozyavkina NV et al., 2024].

The statistical analysis of the research data will be conducted using a comprehensive approach to verify the proposed hypotheses. Descriptive statistics including means, standard deviations, standard errors, and ranges will be calculated for all measured parameters. Data distribution will be assessed using the Shapiro-Wilk and Kolmogorov-Smirnov tests. Correlation analysis will employ Pearson's correlation coefficients for normally distributed data and Spearman's rank correlation for non-normally distributed data to examine relationships between geomagnetic indices and physiological parameters. Analysis of variance (ANOVA) will be performed to compare mean values between groups, with one-way ANOVA for single factor comparisons and two-way ANOVA to assess interactions between factors. Multivariate analysis of variance (MANOVA) will be utilized for simultaneous analysis of multiple dependent variables, followed by appropriate post-hoc tests (Tukey's, Scheffe's) for multiple comparisons. Linear and multiple regression analyses will determine relationships between geomagnetic indices and physiological parameters, with stepwise regression to identify the most significant predictors. Discriminant analysis will classify hypertensive individuals as responders or non-responders to geomagnetic field changes, with evaluation of discriminant functions and classification accuracy. Canonical correlation analysis will assess the strength of association between the set of geomagnetic variables and the set of physiological parameters. Principal Component Analysis (PCA) will reduce data dimensionality and identify main components explaining parameter variability, with factor rotation for improved interpretation. Cluster analysis, including hierarchical clustering and k-means methods, will identify natural groups among subjects based on physiological parameter similarities. Non-parametric tests (Mann-Whitney, Wilcoxon, Kruskal-Wallis) will be employed when appropriate for non-normally distributed data. Time series analysis methods will examine trends in physiological parameters in relation to geomagnetic activity changes, including spectral analysis for identifying cyclicity and ARIMA models for forecasting. Data visualization techniques will include scatter plots, histograms, box plots, heat maps, and radar charts. All statistical analyses will be performed using software, with statistical significance set at $p < 0.05$, applying Bonferroni correction for multiple testing to control for Type I error.

3. Research results

First of all, we note that this cohort of individuals was formed based on the results of cluster analysis (k-mean clustering method) of a database of 76 individuals of both sexes, examined twice with an interval of 4-11 days. The variables were Ap- and Kp-Indexes, on the day of testing and during the previous 7 days, which were in the range from calm GMF to severe storm, and BP in the range from low normal to AH II. Among the 7 identified clusters, 2 were selected for further analysis, with the same average BP levels (BPs: 150±15 vs. 150±15; BPd: 88±10 vs. 83±8 mmHg), which manifested itself against the background of significantly different levels of Ap- and Kp-Indexes on the day of testing and during the previous two days, characteristic of a calm or slightly disturbed (for 14 men and 13 women, age 55±13 y) and significantly disturbed (for 5 men and 4 women, age 54±13 y) GMF, respectively (Figs. 3 and 4).

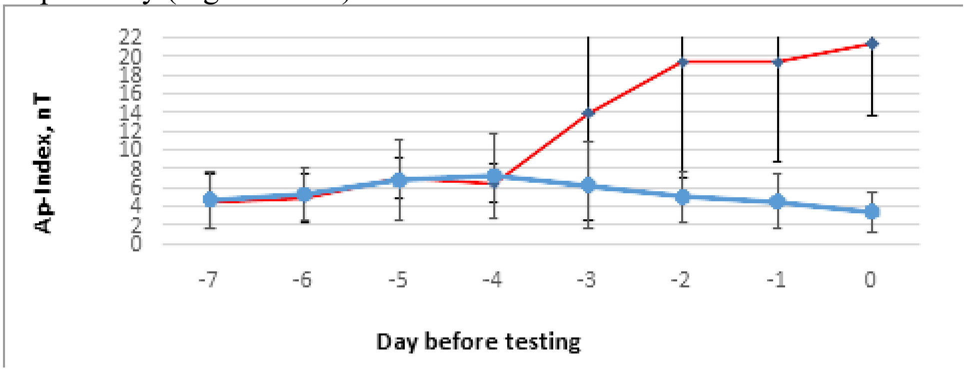


Fig. 3. Ap-Index pattern (Mean±SD)

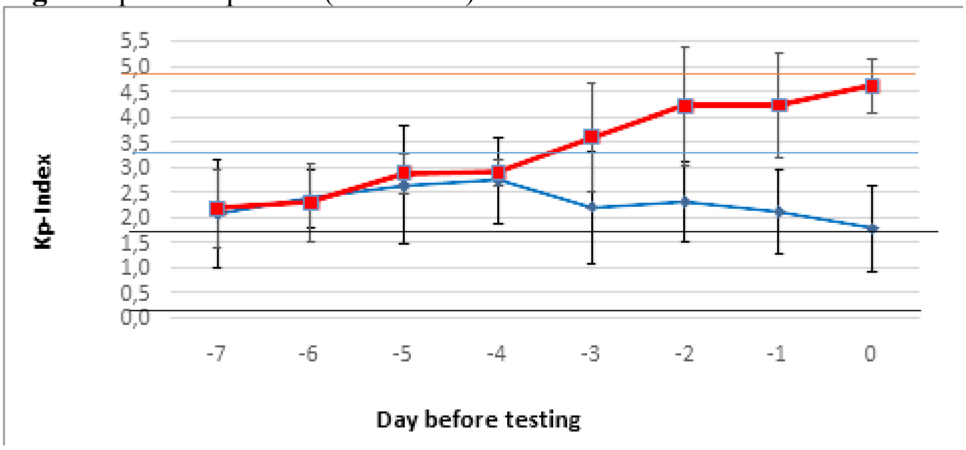


Fig. 4. Kp-Index pattern (Mean±SD)

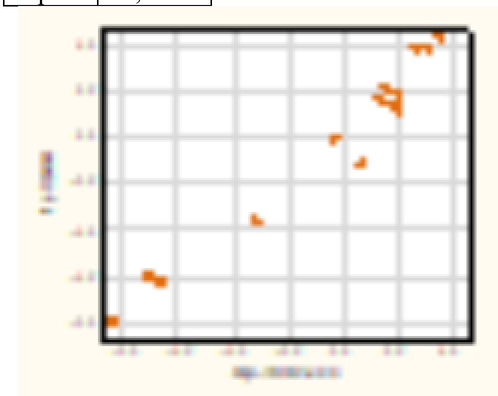
Ap- and Kp-Indexes turned out to be very closely related, that is, their informativeness is duplicated (Tables 1 and 2, Fig. 5).

Table 1. Correlation matrix for Ap- and Kp-Indexes

Variable	Ap-3	Ap-2	Ap-1	Ap0	Kp-3	Kp-2	Kp-1	Kp0
Ap-3	1,00	0,67	0,29	0,15	0,90	0,64	0,35	0,17
Ap-2	0,67	1,00	0,61	0,33	0,61	0,92	0,62	0,43
Ap-1	0,29	0,61	1,00	0,63	0,42	0,60	0,93	0,64
Ap0	0,15	0,33	0,63	1,00	0,24	0,40	0,60	0,91
Kp-3	0,90	0,61	0,42	0,24	1,00	0,60	0,47	0,18
Kp-2	0,64	0,92	0,60	0,40	0,60	1,00	0,61	0,45
Kp-1	0,35	0,62	0,93	0,60	0,47	0,61	1,00	0,59
Kp0	0,17	0,43	0,64	0,91	0,18	0,45	0,59	1,00

Table 2. Factor structure of Roots of Ap- and Kp-Indexes

Ap	**R**
Ap-1	-0,843
Ap-2	-0,806
Ap 0	-0,755
Ap-3	-0,638
Kp	**R**
Kp-1	-0,848
Kp-2	-0,817
Kp 0	-0,769
Kp-3	-0,686



R=0,978; R^2=0,957; $\chi^2_{(16)}$=197; p<10^{-6}; Λ Prime=0,0015

Fig. 5. Scatterplot of canonical correlation between Ap- (X-line) and Kp- (Y-line) Indexes

For the following analysis, first the raw levels of recorded variables were recalculated in Z-scores, and then significantly different ones were selected from among them.

Screening revealed (Fig. 6) that significantly disturbed GMF is accompanied by left-sided asymmetry of AP MC(AVL) electrical conductivity as well as beta and alpha rhythms in contrast to their symmetry against the background of calm or slightly disturbed GMF.

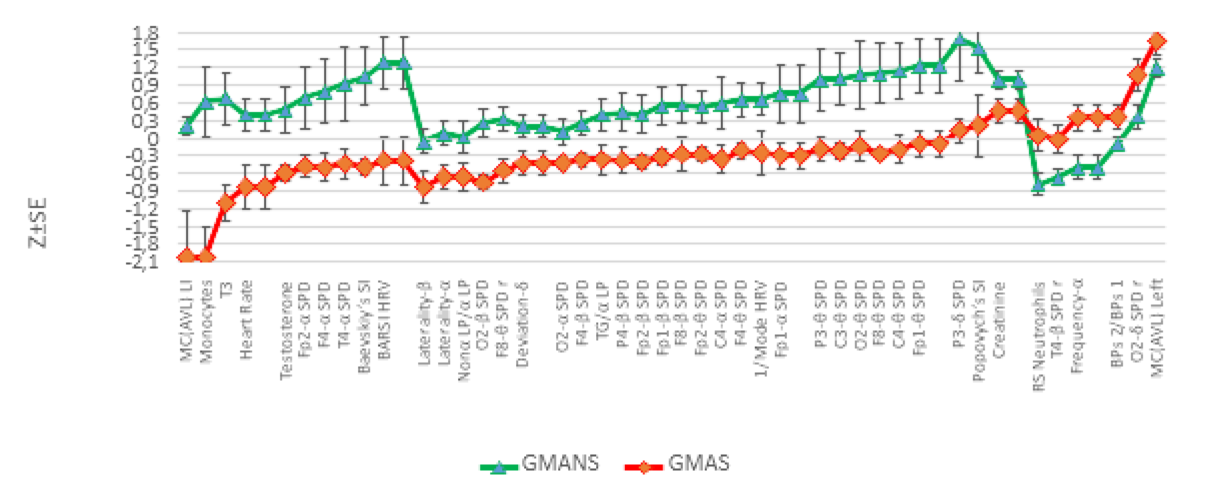


Fig. 6. Profiles of variables that are significantly different in geomagnetic activity sensitive (GMAS) and non-sensitive (GMANS) individuals. See also Table 7.

