Space weather in the 11-year solar cycle and cardio-sensitivity of volunteers in the middle latitudes

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Abstract. There has been studied a cardio-sensitivity of volunteers of the middle latitudes to geomagnetic activity and to the variety of the parameters of the solar wind, Bz-components of interplanetary magnetic field, solar radiation with a wavelength of 10.7 cm and meteorological parameters in the minimum of the 24th 11-year solar cycle. The cardio-sensitivity to geomagnetic activity has been revealed only among 9.1% of the volunteers, which is significantly lower than in the maximum of the 11-year solar cycle (42% of the volunteers). The myocard of the cardio-nonsensitive volunteers to geomagnetic activity has been also nonsensitive to the other studied factors of the space and the earth weather. Thus, in the volunteers of the middle latitudes the period of the 11-year solar cycle determines the degree of synchronization of the myocard state and change of the geomagnetic activity.

1. Introduction
The term “space weather” means the population of dynamic processes in the Sun and in the interplanetary medium. Today, it is said that the weather effect on the human organism carries out by several channels [1]. A cardiovascular system and a nervous system give the first respond to a geomagnetic activity from all of organs and other organism systems. It is known that geomagnetic activity provoke myocardial infarction, hypertensive crisis, apoplectic attack and other vascular events [2-4]. It has been established that the condition of the space weather, including a geomagnetic activity, parameters pulsation and etc., all these factors impact not just the tonus of vessel walls, but also the myocard itself of the solar wind and interplanetary magnetic field, electromagnetic radiation of the Sun, geomagnetic and the blood rheology properties [5-10]. A number of authors consider that the pulse wave velocity, which is responsible for arterial stiffness, has become the most sensible to the space weather [7].

A sensitivity of myocard to a geomagnetic activity is defined by the term “cardio-sensitivity” [9]. Mechanisms of the cardio-sensitivity are not studied enough till present. Some of the scientists think that the effect of a geomagnetic activity to the human organism is carried out by the endogenic system of nitrogen oxide [7, 11]. For inhabitants of the middle and low latitudes there is the role of geomagnetic pulsation Pc1, the periods of which are in the rate of a heart beat [5]. During the multilatitude monitoring in the middle and low latitudes there has been established that the cardio-
sensitivity is typical to healthy volunteers from any region, although it is similar response of the volunteers from various regions only to 43% of geomagnetic activity [9].

The subject of constancy or inconstancy of a cardio-sensitivity is an unstudied item of a geomagnetic cardio-sensitivity of an individual person. The complicacy of solving the item is in the necessity of a long time observation of the groups of volunteers, the use of the same equipment and similar algorithm of the research. The methodology that has been developed and used in the multilatitude simultaneous biophysical experiment “Heliomed” and “Heliomed-2” [9] for many years, as well as the database since 2006, let us compare a cardio-sensitivity of the healthy volunteers in various periods of the 11-year solar cycle, study the peculiarities of a cardiovascular response of a person living in auroral, subauroral and middle latitudes, estimate a myocard response to geomagnetic activity of a various intensity in a complex with characteristics of the solar wind, electromagnetic radiation of the Sun and etc.

2. Goal setting
The aim of the present research is to study the cardio-sensitivity of the volunteers from the middle latitudes to a geomagnetic activity, change of the parameters of the solar wind, Bz-components of interplanetary magnetic field, solar radiation with a wave length of 10.7 cm and meteo parameters in the minimum of the 24th 11-year solar cycle.

3. Methods of the research
The response of the cardiovascular system of the healthy volunteers living in the middle latitudes to geomagnetic change had been studied during March-April of 2019 (in the minimum of the 24th 11-year solar cycle activity). In the group of observation there were 11 persons of the average age of 36.0±5.2 years. The examination had been held daily and according to the algorithm of the established multilatitude monitoring „Heliomed-2“ which is described in details in [8, 9]. 462 parameters of the TSC had been analyzed in the volunteers.

For the parameter of the myocard condition there has been used a t-wave symmetry coefficient (TSC) in a phase portrait of the ECG which displays a condition of myocard repolarization, it is the most valuable criterion of electrophysiological processes in a heart muscle in the impact of extrinsic factors and shows its adaptation potency [12]. The ECG phase portrait had been studied using the express-cardiographer “Fazagraf” (Ukraine).

The TSC value of 0.45-0.70 relative units displays the absence of myocard disorders. In case of the disorders in the myocard repolarization, risk of myocardial dysfunction and ischemic disorders, the TSC becomes more than 0.70 relative units (r.u.), in the TSC value over 1.0 r.u. it is permitted to make a conclusion of a myocard overload [12].

