Effects of Magneto Active Compensation of Geomagnetic Field on Heart Rate Variability of Healthy Males

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Abstract: Geomagnetic field (GMF) is characterized by a strength of a few nT; however, during geomagnetic storms (GMSs), it can be sharply increased hundreds of times and pose a serious threat to magneto-sensitive people. A key scientific question is: How to compensate the possible negative influence of GMSs. The objective of the study was to determine the effects of magneto-active compensation (MAC) of GMF for its future use for protection from the negative influence of GMSs. The measurement of heart rate variability (HRV) on 25 healthy young male volunteers was carried out in the laboratory using the MAC at different levels of outdoor geomagnetic activity (GMA). The geomagnetic K-index was used to characterize the magnitude of GMSs; volunteers were tested during quiet magnetic days (K=1-3), during days with K=4 and during days with GMSs (K≥5). During quiet magnetic days, the comparison between HRV initial values with values measured under GMS compensation mode (CM) did not reveal any changes. On days with K=4 some HRV indices shifted from their initial values, but it was statistically not significant. However, on days with GMSs statistically significant changes in SDNN (p=0.033) and LF/HF (p=0.034) indices of HRV were observed in the GMS CM compared to their initial values. The experiments showed that GMSs cause a sensitive reaction of the heart rate regulatory mechanism, the effect of which can be cancelled in the GMS CM. The efficiency of the used MAC technology is supported by the results presented in this paper.

Key words: Heart rate variability, Geomagnetic storms, Magneto-active compensation.

1. Introduction

Geomagnetic field (GMF), as a weak magnetic field, is characterized by a strength of only a few nT. Solar phenomena such as solar flares, solar energetic particle events, coronal mass ejections (CMEs) and Earth-bound CME induce geomagnetic storms (GMSs), which can pose a serious threat to magneto-sensitive people on Earth and near Earth. When a CME strikes Earth, this causes a world-wide temporary disturbances of GMF that perturbs the GMF over a period of several hours or days. The strength of GMF varies depending on the latitude and corresponds to the several categories of geomagnetic fluctuations up to 350 - 1200 nT. (http://www.geomag.bgs.ac.uk/education/earthmag.html #_Toc2075560). In territories under the Circumpolar Auroral Belt, geomagnetic perturbations are permanent and most intensive (Chernouss, Vinogradov and Vlassova, 2001), although, effects with changes in geomagnetic activity (GMA) are observed also at lower latitudes at times of strong GMA. GMSs break the regular, synchronous rhythm of vital processes, the normal circadian structure of cardiovascular parameters is lost due to reduced melatonin (Palmer S. J, Rycroft, M. J. and Cermack, M., 2006). The de-synchronization grows throughout the storm, leading to an abrupt drop of cardiac activity. This is then followed by the destruction and degradation of cardiomyocytes, which lead to arrhythmias and large-wave fibrillation on a stormy day (Stoupel E., 1995). During GMSs the risk of in-hospital death, myocardial infarction and stroke increase by over 2.9 times (Vencloviene et al., 2013).

1. 1. *Background*

Many works indicating magneto-sensitive reactions to GMSs have been conducted in some of the former Soviet Union countries (e.g., Russia). Numerous publications in English that present results covering this subject matter are now available, the efforts in this field have been summarized in several papers (e.g., Babayev et al., 2012; Stoupel E., 2013). The key scientific question is: How to compensate and protect people from the possible negative influence of GMSs. Several projects have been known to use shielded rooms for magneto-medical and bio-magnetic research with compensation of the external magnetic field. At present, a number of researchers have shown effects of hypomagnetic field (near zero and zero) using Helmholtz's coils; authors reported about increased incidence of somatic defects in animals and deterioration of cognitive processes in humans as a result of the exposure to the hypomagnetic field (Trukhanov et al., 2012; Sarimov, Binhi and Milyaev, 2008; Guanghao et al., 2012; Tombarkiewicz, Roman and Niedzi´ołka, 2004). Some authors have indicated that by the end of 60 minutes of zero magnetic field exposure, significant reductions in heart rate and diastolic blood pressure in healthy subjects without cardiovascular pathologies and in patients with ischemic heart diseases were observed. Authors suggested to use such technology for protection of people from the negative influence of GMSs (Gurfinkel et al., 2016;