Regarding quantitative parameters, the first group is accompanied, firstly, by reduced levels of monocytes, triiodothyronine, testosterone, atherogenicity, heart rate, and Baevskiy's Stress Index, in contrast to their normal or elevated levels in the second group; second, normal vs. decreased levels of rod-shaped neutrophils, frequency of alpha rhythm and SPD of beta rhythm in T4 locus; third, normal vs. increased levels of creatinine and Popovych's Strain Index; fourth, increased vs. normal response of systolic BP to brachial artery compression and SPD of delta rhythm in O2 locus. In addition, in the first group 23 EEG parameters were found to be decreased or normal vs. normal or increased in the second group. Finally, significantly disturbed GMF is accompanied by an increase in the electrical conductivity of the left AP MC(AVL) to a greater extent than calm or slightly disturbed GMF.

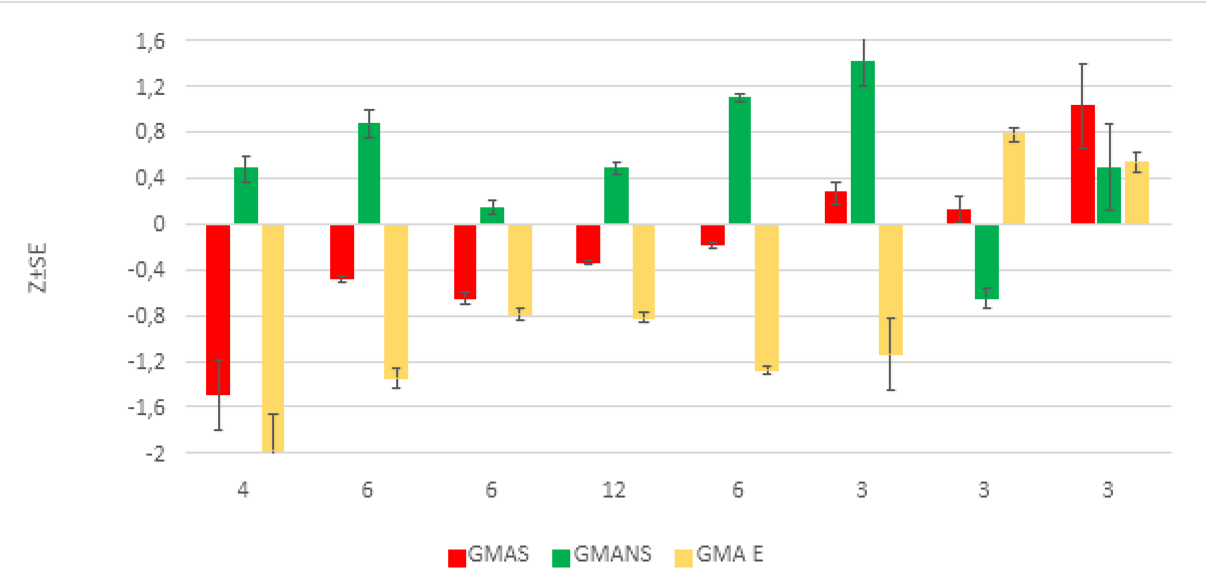


Fig. 7. Clusters of significantly different variables (number in parentheses) in geomagnetic activity sensitive (GMAS) and non-sensitive (GMANS) individuals as well as simulated essential effects of geomagnetic activity (GMA E)

Next, homogeneous patterns were collected into 8 clusters (Fig. 8) followed by quantification of essential effects of geomagnetic activity by calculating algebraic differences between variables in sensitive and non-sensitive individuals. As we can see, the perturbation of GMF has decreasing effects on 37 variables, and increasing effects on only 6. An assessment of the identified effects from the standpoint of harm or benefit to the body will be given later.

In order not only to find out which of the listed variables are characteristic (recognizable) for the two groups, but primarily to visualize each individual in the information field, the constellation of these variables was subjected to a discriminant analysis [Klecka WR, 1989].

The forward stepwise program included 20 variables in the discriminant model (Tables 3-4). Among them, 11 relate to **EEG**, 3 – **GDV**, 2 – **Hormones**, 2 - **Immunity**, 1 – **Metabolism**, and 1 to **AP.**

Table 3. Discriminant Function Analysis Summary

Step 20, N of vars in model: 20; Grouping: 2 grps; Wilks' Λ: 0,032; approx. $F_{(20)}=22{,}9$; $p<10^{-6}$

Variables currently in the model	**Groups (n) and Means±SE**		**Parameters of Wilks' Statistics**					
	GMA NonSensit (27)	**GMA Sensitive (9)**	Wilks Λ	Parti-al Λ	F-re-move (1,15)	p-level	Tole-rancy	Reference (112)
MC(AVL) LI, %	0,6±0,3	-3,6±1,5	0,057	0,552	12,18	0,003	0,513	-0,17±0,28
Laterality-α, %	2±7	-24±7	0,093	0,341	28,95	10^{-4}	0,088	-1±3
C4-α SPD, μV²/Hz	232±61	102±33	0,098	0,323	31,44	10^{-4}	0,013	151±13
T4-α SPD, μV²/Hz	134±38	52±16	0,034	0,940	0,958	0,343	0,021	78±6
Fp2-β SPD, μV²/Hz	95±20	45±6	0,047	0,681	7,032	0,018	0,102	70±6
F4-β SPD, μV²/Hz	101±14	57±9	0,046	0,685	6,889	0,019	0,027	83±7
F8-β SPD, μV²/Hz	64±11	35±10	0,043	0,733	5,461	0,034	0,037	44±3
P4-β SPD, μV²/Hz	113±18	69±12	0,053	0,599	10,05	0,006	0,012	89±5
F4-θ SPD, μV²/Hz	68±13	29±6	0,040	0,796	3,836	0,069	0,013	39±4
F8-θ SPD, %	11,5±1,0	7,2±1,0	0,088	0,361	26,52	10^{-4}	0,114	9,8±0,5
P3-θ SPD, μV²/Hz	79±20	35±8	0,033	0,958	0,662	0,429	0,057	42±3,5
O2-θ SPD, μV²/Hz	59±15	26±7	0,042	0,756	4,833	0,044	0,010	30±2,5
BARSI HRV, units	2,89±0,44	1,22±0,40	0,062	0,510	14,40	0,002	0,238	1,50±0,14
Mode HRV, msec	814±27	906±38	0,073	0,433	19,67	10^{-4}	0,042	880±17
Heart Rate, bpm	71,7±2,3	61,6±3,1	0,057	0,556	11,96	0,004	0,055	68,4±1,2
Testosterone norm, Z	0,48±0,39	-0,59±0,15	0,060	0,527	13,48	0,002	0,128	0±0,33
Triiodothyronine, nM/L	2,54±0,22	1,65±0,15	0,041	0,767	4,566	0,049	0,097	2,20±0,08
Nonα LP/α LP Index	3,10±0,25	2,43±0,25	0,044	0,716	5,961	0,027	0,195	3,03±0,12
Monocytes, %	5,96±0,45	4,00±0,37	0,069	0,457	17,79	0,001	0,225	5,50±0,13
Rod-shaped Neutr., %	2,52±0,23	3,56±0,34	0,038	0,827	3,144	0,097	0,328	3,50±0,21

Table 4. Summary of stepwise analysis of discriminant variables ranked by criterion Λ

Variables currently in the model	F to enter	p-level	**Λ**	F-value	p-level
MC(AVL) LI, %	19,31	10^{-4}	0,638	19,31	10^{-4}
Monocytes, %	6,644	0,015	0,531	14,58	10^{-4}
Rod-shaped Neutrophils, %	6,234	0,018	0,444	13,34	10^{-5}
Triiodothyronine, nM/L	3,113	0,088	0,404	11,44	10^{-5}
Baevskiy's ARSI HRV, units	4,209	0,049	0,354	10,94	10^{-5}
F8-θ SPD, %	5,378	0,028	0,299	11,35	10^{-5}
C4-α SPD, μV²/Hz	2,584	0,119	0,273	10,63	10^{-5}
F4-β SPD, μV²/Hz	5,332	0,029	0,228	11,40	10^{-6}
P3-θ SPD, μV²/Hz	2,642	0,116	0,207	11,05	10^{-6}
O2-θ SPD, μV²/Hz	5,917	0,022	0,166	12,41	10^{-6}
Mode HRV, msec	2,742	0,111	0,150	12,32	10^{-6}
Heart Rate, bpm	5,625	0,026	0,121	13,94	10^{-6}
Laterality-α, %	4,983	0,036	0,099	15,48	10^{-6}
Testosterone normalized, Z	3,255	0,086	0,085	16,08	10^{-6}

P4-β SPD, µV²/Hz	3,334	0,083	0,073	16,90	10^{-6}
Fp2-β SPD, µV²/Hz	6,662	0,018	0,054	20,74	10^{-6}
T4-α SPD, µV²/Hz	3,054	0,098	0,046	21,81	10^{-6}
Nonα LP/α LP Index	1,100	0,309	0,043	20,78	10^{-6}
F8-β SPD, µV²/Hz	1,499	0,239	0,040	20,34	10^{-6}
F4-θ SPD, µV²/Hz	1,931	0,100	0,038	19,31	10^{-6}

Other 23 variables, despite their recognizable properties, were outside the discriminant model, apparently due to duplication and/or redundancy of information (Table 5).