For the daily estimation of a geomagnetic activity there has been used the parameter of a global geomagnetic activity – daily Kp-index which is the best for describing a strong geomagnetic activity as well as weak one, as it is based on a quasi-logarithmic scale. Daily Kp-index parameters over 32 r.u. show a significant geomagnetic activity, parameters from 16 to 32 r.u. – a weak geomagnetic activity of the Earth geomagnetic field.

For more nuanced evaluation of the impact of parameters of the space weather on the cardiovascular system of the volunteers there has been an analysis of a solar wind dynamic pressure, Bz-components of interplanetary magnetic field (IMF), variation of the temperature and density of the Sun in radiation wave length of 10.7 cm (F 10.7). The given daily parameters of the solar activity were loaded from the NASA web site (https://omniweb.gsfc.nasa.gov). The solar wind and IMF data parameters have been received from the WIND satellite which had been at that time on Lagrange L1 location.

Studying the meteorological parameters included the estimation of an air temperature (T, °C), air humidity (%), atmosphere pressure (nPa) and wind velocity (m/s). The meteorological parameters have been loaded from the web site https://climate-energy.ru/weather/archive_weather_341720.php

Individual TSC synchronization maps of each volunteer have been analyzed, including all the
mentioned above parameters of the space and earth weather in a dynamic of a daily two-month monitoring.

According to the results of the TSC synchronization and Kp-index there have been distinguished cardio-sensitive and cardio-non-sensitive persons to the geomagnetic activity (using the algorithm of the “Heliomed-2” monitoring) [8, 9]. The cardio-sensitive volunteers were those of them who in 67% of cases had a myocardial respond caused by the geomagnetic activity, according to TSC in an ECG phase portrait.

By the same methods there have been estimated the TSC synchronization of the volunteers with the parameters of the solar wind dynamic pressure, Bz-components of IMF, the Sun in radiation wave length of 10.7 cm, temperature and air humidity, atmosphere pressure and wind velocity.

Besides, for each of the volunteers there have been determined average values of TSC in the period of the monitoring to estimate the processes of myocard repolarization.

The classification of the volunteers (cardio-sensitive and cardio-nonsensitive) was held by the interactive software (Python programming language) to analyze the synchronization of the myocard condition and the space weather parameters [13]. For building diagrams and statistical calculation there have been used «Origin» and «Medstat» softwares.

The research has been organized according to the Declaration of Helsinki 1964 and its subsequent amendments. All of the participants of the research gave their voluntary informed consent.

4. Results

The research period is characterized by a weak geomagnetic activity, the parameters of the daily Kp-index were changing from 2 to 20 r.u.

There were not any significant geomagnetic activities during the monitoring period. Thus, the research period of the minimum of 11-year solar cycle has been characterized by a mild condition of the Earth geomagnetic field.

The peculiarity of the studied period was also the fact that, despite the whole mildness of the geomagnetic background, almost every 3-4 days there were noted weak geomagnetic activities with the amplitude dynamic of 5-10 r.u. There were noted 11 peak values of the Kp-index – on the 4th, 7th, 10th, 12th, 16th, 19th, 23rd, 26th, 28th, 35th, 37th days of observation.

The TSC of the volunteers were various from 0.52 to 1.5 r.u. Thus, despite the mild geomagnetic background, myocard of healthy volunteers from middle latitudes in the minimum of the 11-year solar cycle activity was characterized by functional disorders of electrophysiological processes in myocard with a potential risk of myocardial dysfunction. The described events were not accompanied by a functional myocard overload, as the average meaning of the TSC of the volunteers was no higher than 1.0 r.u.

The analysis of individual maps of TSC variety comparing with Kp-index variety, in the period of the monitoring, and the synchronization of TSC-Kp displayed that only one volunteer can be cardio-sensitive (9.1% from the group of observation). The synchronization of the TSC-Kp was 72.7% (Figure 1).

In Figure 1 there is a synchronization of TSC-Kp in the 2nd, 3rd, 4th, 5th, 7th, 9th and 10th maximums of the diagram of a daily dynamics of the Kp-index in the monitoring period. On the upper panel of Figure 1 there are changes in the Kp-index in relative units, on the bottom panel – changes of the TSC of the volunteer in relative units, on the x-axis – the days of the monitoring.

In the only cardio-sensitive volunteer the average TSC during the monitoring was 1.03±0.15 r.u., which evidences the myocard repolarization disorder with an event of an overload. Nevertheless, that volunteer demonstratred the cardio-sensitivity to weak geomagnetic varieties in the minimum of the 11-year solar cycle.
Figure 1. TSC of a cardio-sensitive volunteer with a change in the geomagnetic disturbance.

The other volunteers (90.9%) were referred to cardio-non-sensitive, as their TSC-Kp synchronization was maximal only in 41.7% (2 volunteers), in two of the observants there was not revealed any myocardial response to the geomagnetic variability (synchronization of the TSC-Kp – 0%), three of the observants had the synchronization of the TSC-Kp from 8% to 16.7%. So, in the minimum of the 24th 11-year solar cycle activity the myocard of the most part of the volunteers did not respond to weak varieties of the Earth geomagnetic background.