Gurfinkel and Ljubimov, 2004). However, in such rooms, owing to full electromagnetic isolation-induced hypo-magnetic environment, static as well as time-varying components of the GMF were absent, significantly differing from natural GMF conditions and making it impossible to achieve various degree of compensation of GMF.

The principles of magneto-active compensation (MAC) technology for protection of magneto-sensitive people during GMSs have been developed by researchers and engineers' groups of the current study (Khomeriki et al., 2004; Khomeriki, Gogidze and Invia, 2008; Tsibadze et al., 2012). There are also MAC systems available for protecting sensitive EM instruments, such as MRI systems, electron microscopes, etc. from AC/DC environmental magnetic fields, but these systems provide real time compensation of environmental magnetic field fluctuations caused by moving vehicles, trains, elevators, electrical distribution equipment and other sources (https://www.bilz.ag/wp-content/uploads/2016/03/Magnetic-field-compensation-cat-excerpt.pdf; http://www.muellerbbm.com/products/active-magnetic-field-compensation/).

Building on these results, the objective of our current study was to determine the effects of magneto-active compensation of GMF on heart rate variability (HRV) of healthy males, with the purpose of using this information for compensating (removing) negative influences of GMSs.

2. Materials and Methods

Our study was performed at a middle geomagnetic latitude (41°41′38″ N) in Tbilisi, Georgia. The data on GMA were obtained via the Internet (201504AK.txt - 201507AK.txt, U.S. Dept. of Commerce, NOAA, Space Weather Prediction Center). For the analysis and classification of the GMA days, the geomagnetic K-index (Menvielle et al., 2011) was used to characterize the magnitude of the GMS, where days with $K \leq 2$ were ascribed to magnetically quiet periods and those with $K \geq 5$ as those when GMSs occurred. In this study, we used a GMSs magneto-active compensation and simulation device (Invia at al., 2015; Tvildiani at al., 2018). The device works in two different regimes, allowing either compensation or simulation of GMSs. Using a highly sophisticated electronic MAC technology, the system provides a reliable shielding solution from environmental low-frequency MF. The current system (including orthogonally placed cavity circuits of Helmholtz coils in 3-axes system, 3-component fluxgate magnetometer, computer and electronic block) is able (i) to compensate automatically in real-time the disturbed GMF and (ii) to recreate the required characteristics of the GMF with a uniform MF. In the compensation mode the magnetic system compensates for (removes) perturbed variations of the time-varying components of the naturally occurring GMF, but saves the normal GMF variations (in the range < 40 nT). In the simulation mode, the magnetic system also compensates for (removes) naturally occurring GMF variations and saves only the static-component of the GMF where after it simulates the required characteristics of the GMF by using the reprocessed magnetometer data. The calculations of the resultant magnetic system configuration are shown in X- Y- Z- subsystems accordingly, Figure 1; The experimental room is shown in Figure 2 after installation of the active magneto-compensation system.

For measuring the response of the autonomic nervous system (ANS) to GMF variations, HRV monitoring was used to indicate the adaptive reactions of the whole organism (European Society of Cardiology and the North American Society of Pacing and Electrophisiology, 1996). In this work, the following ethical standards were complied with: The laws of Georgia, the Helsinki Declaration as well as data protection stipulations. All participants gave their written consent to participate in this study. The study was conducted according to the guidelines of the clinical trials service of the U.S. National Institutes of Health (https://clinicaltrials.gov/ct2/about-studies/learn).

