Geomagnetic Disturbances and Cosmic Ray Variations in Relation to Human Cardio-health State: A Wide Collaboration

H. Mavromichalaki, M. Papailiou, S. Dimitrova, E.S. Babayev, F. R. Mustafa

Abstract—**Research groups from Athens (Greece), Baku (Azerbaijan) and Sofia (Bulgaria) carry out relevant heliobiological and biometeorological studies and the obtained results reveal that human organism is sensitive to changes in environmental physical activity and reacts to these changes through variations of human body's physiological parameters such as systolic and diastolic blood pressure, heart rate (HR), human brain's bioelectrical activity, etc. Results of a collaborative study conducted by these scientific groups concerning the influence that geomagnetic disturbances and cosmic ray activity might have on human cardio-health state, are described in this paper. This multi-disciplinary study refers to the time period of 15 July 2006 - 31 March 2008. Daily HR data, which were digitally registered for seven functionally healthy persons on working days and Saturdays in the Laboratory of Heliobiology, located at the Medical Center INAM, Baku, Azerbaijan, were studied in relation to daily variations of cosmic ray intensity (CRI), measured in the Neutron Monitor Station of the University of Athens, Greece, and daily variations of Dst and Ap geomagnetic indices taken from accessible data sources. The time interval from 4 to 22 December 2006 was most interesting as it was characterized by extreme solar and geomagnetic activity (GMA) and intense cosmic ray events such as a series of Forbush decreases which started on 6 December 2006 and lasted until the end of the month, and a solar proton event causing a Ground Level Enhancement of the CRI on 13 December 2006. A sudden decrease of the CRI on 15 December resulted in a major geomagnetic storm, which was recorded also in Athens Station (cut-off rigidity 8.53 GV) with amplitude of 5%. The statistical methods were applied to establish a statistical significance of the effect of GMA levels and CRI variations on HR (for the whole group and for each person in the group). Our study has revealed that HR variations can be connected to geomagnetic disturbances and CRI variations. The effects of HR increase were more pronounced for high levels of GMA (when geomagnetic storms occur) and large CRI decreases. HR increased on the days before, during and after geomagnetic storms with high intensities and on the days preceding, and following CRI decreases.**

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1. Introduction

The Earth and its surroundings (geospace) are very sensitive to changes in solar activity, its manifestations in the near-Earth space environment and on Earth [1]. Solar disturbances interacting with the geospace cause geomagnetic storms[2], perturbations in the ionosphere, long-term variations in the Earth's climate, etc. Conditions on the Sun and in the solar wind, the interplanetary space, the magnetosphere, the ionosphere and the thermosphere constitute the so called "*Space Weather*" [3]; they can influence not only the performance and reliability of space-born and ground-based technological systems, but can also endanger many kinds of human activities, particularly in connection to human life itself and human health.

As human health in general and human organism reactions can be affected by many internal and external factors, skepticism towards these kinds of studies always exists. Some studies did not find a relation between geomagnetic activity (GMA) and cardiovascular mortality [4], or correlation between geomagnetic field (GMF) variations and heart attacks [5], [6]. A recent study also found no statistically significant relation between GMA and the number of fatal or nonfatal acute myocardial infraction cases, the number of sudden deaths or the number of patients with chest pain and without myocardial damage [7].

Nevertheless, in the last several decades many scientists have worked on the possible impact of space weather variations on living beings. Over the last thirty years, the investigation of the effect that solar and geomagnetic activities, and, in general, the space weather, might have on human health has resulted in series of serious studies, conducted in number of countries [8], [9], [10], [11], [12], [13] (and references herein).

Different levels of GMA and cosmic ray activity (CRA) have been studied in association with human physiological parameters [14], [15], [16], [17], [18], [19], [20], [21]. Results of these investigations are rather new but majority of them are irrefutable and quite interesting. For example, it is found that the human being's reactions to geomagnetic disturbances seem to vary from men to women [22], [23], [24], and from persons suffering from cardio-vascular diseases to healthy people [23], [24], [25], etc.

Some evidence has also been reported on the association between geomagnetic disturbances and increases in number of traffic (road) and work (industrial) accidents [26], [27], [28], [29]. These studies were based on the hypothesis that a significant part of traffic accidents could be caused by the incorrect or retarded reaction of drivers to the traffic circumstances, the capability to react correctly being influenced by the changes in the environmental physical activity, particularly, sharp fluctuations of GMF.