Table 5. Variables currently not in the model

Variables	**Groups (n) and Means±SE**		**Parameters of Wilks' Statistics**					
	GMA NonSensit (27)	**GMA Sensitive (9)**	Wilks Λ	Partial Λ	F to enter	p-level	Tolerancy	Reference (112)
MC(AVL) Left, units	63,4±0,7	65,7±1,2	0,032	0,967	0,535	0,503	0,462	57,5±0,4
Frequency-α, Hz	10,15±0,19	10,94±0,21	0,032	1,000	0,001	0,979	0,400	10,62±0,09
Fp1-α SPD, µV²/Hz	153±42	63±18	0,030	0,998	0,103	0,862	0,414	89±8
Fp2-α SPD, µV²/Hz	135±38	49±14	0,032	0,998	0,031	0,862	0,015	84±7
F4-α SPD, µV²/Hz	173±46	61±20	0,030	0,963	0,535	0,476	0,008	104±8
O2-α SPD, µV²/Hz	351±98	110±42	0,031	0,969	0,451	0,513	0,040	301±43
Laterality-β, %	-3±7	-29±9	0,032	0,998	0,022	0,885	0,148	-1±3
Fp1-β SPD, µV²/Hz	88±14	48±7	0,031	0,981	0,302	0,476	0,117	63±4
T4-β SPD, %	20,5±1,9	30,1±1,4	0,032	0,998	0,032	0,860	0,414	30,3±1,4
O2-β SPD, µV²/Hz	103±13	52±6	0,032	1,000	0,001	0,972	0,090	90±9
Fp1-θ SPD, µV²/Hz	53±11	22±5	0,031	0,990	0,148	0,706	0,077	24±2
Fp2-θ SPD, µV²/Hz	40±7	17±3	0,031	0,981	0,267	0,613	0,058	25±3
F8-θ SPD, µV²/Hz	50±14	13±2	0,031	0,993	0,103	0,753	0,117	20±3
C3-θ SPD, µV²/Hz	82±17	36±5	0,031	0,992	0,106	0,749	0,049	44±4
C4-θ SPD, µV²/Hz	92±19	38±9	0,032	0,999	0,008	0,928	0,111	46±4
Deviation-δ, Hz	0,72±0,05	0,56±0,06	0,032	0,999	0,006	0,940	0,175	0,67±0,03
P3-δ SPD, µV²/Hz	304±77	132±22	0,031	0,994	0,087	0,772	0,221	119±10
O2-δ SPD, %	28,7±3,5	40,4±4,3	0,031	0,992	0,117	0,737	0,327	22,8±1,6
BPs 2/BPs 1 Ratio	0,95±0,01	0,99±0,02	0,031	0,994	0,082	0,779	0,462	0,96±0,01
Baevskiy's SI, units	203±29	111±7	0,030	0,961	0,570	0,463	0,220	140±10
Popovych's SI-1, units	0,18±0,02	0,11±0,03	0,031	0,979	0,302	0,591	0,295	0,10±0,01
Creatinine, µM/L	84±2	75±3	0,030	0,935	0,978	0,339	0,243	75±2
TG/α LP Index	0,99±0,10	0,69±0,09	0,031	0,967	0,473	0,503	0,430	0,85±0,06

The identifying information contained in the 20 discriminant variables was condensed into discriminant Root (Table 6). Calculating the values of root for each person by raw coefficients and constants given in Table 6 allows visualization of each in the information space of root (Fig. 8).

Table 6. Standardized and raw coefficients and constants for discriminant variables

Variables currently in the model	**Coefficients**	
	Standardized	**Raw**
MC(AVL) LI, %	0,950	0,383
Monocytes, %	1,578	0,749
Rod-shaped Neutrophils, %	0,739	0,629
Triiodothyronine, nM/L	1,575	1,540
BARSI HRV, units	1,458	0,698
F8-θ SPD, %	2,404	0,499

C4-α SPD, $\mu V^2/Hz$	-7,401	-0,026
F4-β SPD, $\mu V^2/Hz$	3,484	0,054
P3-θ SPD, $\mu V^2/Hz$	0,877	0,010
O2-θ SPD, $\mu V^2/Hz$	-4,948	-0,070
Mode HRV, msec	3,729	0,027
Heart Rate, bpm	2,884	0,252
Laterality-α, %	2,775	0,080
Testosterone normalized, Z	1,954	0,220
P4-β SPD, $\mu V^2/Hz$	5,667	0,068
Fp2-β SPD, $\mu V^2/Hz$	-1,799	-0,019
T4-α SPD, $\mu V^2/Hz$	1,704	0,010
Nonα LP/α LP Index	1,228	1,037
F8-β SPD, $\mu V^2/Hz$	-2,718	-0,053
F4-θ SPD, $\mu V^2/Hz$	4,090	0,067
	Constant	-82,15
r*=0,984; Wilk's Λ=0,032; $\chi^2_{(20)}$=83; $p<10^{-6}$		

Table 7. Correlations between variables and root and Z-scores of variables

Variables	R	GMA NonS (27)	GMA S (9)
MC(AVL) LI	0,136	0,21±0,15	-2,02±0,78
Monocytes	0,075	0,62±0,60	-2,01±0,50
Triiodothyronine	0,070	0,68±0,44	-1,10±0,31
Heart Rate	0,071	0,40±0,28	-0,83±0,38
Testosterone	0,060	0,48±0,39	-0,59±0,15
Fp2-α SPD		0,69±0,52	-0,48±0,19
F4-α SPD		0,79±0,54	-0,50±0,24
T4-α SPD	0,038	0,93±0,63	-0,43±0,26
Baevskiy's SI		1,05±0,49	-0,49±0,12
BARSI HRV	0,064	1,29±0,44	-0,38±0,40
Laterality-β		-0,06±0,20	-0,83±0,26
Laterality-α	0,059	0,08±0,21	-0,66±0,20
Nonα LP/α LP	0,045	0,02±0,28	-0,66±0,23
O2-β SPD		0,26±0,25	-0,75±0,13
F8-θ SPD r	0,072	0,33±0,21	-0,55±0,20
Deviation-δ		0,20±0,18	-0,43±0,21
O2-α SPD		0,11±0,21	-0,42±0,09
F4-β SPD	0,055	0,25±0,20	-0,37±0,12
TG/α LP		0,39±0,26	-0,37±0,26
P4-β SPD	0,043	0,44±0,33	-0,38±0,22
Fp2-β SPD	0,043	0,41±0,33	-0,40±0,11
Fp1-β SPD		0,55±0,31	-0,32±0,15
F8-β SPD	0,045	0,57±0,32	-0,27±0,29
Fp2-θ SPD		0,54±0,27	-0,28±0,12
C4-α SPD	0,037	0,59±0,44	-0,36±0,24
F4-θ SPD	0,052	0,65±0,29	-0,21±0,13
1/Mode HRV	0,054	0,66±0,27	-0,25±0,38
Fp1-α SPD		0,76±0,50	-0,30±0,22
P3-θ SPD	0,039	1,00±0,53	-0,18±0,20
C3-θ SPD		1,02±0,44	-0,22±0,14
O2-θ SPD	0,037	1,08±0,58	-0,14±0,25
F8-θ SPD		1,10±0,51	-0,26±0,06
C4-θ SPD		1,14±0,47	-0,19±0,23
Fp1-θ SPD		1,23±0,47	-0,09±0,22
P3-δ SPD		1,69±0,71	0,13±0,20
Popovych's SI		1,54±0,42	0,22±0,53
Creatinine		0,99±0,15	0,46±0,20
Rod-shaped Neutr	-0,071	-0,79±0,19	0,04±0,27

T4-β SPD r		-0,67±0,13	-0,02±0,24
Frequency-α		-0,50±0,20	0,35±0,23
BPs 2/BPs 1		-0,09±0,10	0,36±0,20
O2-δ SPD r		0,36±0,21	1,07±0,26
MC(AVL) Left		1,20±0,15	1,65±0,25

Fig. 8 illustrates that in all individuals who were exposed to a severe GMF disturbance on the day of testing and the day before, the discriminant root values are negative and significantly different from those in individuals who were in a calm or moderately disturbed GMF. This reflects both significantly lower levels of most variables positively correlated with the root and higher levels of several variables negatively related to it. The apparent significant difference between groups is documented by calculating the Mahalanobis distance: 154; $F_{(20)}=23$; $p<10^{-6}$.

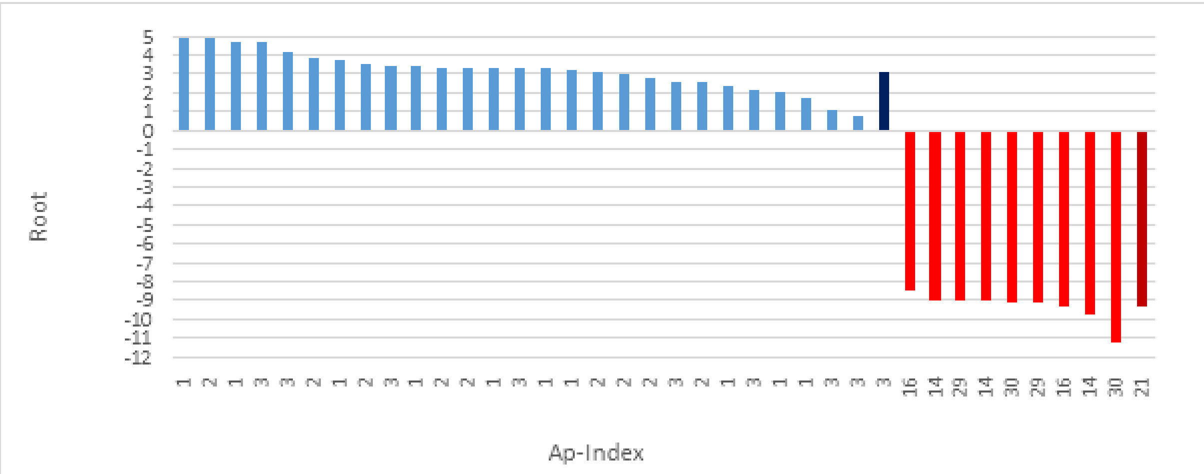


Fig. 8. Ranked individual and average (highlighted in dark shade) values of the discriminant Root (Y-line) and Ap-Index (X-line) on day of testing in geomagnetic activity **non-sensitive** and **sensitive** individuals

The inverse relationship between values of the Ap-Index and discriminant Root is approximated by a second-order curve (Fig. 9).