The work performed was conducted as an open, three-step, cohort, prospective and parallel study. Research was performed by a single blind method. Volunteers who participated were informed about the essence of the experiment, however, to avoid psychological stress and ensure the reliability of the results, they were not informed of approaching GMSs and the exact date when they were compensated for in the experimental room. All stages of measurements were done in the experimental room. Each study participant was placed in the room three times in total at one-week intervals, while under the conditions of compensated GMSs they stayed only once or twice within two weeks. A prerequisite precondition for the test volunteers was to avoid any negative influences, resulting from emotional and physical excitation, heavy nutrition, alcohol use, etc., within 3 days before recordings. Measurements were taken at least 1.5-2 hours after a meal, with a constant temperature in the experimental room ranging within the interval 20-22°C. A period of 20 minutes for adaptation of volunteers to local environmental conditions preceded measurements. The records were carried out in the supine position with quiet breathing. The experiments performed in this work compared changes in HRV endpoints and geomagnetic perturbations. This allowed to make a comparison of HRV indices taken during quiet geomagnetic days and on days with GMSs with those obtained when groups were exposed to the conditions of compensation of perturbed time-varying component of GMS (see above).

HRV was assessed during three 20-minute consecutive sub-spans, in pre (when the device was turned off), during compensation (when the device was turned on) and on the restoration (when the device was turned off) stages, using the ArguSys++ Holter monitoring system (www.innomed.hu). The Holter monitoring system's standard software provided the following HRV indices: HR (b/min), SDNN (ms), RMSSD (ms), LF (ms^2), HF (ms^2), VLF (ms^2); where HR (heart rate, in beats/min), SDNN (Standard deviation of all Normal to Normal RR intervals, stands for the total effect of autonomic regulation of blood circulation), RMSSD (square root of the arithmetical mean of the sum of the squares of differences between adjacent NN intervals, stands for the activity of the parasympathetic part of the ANS); HF-spectral power in the high frequency range, physiological interpretation: relative activity level of the parasympathetic part of regulation; LF-spectral power in the low frequency range, physiological interpretation: relative level of activity of the vasomotor centre; VLF - characterizes influence of highest autonomic centers on cardiovascular sub cortical center. The numbers of derivative parameters were calculated using the Microsoft access software support (Tskhvediani et al., 2015) among which: LF/HF (Ratio LF $[ms^2]$/HF $[ms^2]$ - physiological interpretation: the autonomic nervous system

Table 1 - Values of HRV of healthy males in three 20-minute consecutive sub-spans of experiments during different levels of GMA in the outdoor environment.

n	Stages	K	HR (b/m)	SDNN (ms)	RMSSD (ms)	LF/HF	SI (c. u.)
8	In. values	1-3	68.88±2.96	79.38±8.5	29.88±8	1.175±0.05	167±39
	CM	0	68.1±3.1	70.25±13	40.1±7.4	1.24±0.1	165±50
	RS	1-3	67.75±2.9	77.5±12.3	33.5±7.3	1.26±0.06	144±32
11	In. values	4	72.6±2.97	60.5±6.9	23.9±5.4	1.23±0.12	303±70
	CM	0	70.55±2.3	72.5±8.4	32.8±5.7	1.17±0.11	262±52
	RS	4	69.2±2.1	78.7±9.3	30.4±5.7	1.19±0.08	178±25
6	In. values	≥5	83.3±3.57	50.17±6.6	31.7±7.2	1.097±0.12	316±74
	CM	0	78±2.6	67.3±7*	49.3±12	1.33±0.18*	247±86
	p-value		0.106	0.033*	0.096	0.034*	0.48
	RS	≥5	79.5±2.67	65.17±5.9	22.5±3.2	1.5±0.6	240±64
	p-value		0.29	0.69	0.1	0.37	0.93