In Figure 2 there is an average diagram of the TSC in the group of cardio-non-sensitive volunteers and the variation of the space weather parameters in the monitoring period.

Figure 2. TSC of a group of cardio-insensitive volunteers when changing parameters of space weather.
On the x-axis there are days of the monitoring, on the upper panel of Figure 2 - daily values of the Kp-index in r.u., on the second upper panel – TSC variations in r.u., on the third – variety of Bz-components of IMF (r.u.), on the bottom panel – variety of the Sun radiation with wave length of 10.7 cm (10-22WM-2Hz-1). In order to simplify the visualization of possible coincidences of the TSC maximums of the volunteers with the maximums of the space weather parameters, there are vertical dashed lines from TSC maximums on the picture. The figure demonstrates the absence of the synchronization variety of TSC not only with the Kp-index, but with the other studied geophysical parameters. Thus, in the minimum of the 11-year solar cycle activity in the most of the volunteers (90.9%) we have not revealed the myocard response to weak geomagnetic change, variety of Bz-components of IMF, a solar wind dynamic pressure and solar radiation with a wave length of 10.7 cm.

In cardio-non-sensitive volunteers we have analyzed a possible impact of meteoparameters on a cardiovascular system (Figure 3). On the x-axis there are days of the monitoring, on the upper panel of the picture – TSC variations (r.u.), on the second upper panel – air temperature (°C); on the third panel – air humidity (%), on the fourth panel – atmospheric pressure (hPa), on the bottom panel – wind velocity (m/s). In order to simplify the visualization of possible coincidences of the TSC maximums of the volunteers with the maximums of the meteoparameters, there are vertical dashed lines from TSC maximums on the picture. We also have not revealed any sensitivity to meteoparameters in the volunteers from this group, as there was no TSC synchronization with an air humidity and temperature, atmospheric pressure and wind velocity.

We can see that in the minimum of the 11-year solar cycle activity myocard of the most of the healthy volunteers from middle latitudes does not respond to geophysical and meteoparameters variations.

![Figure 3. TSC of a group of cardio-insensitive volunteers when changing meteorological parameters.](image-url)
For comparison with analogical parameters in the maximums of the 11-year solar cycle activity we used the results presented in the research [9] of a cardio-sensitivity of healthy volunteers in 2014. In that research there was revealed that in middle latitudes in the maximum of the 11-year solar cycle the cardio-sensitivity was established in 42% of healthy volunteers.

The myocard condition in cardio-non-sensitive volunteers in the minimum of the 24th 11-year solar cycle activity was absolutely different. In 20% of persons from the group of cardio-nonnatives there was not revealed repolarization disorders, in 70% - modest rise of the TSC from 0.7 to 1.0 r.u., in 10% - a significant rise of the TSC over 1.0 r.u., which says about myocard overload. An average meaning of the TSC in the group of cardio-non-sensitive was 0.80±0.04 r.u. which is higher than normal TSC in an ECG phase portrait (0.45-0.7 r.u.). So, in average, the myocard condition in cardio-nonnative patients was characterized by a modest disorder of repolarization of a heart muscle.

The results of the research display that disorders of repolarization in healthy volunteers in middle latitudes in the minimum of the 11-year solar cycle activity has been revealed in cardio-sensitvity as well as in cardio-nonsensitivity in volunteers.

5. Discussion
The results of our research showing a very low cardio-sensitivity of myocard of the volunteers (only 9.1% of the observant) is connected, as we consider, with the studied period of the 11-year solar cycle activity – the minimum of the cycle.

Earlier, while studying the cardio-sensitivity of the volunteers to the geomagnetic activity in the maximum of the 24th 11-year solar cycle (in 2014), we found out that 42% of the volunteers from middle latitudes were cardio-sensitive [9]. It is necessary to notice that the long term monitoring with the use of the same equipment and the similar research algorithm significantly minimize the mistakes of a preanalytical phase of the research. The single point of the examination in the middle latitudes (Saratov) does not allow explaining such a big difference in the proportion of the cardio-sensitive and cardio-non-sensitive volunteers by geographical features.

From there, we established that in the minimum of the 11-year solar cycle activity the cardio-sensitivity of the volunteers from middle latitudes to geomagnetic activity is significantly lower than in the maximum (in 9.1% and 42% of the volunteers respectively, p<0.05). So, the natural synchronization of the cardiovascular system rhythm and geocosmophysical factors depends on the 11-year solar cycle activity.