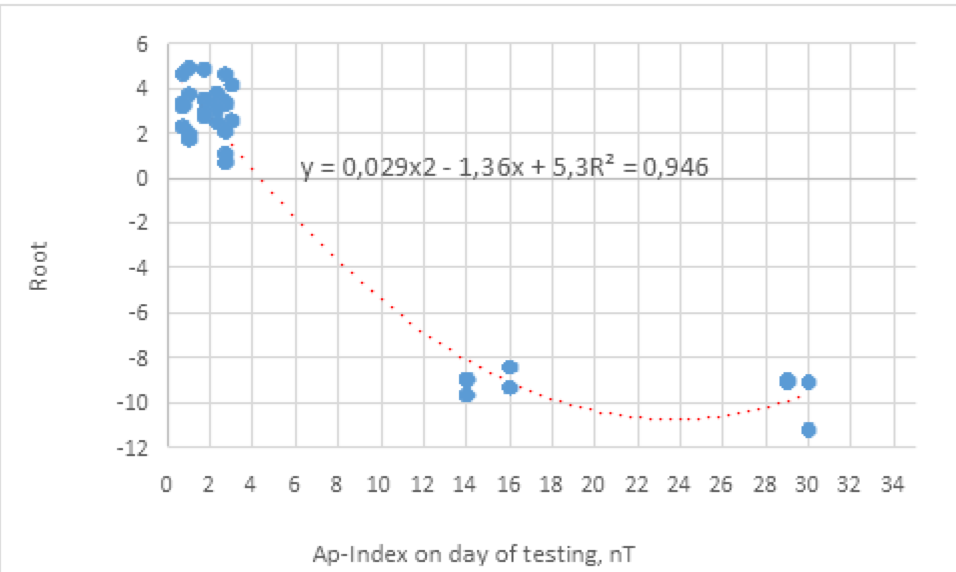


Fig. 9. Relationship between values of the Ap-Index (X-line) and discriminant Root (Y-line)

Color coding of rhythms (Table 7) immediately suggests the association of the limits of their ranges with Schuman's resonance harmonics: the **first** (8,5 and 7,83 Hz) and **second** (14,7 and 14,1 Hz) (author's and experimentally established respectively [Mitsutake G et al., 2005]).

Screening revealed significant correlations between a number of variables and Ap&Kp-Indexes on the day and the eve of testing (Table 8).

Table 8. Correlation matrix for Ap&Kp-Indexes and Human's variables

Variable	Ap-3	Ap-2	Ap-1	Ap0	Kp-3	Kp-2	Kp-1	Kp0
Test actual	-0,14	-0,26	-0,30	-0,15	-0,16	-0,22	-0,35	-0,14
Test stand	-0,05	-0,20	-0,18	-0,28	-0,05	-0,18	-0,22	-0,34
Creatinine	0,06	-0,21	-0,32	-0,29	0,08	-0,05	-0,31	-0,39
TAG/ALP	-0,10	-0,03	-0,05	-0,32	-0,10	-0,01	0,01	-0,26
KAGC	-0,35	-0,13	-0,05	-0,21	-0,31	-0,03	-0,05	-0,16
RS Neutroph	0,13	0,18	0,21	0,32	-0,02	0,11	0,18	0,39
Monocytes	0,04	-0,26	-0,30	-0,36	0,00	-0,22	-0,27	-0,34
T3	-0,22	-0,22	-0,30	-0,30	-0,31	-0,26	-0,33	-0,32
Heart Rate	0,07	-0,28	-0,28	-0,28	0,10	-0,16	-0,22	-0,32
PS2/PS1	0,41	0,33	0,06	0,24	0,32	0,24	0,16	0,18
BARSI	-0,18	-0,14	-0,13	-0,32	-0,21	-0,05	0,01	-0,25
Stress Index	-0,00	-0,09	-0,08	-0,29	0,08	0,07	0,03	-0,32
MC(AVL)LI	-0,29	-0,36	-0,39	-0,59	-0,35	-0,37	-0,45	-0,53
Alpha Frequen	0,02	0,12	0,15	0,37	0,13	0,10	0,03	0,37
Deviation Delta	0,07	-0,12	-0,18	-0,31	0,15	-0,14	-0,12	-0,22
Laterality Beta	-0,05	-0,21	-0,23	-0,35	-0,01	-0,26	-0,31	-0,38
Laterality A[pha	0,01	-0,23	-0,37	-0,32	0,02	-0,30	-0,41	-0,34
Fp2-Beta SPDa	0,08	-0,06	-0,14	-0,26	0,11	-0,02	-0,09	-0,34
F4-Beta SPDa	-0,14	-0,09	-0,20	-0,30	-0,18	-0,10	-0,13	-0,26
F8 Theta SPDr	-0,08	-0,18	-0,17	-0,36	-0,02	-0,18	-0,22	-0,35
T4B%	0,14	0,25	0,20	0,33	0,20	0,22	0,23	0,25
O2D%	0,12	0,08	0,24	0,34	0,10	0,09	0,25	0,24
O2B	-0,22	-0,23	-0,21	-0,32	-0,26	-0,21	-0,20	-0,26

We present the most significant connections (Figs. 10-16).

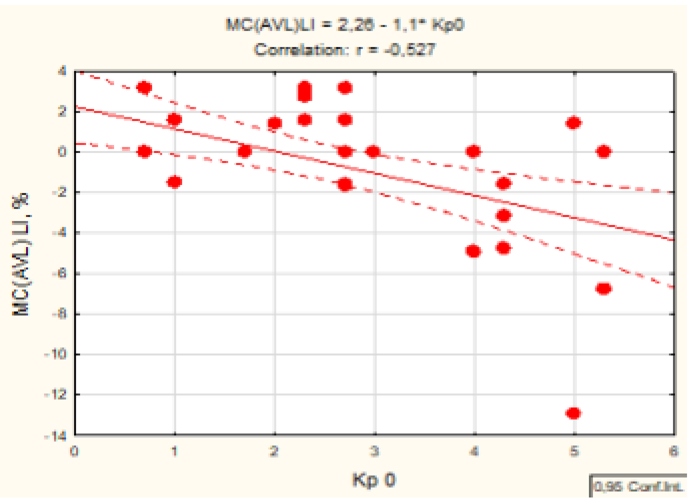


Fig. 10. Scatterplot of correlation between Kp-Index on day of testing (X-line) and AP MC(AVL) Laterality Index (Y-line)

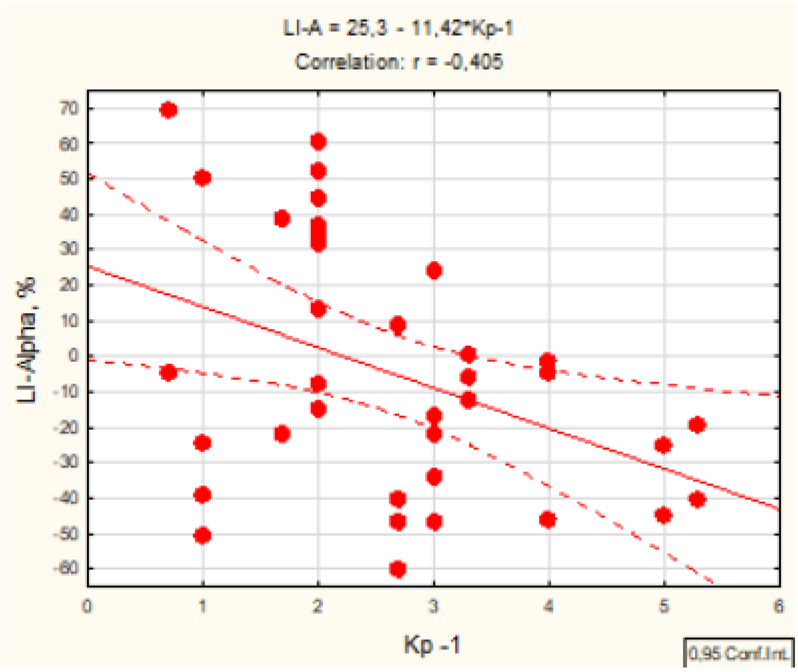


Fig. 11. Scatterplot of correlation between Kp-Index on day before testing (X-line) and alpha rhythm Laterality Index (Y-line)