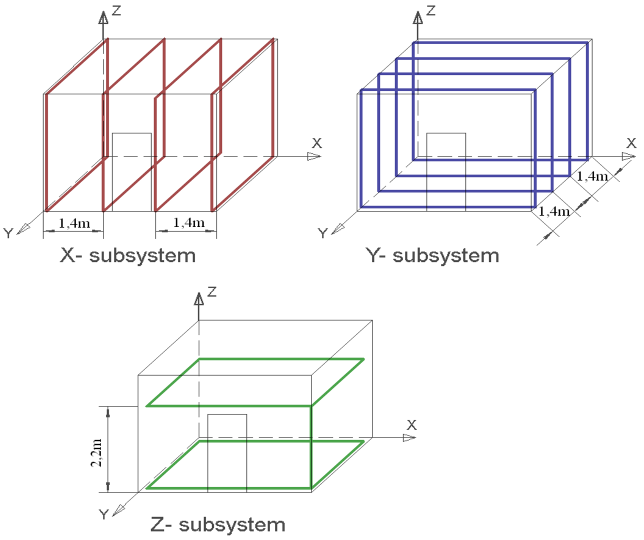

Figure 1. The configuration of the magnetic system.

balance index); SI - Stress Index, which reflects a degree of the prevalence of central regulatory mechanisms activity over that of the autonomic system; it basically characterizes activity of the sympathetic part of ANS. SI could serve as a measure for adaptive processes in humans and could be calculated from standard parameters of the rhytmogram (we used Pulse oximeter Contec CMS50E):

$$SI = A_{Mo} / \Delta X \cdot M_o,$$

where: Mo is the mode of individual R-R intervals (in seconds), A_{Mo} is the percentage of cycles, corresponding to Mo, and ΔX is the difference between the shortest and longest R-R intervals (in seconds).

In the current study took part 18- to 24-year old healthy male students who were selected and underwent a medical examination by standard health assessment. In total we performed 76 short-term recordings for 25 volunteers; measurements were performed over 3 months. For statistical analysis of the data obtained we used “Primer of Biostatistics” software by Stanton A. Glantz, fifth edition. The software yields results with corresponding 95% confidence intervals. All of above mentioned HRV indices were processed and evaluated.

3. Results

Measurements were obtained at different outdoor levels of GMA: 8 volunteers were tested during quiet magnetic days (K=1-3); 11 volunteers during days with K=4; and 6 volunteers were tested during days with GMS (K≥5) Table 1 shows results of the comparison of averages of measured HRV indices to the K index of GMF in three 20-minute consecutive sub-spans of experiments.

During quiet magnetic days, the comparison between HRV initial values with the values measured under GMS CM did not reveal any changes in the ANS. However, in the case of pronounced natural magnetic activity (K=4-5) as observed under natural conditions, a similar comparison clearly showed changes in the ANS within the investigated subgroups. During K= 4 in outdoor environment conditions, HR and SI values apparently show a shift from their initial

Figure 2. The current view of the experimental room.

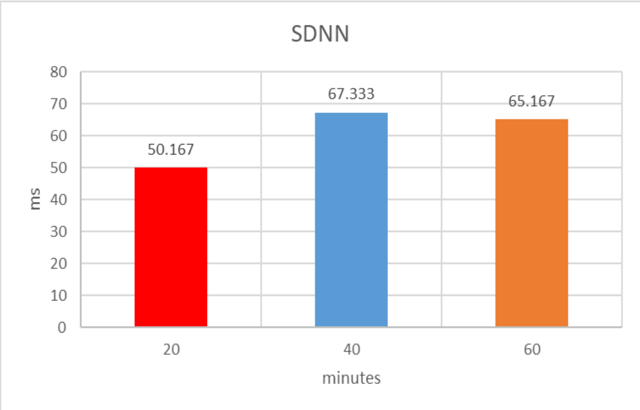

Figure 3. the shift of the average of SDNN under GMS CM during outdoor GMS conditions.