The given results correlate to the results of the research of MV Ragulskaya and SM Chibisov [8], who displayed that maximal synchronization of an organism was observed in the most active periods of the 11-year solar cycle activity. There was significantly revealed a long-term change in the structure and hemodynamics of rabbits’ hearts in various phases of the 11-year solar cycle activity.

It is known that the bond of a human organism with the external factors is of an adaptation origin. Factors of the space weather in the process of realization its impact on an organism through water structures and essential metabolic cycles (NO cycle) are turned to be a kind of a training and adaptation factors of various systems of an organism. It has been established that together with myocard a pulse wave velocity responsible for arterial stiffness also impacts the geomagnetic variety [7]. There is not a big number of articles analyzing the dependence of adaptation mechanisms to the space weather factors under the impact of the 11-year solar cycle activity [1, 10]. The results, we have got from the research about a various degree of myocard sensitivity of the volunteers from middle latitudes to geomagnetic activity in the period of the 11-year solar cycle activity, show us that the period of a solar cycle determines adaptation mechanisms of a cardiovascular system to the space weather factors.

The differences in the cardio-sensitivity of the volunteers from middle latitudes to geomagnetic variations in the period of the minimum and maximum of the solar cycle can be connected with the difference of these periods in the presence or absence of geomagnetic pulsation Pc1, which are in the rate of a heart beat, as a number of the authors think that Pc1 impacts a biotropism of the space weather factors in middle latitudes [5].
In other previous researches the attention of the scientists is attracted by the volunteers who, first of all, respond to geomagnetic activity and other factors of the space weather, and the so called cardio-non-sensitives are out of the analysis of the research. As it is presented in the research the most of the volunteers have demonstrated cardio-nonsensitivity to a weak geomagnetic activity, we have tried to determine if their myocard condition and variations of the heart muscle electrogensis are connected with other space weather factors – solar wind parameters, Bz-components of IMF and the Sun radiation, and with meteoparameters change in the monitoring periods.

We have not got the data if the cardio-non-sensitive volunteers are sensitive to any other factors of the space and the earth weather.

In this group of the volunteers there is a refractoriness of the heart muscles to all natural factors, no adaptation of the cardiovascular system to external physical factors has been observed. The obtained results let us suppose that in the minimum of the 11-year solar cycle activity a human organism in middle latitudes has refractoriness to the space and earth weather. It is possible that “training” effect of external natural factors on adaptation mechanisms of a cardiovascular system is cyclic in accordance with a solar cycle activity.

We have also analyzed electrophysiological condition of a heart muscle of the volunteers in the research period. It has been found out that the myocardial condition of the healthy volunteers in the minimum of the solar activity in middle latitudes, on the whole, has been characterized by functional disorders in the processes of repolarization, which is displayed by an average TSC value in the group of the volunteers 0.91±0.09 r.u. According to the graduation of disorders in electrophysiological processes in myocard used in “Fazagraft” this value of the TSC corresponds to the condition of the “tired” heart muscle (TSC 0.71-1.00 r.u.) [12].

The rise of TSC in the healthy volunteers in the minimum of the 11-year solar cycle activity can be connected with the peculiarities of hemorheology and endothelium function in the healthy persons in the periods of an increase and decrease of the solar cycle activity [10]. Thus, there has been displayed that in the period of the decrease of the 11-year solar cycle the deformability of erythrocytes reduces – there is a failure in the main adaptation rheological mechanism producing oxygenation of tissues including the heart tissues. Perhaps, the decrease of the erythrocytes deformability leads to the blood circulation disorder and, as a result, to the disorder in electrophysiological properties of myocard. It cannot be excluded that the heart muscle in the condition of the “tired” heart muscle according to TSC in the ECG phase portrait, becomes less sensitive to synchronizing impact of the space weather.

6. Conclusions
1. Myocard of the most of healthy volunteers from the middle latitudes (90.9%) in the minimum of the 11-year solar cycle is not sensitive to weak variations of the geomagnetic activity, a solar wind dynamic pressure, Bz-components of the IMF and the Sun radiation with the wave length of 10.7 cm.

2. The variations of meteo-parameters (air temperature and humidity, atmospheric pressure and wind velocity) also do not impact the myocard condition of healthy volunteers from middle latitudes in the minimum of the solar cycle activity.

3. There had been revealed the decrease of cardio-sensitive healthy volunteers from middle latitudes in the period of the minimum of the 11-year solar cycle activity (9.1% of the volunteers) in comparison with the period of the maximum of the 11-year solar cycle activity (42% of the volunteers).

4. In the minimum of the 11-year solar cycle activity the myocard condition of the healthy volunteers in the middle latitudes is characterized by modest disorders of myocard repolarization according to TSC parameters in the ECG phase portrait.

5. The period of the solar cycle should be included in the analysis of the results of the impact of the space and earth weather on the cardiovascular system condition of healthy volunteers.

7. References
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