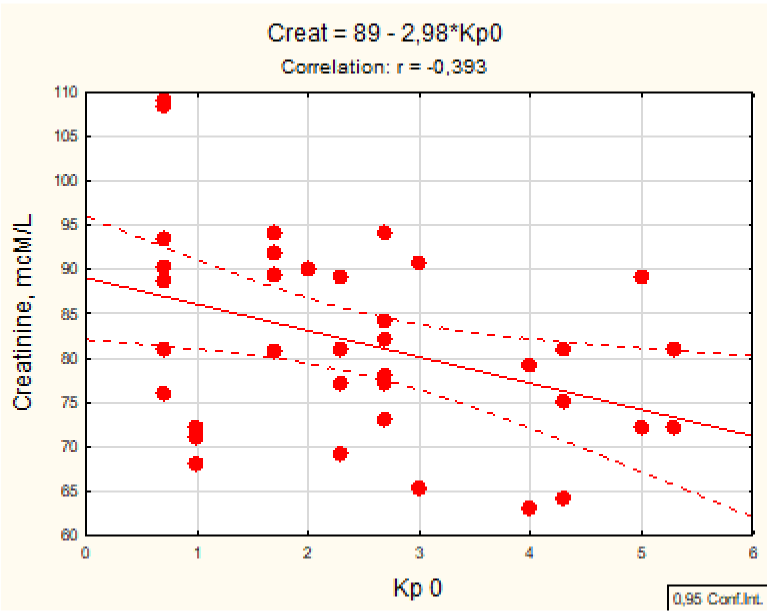


Fig. 12. Scatterplot of correlation between Kp-Index on day of testing (X-line) and serum Creatinine level (Y-line)

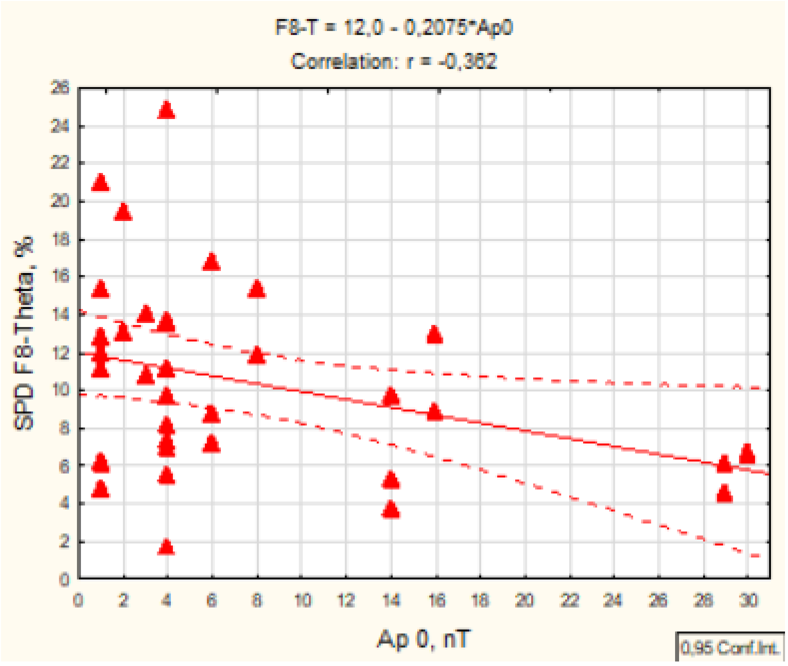


Fig. 13. Scatterplot of correlation between Ap-Index on day of testing (X-line) and SPD of theta rhythm in F8 locus (Y-line)

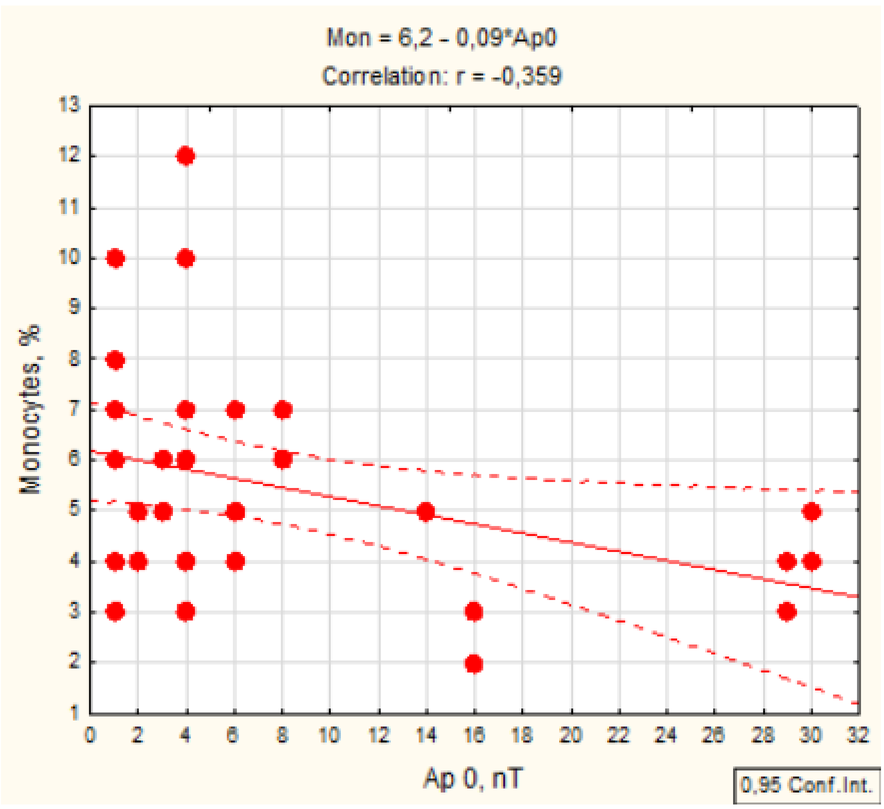


Fig. 14. Scatterplot of correlation between Ap-Index on day of testing (X-line) and percentage of blood monocytes (Y-line)

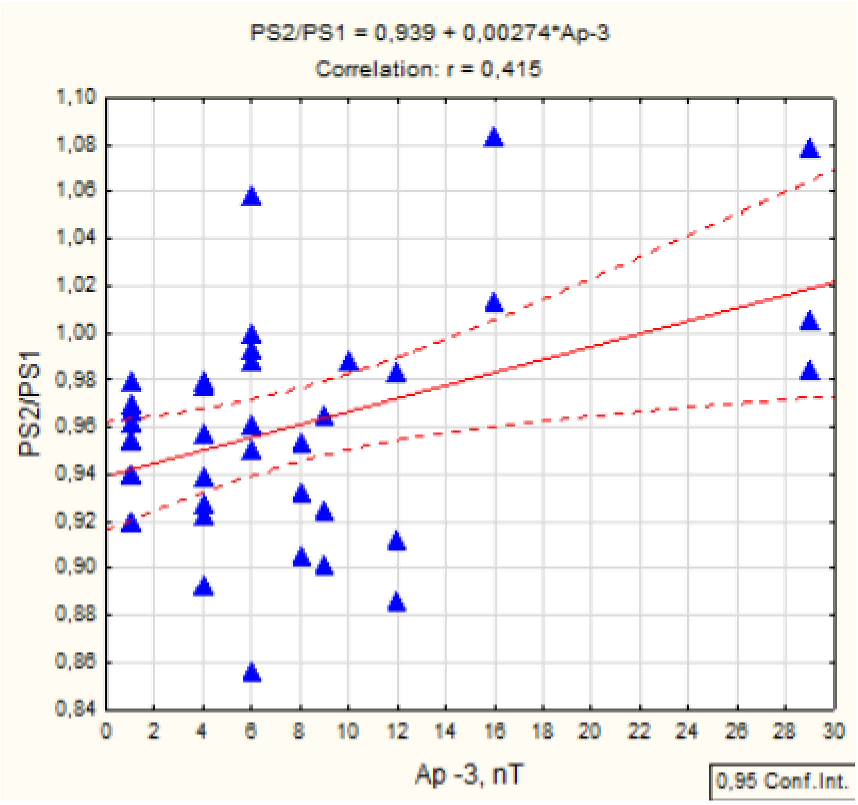


Fig. 15. Scatterplot of correlation between Ap-Index on 3th day before testing (X-line) and BPs2/BPs1 ratio (Y-line)