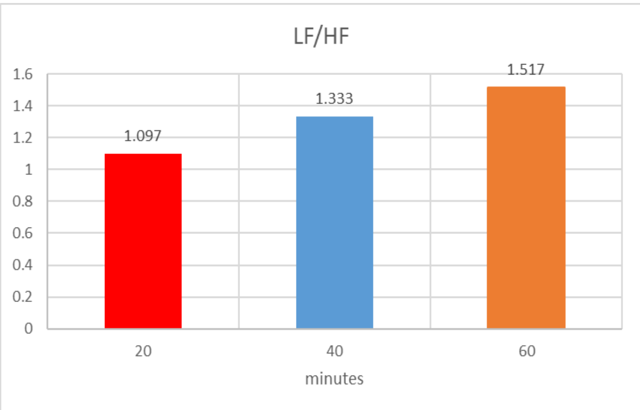

Figure 4. the shift of the average of LF/HF under GMS CM during outdoor GMS conditions.

values (the levels were reduced under GMS CM and RS); however, these differences have not reached statistical significance. For K=5 during GMSs in outdoor environment conditions, statistically significant changes in SDNN and changes occurred in HR and RMSSD values (the shifts LF/HF indices are clearly seen in the GMS CM. During the RS, gradually reduce) compared to the initial values. The reduced shifts manifest the removal of the deviations in the ANS of the investigated persons. The experiments showed that GMSs cause a sensitive reaction of the heart rate regulatory mechanisms in healthy young males, the effect of which can be cancelled in the GMS CM and returned to the initial functional state under the restoration stage when the GMS CM is switched off; however, LF/HF still remains shifted, that can be explained that the GMS compensation mode balances the regulatory mechanism of the heart rate and therefore in magneto-sensitive patients it can be used for the correction of drug-therapy regimens to facilitate the restoration of the autonomic regulation balance. Statistically significant changes of the averages of SDNN and LF/HF are shown in Figures 3 and 4, on the second sub-span of experiments during outdoor GMS conditions.

4. Discussion

Results of the experiments extend studies that report effects with changes in GMA observed also at lower latitudes at times of strong GMA (Palmer S. J, Rycroft, M. J., Cermack, M., 2006) and confirm the existence of GMA as the specific risk factor (Babayev et al., 2012; Stoupel E., 2013). Results extend and confirm also some previous studies reporting that hypomagnetic conditions (zero magnetic field) exposure reduces the heart rate to the end of 60-minute exposure (Gurfinkel et al., 2016; Gurfinkel and Ljubimov, 2004). However, effects of MAC of GMF differ from the effects of zero and near zero magnetic fields; absence as static as well as time-varying components of GMF (see section 1.1. Background for study) makes it impossible to compensate for perturbed time-varying component of GMF and achieve natural quiet geomagnetic conditions, saving normal variations and static component of GMF to which a human organism is adapted evolutionarily. Based on the above, the efficiency of the used MAC technology for the protection of magneto-sensitive people from the negative influence of GMSs and its further clinical usage are supported by the results presented in this paper. In addition, used technology with specially created room do not cause psychological and physical discomfort during investigations and can provide an increased level of safety during GMSs.

5. Conclusions

The performed experiments consistently showed that GMA events produce significant health effects. The results obtained in our study demonstrate effects only to brief exposure of compensated perturbed geomagnetic field on HRV. Measurements carried out under artificially compensated GMS conditions significantly changes SDNN ($p=0.033$) and LF/HF ($p=0.034$) indices to the end of 60 minutes of experiments. Interpretations of the results from our study are summarized here:

1. Strong geomagnetic storms have an effect on healthy males at middle latitudes, but have not caused significant stress reactions.

2. The magneto-active compensation technology may be used for the safety and protection of magneto-sensitive people during GMSs via compensating the negative influence of GMSs and balancing the regulatory mechanism of heart rate.

These conclusions give support to the hypothesis that an unusually weak magnetic field, such as the GMF seems to have an effect on human health. The current study has some limitations due to the number of investigated subjects in the groups being small. In order to arrive at more definite conclusions, we propose to continue such studies by collecting and analyzing more data, using the device described in this paper.

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