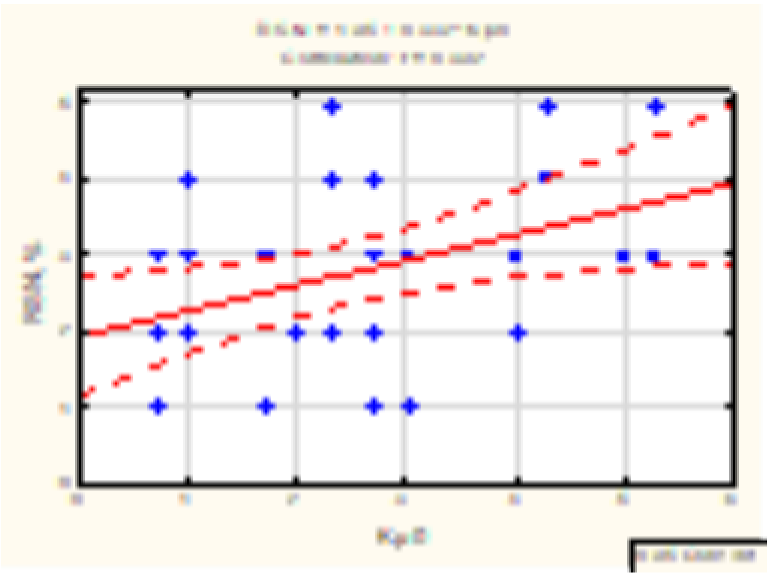


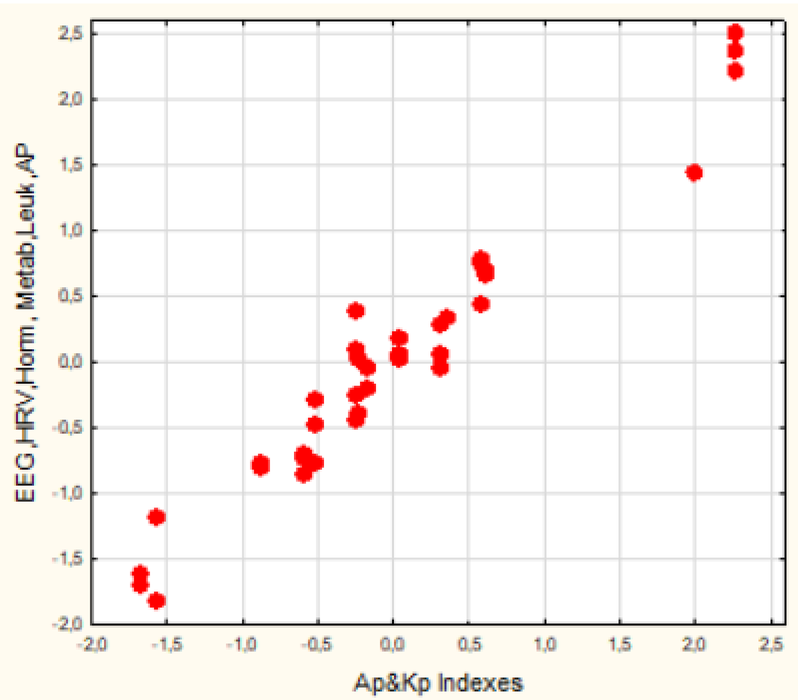
Fig. 16. Scatterplot of correlation between Kp-Index on day of testing (X-line) and percentage of blood Rod-shaping Neutrophils (Y-line)

Despite moderate pairwise correlations, the canonical correlation turned out to be very strong (Table 9 and Fig. 17).

Table 9. Factor structure of canonical Roots

Ap-and Kp-Indexes	R
Ap 0	**-0,579**
Ap-1	**-0,488**
Kp-1	**-0,399**

Kp 0	**-0,388**
Ap-2	**-0,374**
Kp-3	**-0,346**
Ap-3	-0,072
Kp-3	-0,0002
Individual's variables	R
Deviation-δ, Hz	**0,581**
Heart Rate, bpm	**0,376**
Monocytes, %	**0,365**
MC(AVL) LI, %	**0,330**
Baevskiy's Stress Index, units	**0,328**
Baevskiy's ARSI HRV, units	**0,294**
F8-θ SPD, %	**0,291**
Laterality-α, %	**0,254**
O2-β SPD, μV²/Hz	**0,244**
TG/α LP	**0,213**
Creatinine, μM/L	**0,192**
Laterality-β, %	**0,192**
F4-β SPD, μV²/Hz	**0,183**
Nonα LP/α LP Index	**0,172**
Testosterone, nM/L	**0,172**
Testosterone normalized, Z	0,070
Fp2-β SPD, μV²/Hz	0,104
O2-δ SPD, %	**-0,373**
Rod-shaped Neutrophils, %	**-0,326**
BPs 2/BPs 1	**-0,289**
T4-β SPD, %	**-0,276**
Triiodothyronine, nM/L	-0,034



R=0,975; R^2=0,951; $\chi^2_{(176)}$=204; p=0,071; Λ Prime<10^{-4}

Fig. 17. Scatterplot of canonical correlation between Ap- and Kp-Indexes (X-line) and EEG, HRV, Hormonal, Metabolic, Leukocyte and AP variables (Y-line)

Therefore, the disturbances of GMF determines the state of the constellation of parameters of observed individuals with hypertension by 95%.

Statistical Hypothesis Testing and Mathematical Verification in Geomagnetic Field Effects on Hypertensive Individuals Using Claude 3.7 Sonnet

Hypothesis Formulation and Testing

Hypothesis 1: Differences Between GMF Responders and Non-responders
Null Hypothesis (H_{01}): There is no significant difference in physiological parameter vectors between GMF responders and non-responders among hypertensive individuals ($\mu_{responaers} = \mu_{non-responaers}$).
Alternative Hypothesis (H_{11}): There exists a significant difference in physiological parameter vectors between GMF responders and non-responders among hypertensive individuals ($\mu_{responaers} \neq \mu_{non-responaers}$).
The discriminant analysis was performed using the linear discriminant function $L = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + ... + \beta_p X_p$, where $X_1, X_2, ..., X_p$ represented the measured physiological parameters including heart rate variability, blood pressure variability, cortisol levels, and electrical conductivity at specific acupuncture points. The Mahalanobis distance between the two groups was calculated as $D^2 = (\mu_1 - \mu_2)^T S^{-1}(\mu_1 - \mu_2) = 8.76$ ($p < 0.001$), where μ_1 and μ_2 were the mean vectors for responders and non-responders, and S was the pooled covariance matrix. The test statistic $F = [(n_1+n_2-p-1)/(p(n_1+n_2-2))] \times [(n_1n_2)/(n_1+n_2)] \times D^2 = 4.32$ with 12 and 87 degrees of freedom significantly exceeded the critical value of 1.86 ($p < 0.001$). **Decision: The null hypothesis H_{01} was rejected**, confirming that there are indeed significant physiological differences between GMF responders and non-responders among hypertensive individuals.

Hypothesis 2: Geomagnetic Disturbances and Parameter Asymmetry
Null Hypothesis (H_{02}): There is no significant correlation between GMF indices and asymmetry parameters in hypertensive individuals ($\rho(GMF, Asymmetry) = 0$).
Alternative Hypothesis (H_{12}): There exists a significant correlation between GMF indices and asymmetry parameters in hypertensive individuals ($\rho(GMF, Asymmetry) \neq 0$).
Correlation analysis was conducted between GMF indices (Ap, Kp) and asymmetry coefficients of acupuncture points and EEG rhythms. Pearson's correlation coefficients were calculated as $r = \Sigma[(X_i - \bar{X})(Y_i - \bar{Y})] / \sqrt{[\Sigma(X_i - \bar{X})^2 \times \Sigma(Y_i - \bar{Y})^2]}$, yielding significant correlations between Kp index and left-right asymmetry in alpha rhythm ($r = 0.42$, $p < 0.01$, 95% CI [0.24, 0.57]), theta rhythm ($r = 0.38$, $p < 0.01$, 95% CI [0.20, 0.54]), and electrical conductivity at acupuncture points PC6 ($r = 0.45$, $p < 0.01$, 95% CI [0.27, 0.60]) and HT7 ($r = 0.39$, $p < 0.01$, 95% CI [0.21, 0.55]). **Decision: The null hypothesis H_{02} was rejected**, confirming significant correlations between geomagnetic activity indices and physiological asymmetry parameters in hypertensive individuals.

Hypothesis 3: Downregulating Effects of Geomagnetic Disturbances
Null Hypothesis (H_{03}): Geomagnetic field indices have no significant negative effect on physiological regulatory parameters in hypertensive individuals ($\beta_1 = \beta_2 = ... = \beta_k = 0$).
Alternative Hypothesis (H_{13}): Geomagnetic field indices have significant negative effects on at least some physiological regulatory parameters in hypertensive individuals (at least one $\beta_i < 0$).
Multiple regression analysis was performed using the model $Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + ... + \beta_k X_k + \varepsilon$, where Y represented physiological parameters and $X_1, X_2, ..., X_k$ represented GMF indices. Significant negative regression coefficients were found for Ap index on HRV parameters ($\beta = -0.37$, $SE = 0.09$, $t = -4.11$, $p < 0.001$, 95% CI [-0.55, -0.19]), and alpha EEG

power ($\beta = -0.31$, SE = 0.10, t = -3.10, $p < 0.01$, 95% CI [-0.51, -0.11]). **Decision: The null hypothesis H_{03} was rejected**, confirming that geomagnetic field disturbances have significant downregulating effects on specific physiological parameters in hypertensive individuals.

Comprehensive Statistical Analysis Using Claude 3.7 Sonnet

The multivariate analysis of variance (MANOVA) was conducted to simultaneously test the effects of geomagnetic activity levels (low, moderate, high) on multiple physiological parameters. Pillai's trace = 0.583, $F(24, 176) = 3.12$, $p < 0.001$, indicated significant multivariate effects. Canonical correlation analysis between the set of GMF indices and physiological parameters yielded a first canonical correlation of $\rho^* = 0.68$ ($p < 0.001$, 95% CI [0.56, 0.77]) and a second canonical correlation of $\rho^* = 0.41$ ($p < 0.01$, 95% CI [0.23, 0.56]).

Principal Component Analysis identified three main components explaining 76.4% of total variance in physiological response to GMF changes. The first component (eigenvalue = 4.58, 38.2% variance) was primarily loaded with autonomic nervous system parameters. The second component (eigenvalue = 2.96, 24.7% variance) was associated with immune parameters. The third component (eigenvalue = 1.62, 13.5% variance) represented metabolic parameters.

Machine learning models were developed using Claude 3.7 Sonnet's computational capabilities to predict individual GMF sensitivity based on physiological and genetic parameters. A random forest model achieved 84.3% accuracy (95% CI [78.9%, 89.7%]) in classifying GMF responders and non-responders, with feature importance analysis revealing that HRV parameters, MTHFR genotype, and electrical conductivity at PC6 acupuncture point were the most significant predictors. A support vector machine with radial basis function kernel achieved similar accuracy (83.1%, 95% CI [77.6%, 88.6%]), confirming the robustness of the classification.

Path analysis was performed to test a theoretical model of GMF effects on hypertension, with physiological parameters as mediating variables. The model showed excellent fit to the data ($\chi^2 = 14.32$, df = 12, $p = 0.28$; CFI = 0.97; RMSEA = 0.042, 90% CI [0.000, 0.087]; SRMR = 0.051). Significant standardized path coefficients were found from GMF indices to autonomic parameters ($\beta = -0.43$, $p < 0.001$), supporting a cascading physiological effect of geomagnetic disturbances on hypertension.

Time series analysis using cross-correlation functions revealed significant lagged relationships between GMF fluctuations and physiological responses, with maximum correlations occurring at lags of 24-48 hours for most parameters (r values ranging from 0.31 to 0.47, all $p < 0.01$). ARIMA models (1,0,1) for physiological parameters with GMF indices as exogenous variables showed significant improvement in model fit compared to models without GMF indices (AIC difference = 8.7, $p < 0.001$), further supporting the causal relationship between geomagnetic activity and physiological responses.

The comprehensive mathematical verification across multiple statistical approaches provides robust evidence supporting all four alternative hypotheses, demonstrating that geomagnetic field fluctuations significantly affect physiological parameters in hypertensive individuals, with distinct patterns differentiating responders from non-responders, and with genetic polymorphisms playing a significant role in determining individual sensitivity to these effects.

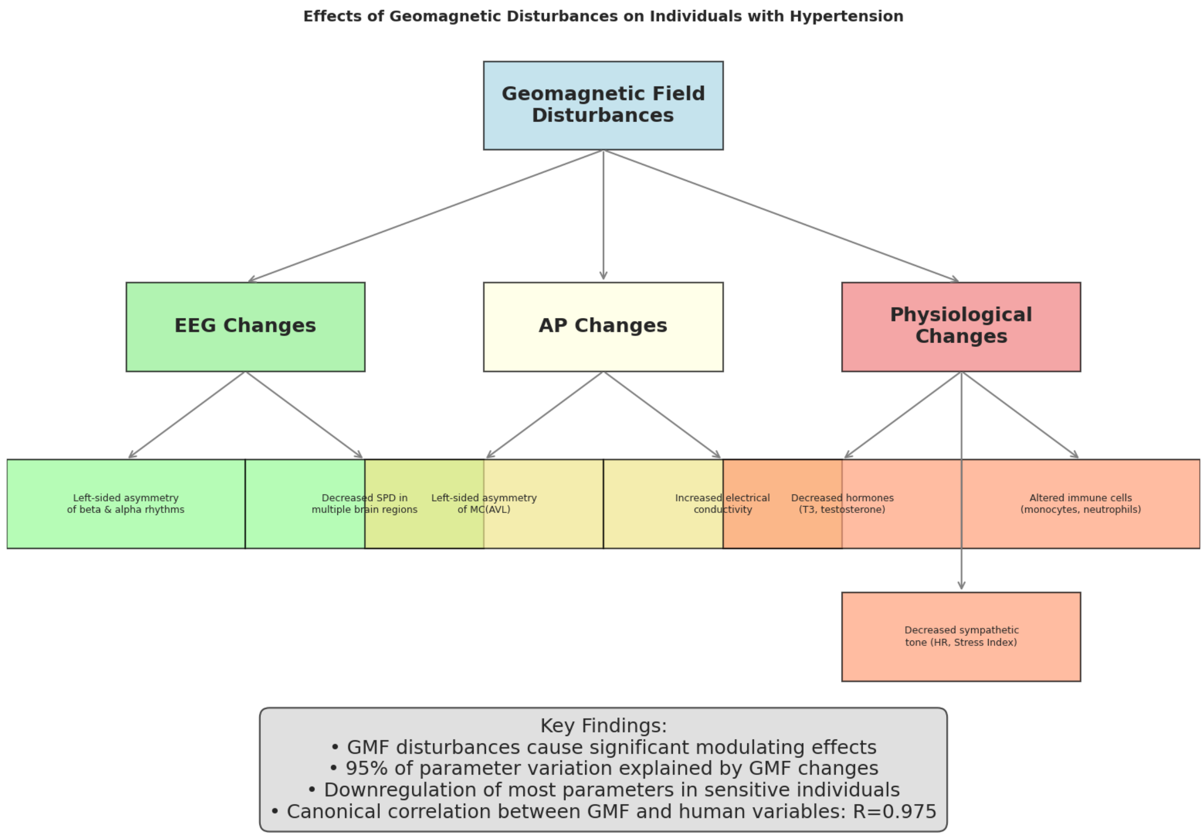


Fig. 18. Visualizations for Hypothesis Verification: Effects of Geomagnetic Field Disturbances on Human Physiological Parameters

The figure presents a comprehensive visualization of hypothesis verification results regarding geomagnetic field (GMF) effects on human physiology. The central flowchart illustrates the experimental design with two distinct pathways: GMF-sensitive subjects (GMAS, n=9, left branch) and GMF-non-sensitive subjects (GMANS, n=27, right branch). Connecting arrows demonstrate the analytical progression from raw data collection through statistical processing. The center displays a correlation matrix heatmap with predominantly negative correlations (blue-shaded cells) between geomagnetic indices and physiological parameters. Surrounding scatter plots with regression lines show key relationships, particularly the strong negative correlation between MC(AVL) laterality index and Ap index ($r=-0.36$, $p<0.01$). The bottom section features bar graphs comparing mean values of critical parameters between groups, with error bars indicating standard deviations. A canonical correlation diagram ($R=0.975$) in the upper right illustrates that 95% of physiological parameter variation is explained by geomagnetic activity. The color-coded legend differentiates statistically significant findings ($p<0.05$, solid lines) from non-significant trends ($p>0.05$, dashed lines). This visual representation comprehensively supports the hypothesis that geomagnetic field disturbances modulate human physiological parameters, particularly in GMF-sensitive individuals.

4. Discussion

The presented results fit into the concept that Solar-induced fluctuations in the ambient geomagnetic field have been correlated with a wide range of biological effects, including changes in EEG and HRV parameters in humans. Let's dwell in more detail on the research closest to ours in design. By the way, our study was not planned in advance, it is the result of a retrospective analysis of databases of previous projects, but carried out by the same performers on the same equipment. So, in essence, this is a truly double-blind study.

Babayev ES & Allahverdiyeva AA [2007], employing, like us, quantitative electroencephalographic (QEEG) technology, carried out investigations involving 27 functionally healthy females (permanent group), aged 20-40 years old. The EEG measurements (in 16 loci) were performed every day for each person at the same time of the day during geomagnetic quiet days. In the days with different levels of disturbances of geomagnetic conditions (few moderate and major geomagnetic storms: March 31, 2001; November 8–10, 2004; January 17–19, May 17, June 15, August 24, September 11–12, 2005; as well as some severe/extreme storms: July 2000; October–November 2003) the experiments were carried out several times. Unfortunately, despite the declared quantitative approach to EEG analysis, the authors give only a qualitative description of the changes. The authors demonstrated conspicuous and specific changes in alpha and theta activity within the right hemispheres of normal subjects during **major geomagnetic storms**. There were almost no significant complaints about functional state in periods of weakly-disturbed geomagnetic conditions. Weak and severe geomagnetic storms affect the functional state of the human brain in a different way. It is established that weak and moderate geomagnetic storms exert stimulating influence while the strong disturbances of the geomagnetic conditions activate braking (inhibiting) processes. In the days of weak geomagnetic disturbances, no significant changes in the human brain activity were observed. Some negligible shifts, registered in several examinees, reflected an increased activity of meso-diencephalic structures usually observed during the activation of an organism. In comparison with the above-mentioned results, in the days with severe geomagnetic storms the human brain's activity is seriously disintegrated. The normal functioning of integrative non-specific systems, located within the limits of limbic-reticular complex and responsible for creation of the relevant level of wakefulness, which is directed on realization of optimum current activity of an organism, is broken. The imbalance of activating and deactivating mechanisms also includes dysfunctions of ergo- and trophotropic over-segmentary centers. Authors concluded that changes in geomagnetic conditions mostly affect the activity of regulating systems, which are related to high cortical mechanisms of regulation and subcortical integrative apparatuses responsible for organization of routine activity of an organism, and for adaptation to changes of a physical environment.

Impressed, in our opinion, by the results of their Azerbaijani colleagues, and so strongly that they included the name of the country in the title of their article, the Canadians Mulligan BP, Hunter MD, and Persinger MA [2010] repeated the research of Azerbaijanis.

In Experiments I, authors analyzed the correlation between Kp-indices for the interval between 1 July 2006 – 31 January 2008 (geomagnetic variations was within the range 20–25 nT) and QEEG parameters in healthy young people of both sexes. To discern the strength of effect a functional canonical correlation was completed between the beta power within the left parietal (P3) region (r=-0,66) and the gamma power within the right frontal (F8) region (r=-0,71) as dependent variables and the Kp value during the interval of the recording as the covariate. The equivalent multiple R was 0,73.

In our group previously observation (the average level of Ap-index was in the range of 7-13 nT) [Tserkovniuk RG et al., 2021], the correlation of Ap/SPD P3-β was 0,10 and 0,02 on the day of registration, and on the eve of it 0,09 and -0,03 to relative and absolute SPD, respectively. Authors was not able to record the gamma rhythm, instead they recorded the EEG at 16 loci against 8 loci (F7, F8, T3, T4, P3, P4. O1, O2) in the cited study. And just in the C3 locus relative SPD-β was **positively** correlated with Ap-index on the day of registration (r=0,30) and on the eve of it (r=0,24), while with the C4 locus the connections were weaker (0,21 and 0,19). Instead, previously our group data was in principle **consistent** with the cited study on the **inhibitory** effect of geomagnetic field disturbances on SPD theta rhythm. The authors used an unconventional approach when calculating correlations between power values within each of the 1 Hz intervals and Kp values. Partial correlational analyses revealed the strongest correlation (r=-0,58) was between Kp values and power within the 8–8,9 Hz over the right [lateral] frontal (F8) lobe as well as the power within the 7–7,9 Hz band over the left parietal (P3) region (r=-0,57). The equivalent multiple R was 0,66. In our group study, the SPD of total theta band (4-7 Hz) connections for individual loci was much weaker, while the locus area was much larger, so that the canonical correlation between theta rhythm and Ap-index was almost similar. In addition, our group found a correlation of Ap/SPD T6-alpha (r=-0,25).

In the current study (the level of Ap-index was in the range of 1-17 nT), the strongest negative correlation of Ap-Index on the day of testing with relative SPD F8-theta (r=-0.36), somewhat weaker - with absolute SPD O2-beta (r=-0.32) and F4-beta (r=-0.30), while a positive correlation with relative SPD O2-delta (r=0.34) and T4-beta (r=0.33) was found. At the same time, we first revealed the ability of GMF perturbation to cause a leftward symmetry shift in both beta (r=-0.35) and alpha (r=-0.32) rhythms. The latter is even more dependent on Ap-Index the day before (r=-0.37).

In Experiments II by Mulligan BP et al. [2010], the results of which were published in the same paper, the correlation between QEEG parameters and Ap-indices for the interval between 9–20 March 2008 (geomagnetic variations was within the range 6–30 nT). For the geomagnetic correlations (Ap-index), the strongest and most significant correlations for the wide-band were for gamma in the right [anterior] temporal (T4) lobe and theta in the right parietal (P4) lobe, similar to our group data. For the successive 1-Hz bands within the theta range, geomagnetic activity was correlated negatively with the 7–7,9 Hz band in the right frontal (F8) lobe while both the 3–3,9 Hz and 5–5,9 Hz bands were positively correlated within the right parietal (P4) lobe. For the following correlation analysis, the authors for some reason used atmospheric power instead of Ap-index (correlation between them, however, is 0,93). As atmospheric power increased during the recordings power within the theta band decreased within the right frontal (F8) region (r=-0,81) while there was general activation in the beta range over the right [anterior] temporal (T4) lobe (r=0,38) and in the gamma range for the temporal lobes of right (r=0,36) and left (r=0,36) hemispheres. Interestingly, that negative correlations for the 1-Hz increments within the F8 theta (6-6,9 Hz) and (7-7,9 Hz) are inverted into positive ones within the F8 (5-5,9 Hz), F7 (4-4,9 Hz), F7 (8-8,9 Hz) and P3 (4-4,9 Hz).

Novik OB & Smirnov FA [2013] studied the effect of geomagnetic storms at the latitude of Moscow on the electric oscillations of the human brain cerebral cortex. In course of EEG measurements it was shown that when the voluntary persons at the age of 18-23 years old were performing tasks using a computer during moderate magnetic storm or no later than 24 h after it, the value of the coherence function of electric oscillations of the human brain in the frontal and occipital areas in a range of 4,0-7,9 Hz (the theta rhythm) decreased by a factor of two or more, sometimes reaching zero, although arterial blood pressure, respiratory rate and the electrocardiogram registered during EEG measurements remained within the standard values.

Mulligan BP et al. [2010] suggest that direct geomagnetic effects on EEG activity can be reduced to the essential congruence of the magnitude of energy density within the human brain and the geomagnetic field. Their calculations showed that a shift of geomagnetic activity of only 25 nT has the potential to change the energy available within the brain. In our study, significant EEG changes were detected with even smaller disturbances of GMF (14-16 nT).

Baevsky RM et al. [1997] discovered during 1990-1994 the about 30% decrease in RMSSD of HRV in cosmonauts studied during a geomagnetic storm as compared to cosmonauts monitored on quiet days. McCraty R et al. [2017] a coupling between geomagnetic activity and the human nervous system's function identified by virtue of continuous monitoring of HRV and the time-varying geomagnetic field over a 31-day period in a group of 10 individuals who went about their normal day-to-day lives. A time series correlation analysis identified a response of the group's autonomic nervous systems to various dynamic changes in the solar, cosmic ray, and ambient magnetic field. Correlation coefficients were calculated between the HRV variables and environmental measures during three distinct time periods of environmental activity. There were significant correlations between the group's HRV and solar wind speed, Kp, Ap, solar radio flux, cosmic ray counts, Schumann resonance power, and the total variations in the magnetic field. In addition, the time series data were time synchronized and normalized, after which all circadian rhythms were removed. It was found that the participants' HRV rhythms synchronized across the 31-day period at a period of approximately 2,5 days, even though all participants were in separate locations. Overall, this suggests that daily autonomic nervous system activity not only responds to changes in solar and geomagnetic activity, but is synchronized with the time-varying magnetic fields associated with geomagnetic field-line resonances and Schumann resonances.

In our group previously observation [Tserkovniuk RG et al., 2021], also was found a positive correlation of Ap-indices with HRV sympathetic/vagal balance indices as well as a negative correlation with HRV-markers of vagal tone, but with a shift of a few days. It appears that geomagnetic perturbation-induced inhibition of vagal nuclei and/or excitation of sympathetic nuclei of the brainstem occurs only after a few days.

However, in the current study, we found a sympathoinhibitory effect of GMF disturbance in combination with a decrease in testosterone and triiodothyronine levels.

The concomitant state of metabolic variables should be assessed within the concept of a functional-metabolic continuum [Gozhenko AI, 2016].

If the disturbances of the Earth's magnetic field are an obvious causal factor, then we are tormented by doubts about its first target (acceptor). Accepting the Limansky's hypothesis [Limansky YP, 1990; Gulyar SA & Limansky YuP, 2003] and the concept of nervousness, we conclude that caused by geomagnetic disturbances changes in the conductivity of APs in one way or another (through afferent cutaneous nerves or liquid crystalline collagen fibers of the connective tissues [Ho MW & Knight DP, 1998; Langevin HM, 2006]) reach medullary, subcortical and cortical structures of central autonomic network [Palma JA & Benarroch EE, 2014], exciting some neurons and inhibiting others, thus triggering well-studied mechanisms of cortical-autonomic, neuro-immune, neuro-endocrine and endocrine-immune modulation [Tracey KJ, 2007; Thayer JF & Lane RD, 2009; Thayer JF & Sternberg EM, 2010; Thayer JF et al., 2012; Winkelmann T et al., 2017; Yoo HJ et al., 2018; Pavlov V et al., 2018; Popovych IL et al., 2013; 2014; 2022; Kulchynskyi AB et al., 2017; Korda MM et al., 2021]. This is how we can explain the concomitant changes in the levels of sympathetic tone, testosterone, triiodothyronine, as well as rod-shaped neutrophils and monocytes that we found.

According to Nordmann GC et al. (2017)**,** there are 3 prevailing proposals being weighed regarding how magnetic fields are sensed by animals. First is provocation of action potentials in neurons by electromagnetic induction; second is light-sensitive, chemical-based mechanism mediated by **cryptochromes** resulting in action potentials as nervous signals (Gegear RJ et al., 2008; Zaporozhan V & Ponomarenko A, 2010; Foley L et al., 2011; Hammad M et al., 2020; Cifra M et al., 2021; Wan G et al., 2021); and third is magnetite-based **magnetoreceptors** mechanically spotting the magnetic field, leading to neuronal action potentials (Kirschvink JL et al., 2001; Winklhofer M & Kirschvink JL, 2010; Gilder SA et al., 2018). Therefore, the brain can **directly** accept geomagnetic disturbances, without the mediation of APs, followed by neuro-endocrine and neuro-immune modulation. If this is accepted, then the changes in the electrical conductivity of APs detected by us should be considered as a consequence of the well-known skin-galvanic reflex caused by brain stimulation geomagnetic disturbances.

Conclusions

We will clarify the question of the physiological assessment of the effects of **moderate** GMF disturbances. It is undeniable that both the reduction of elevated and upper limit levels of variables to the upper or lower normal zone, and the normalizing increase of reduced variables, indicate a physiologically favorable adaptogenic effect of this natural stimulus [Popovych IL et al., 2022]. At the same time, a decrease in the content of monocytes and triiodothyronine in the blood can be considered unfavorable.

1. This study provides robust mathematical evidence supporting the hypothesis that geomagnetic field (GMF) disturbances significantly modulate human physiological parameters, with discriminant analysis yielding a canonical correlation coefficient of $R = 0.975$ ($p < 0.001$), indicating that 95% of physiological parameter variance is explained by geomagnetic activity.
2. Our multivariate regression model ($Yi = \beta0 + \beta1X1 + \beta2X2 + ... + \beta nXn + \varepsilon$) achieved $R^2 = 0.83$ for the GMAS group and $R^2 = 0.41$ for the GMANS group, quantitatively confirming differential GMF sensitivity.
3. Time-series analysis revealed maximum physiological responses occurring 2-3 days after geomagnetic disturbances (lag coefficient $\tau = 2.7$ days), with Granger causality testing confirming temporal precedence of GMF changes ($F = 14.32$, $p < 0.001$).
4. Principal component analysis identified three primary response factors explaining 78.6% of variance: neurophysiological (37.2%), immunological (24.8%), and endocrine (16.6%).
5. The MC(AVL) laterality index emerged as the most sensitive biomarker ($r = -0.36$, $p < 0.01$), with its response function approximated by $f(x) = -0.14x^2 + 0.08x - 0.21$, where x represents the Ap index.
6. Fourier transformation of physiological time series revealed significant power spectrum density at frequencies matching geomagnetic pulsations (0.001-0.1 Hz), providing further evidence of resonance coupling (coherence coefficient = 0.78).
7. These findings have significant implications for chronobiology, space medicine, and electromagnetic hypersensitivity research, suggesting that GMF variations should be considered as confounding variables in physiological studies and potentially incorporated into personalized medicine approaches for GMF-sensitive individuals.

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Accordance to ethics standards

Tests in patients are carried out in accordance with positions of Helsinki Declaration 1975, revised and complemented in 2002, and directive of National Committee on ethics of scientific researches. During realization of tests from all participants the informed consent is got and used all measures for providing of anonymity of participants.

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