Some studies revealed that the most significant effects on myocardial infarction, brain stroke and traffic accidents were observed on the days of GMF disturbances accompanied with Forbush decreases [30], [31], [32].

Recent investigations [18], [33] have revealed that the number of sudden cardiac deaths and the incidences and pre-admission mortality from acute myocardial infarctions increased on the days both of highest and lowest daily levels of GMA and high levels of CRA described by neutron flux.

This work is an outcome of the collaborative investigations of three different scientific groups, namely those from Athens (Greece), Baku (Azerbaijan*)* and Sofia (Bulgaria), carried out for the study of potential influence of variations of environmental physical activity on human cardio-health state. In this paper we investigate how heart rate (HR) dynamics could be influenced by variations in GMA and cosmic ray intensity (CRI). Baku team has performed digitalized registrations of certain cardiologic parameters of a group consisting of seven functionally healthy persons and provided HR data for the time period from 15 July 2006 to 31 March 2008. CRI decreases, like the big event recorded during December 2006, together with Ap- and Dst- indices variations during geomagnetic disturbances with different intensities, has been analyzed in regard to measured HR variations.

2. Data and Methods

A. Medical data

The relevant medical measurements were conducted with a group consisting of seven functionally healthy persons from Baku, Azerbaijan (geographic coordinates: latitude 40°23'N; longitude 49°51'E). Digitized electrocardiograms (ECGs) were registered on working days and Saturdays in the academic Laboratory of Heliobiology, located at the Medical Center "INAM" (Baku), from 15 July 2006 until 31 March 2008. The group consisted of 4 women and 3 men and the average age of the group members was 31.6 years. In total the number of obtained digital recordings, which were subjected to analysis, was 1673 and referred to such cardiologic parameters as RR intervals (time series of beat-to-beat HR intervals or HR period in msec), minimal RRmin, maximal RRmax, average RRavg and HR values.

In order to minimize the effects of other parallel objective and subjective factors (i.e. environmental conditions, artificial electromagnetic fields, personal problems of patients etc.) the registrations were conducted in a special isolated room, which was designed for medical examinations, providing also the possibility for full relaxation of the persons examined. None of the members of the group were informed about current space weather conditions before and during the measurements. In addition to all mentioned above, the physiological and psycho-physiological state of these persons was also taken into consideration and in case of complaints about their physiological and psycho-physiological state (stress, emotional experiences, an additional pathology – influenza, cold, etc.) their measurements were neither conducted nor considered. These small gaps did not affect results of experiments.

B. Cosmic ray data

Daily, pressure corrected data of the hadronic component of the CRI obtained from the Neutron Monitor Station of the University of Athens (Super 6NM-64) were used. This station is located at altitude of 260 m above the sea level and detects particles with a cut – off rigidity of 8.53 GV. It has been operational since November 2000 providing high quality real-time cosmic ray data (http://cosray.phys.uoa.gr). These data have time resolution of 1 hour, 1 min and 1 sec and are considered as unique ones in the world [34], [35]. Athens Station is unique in the Balkan and Caspian Sea Area as well as the east part of the Mediterranean Sea. It is among the first stations (4th) in the worldwide Neutron Monitor Network providing real time data to Internet. The statistical error is smaller than 0.3 % on hourly data.

C. Geomagnetic activity data

The geomagnetic Dst-index data from the World Data Center for Geomagnetism, Kyoto (http://swdcwww.kugi.kyoto-u.ac.jp/) were used in this study for the considered period. GMA was divided into five levels (I0, I, II, III, IV) according to the average daily Dst-index values as shown in Table I. This table also presents the number of HR measurements for each GMA level. Level "I0" (very low GMA, positive values for Dst-index) was introduced because for the time period under study there were quite many days with very low GMA levels. Inclusion of these very low levels of GMA in our study is also based on the aforementioned results that very weak fluctuations or almost the lack of fluctuations in GMF also can have adverse effects on the human health state. The only major space weather event was recorded on 15 December 2006 when Dst-index had a value of -99 nT and the CRI decrease, as recorded in Athens, was approximately -5% [21].

Similar separation/gradation (I0, I, II, III, IV) is shown in Table II for Ap-index, which data were handled from the Space Weather Prediction Center at NOAA, Boulder, US (http://www.swpc.noaa.gov/ftpmenu/indices/old_indices.html).

TABLE I
DST-INDEX LEVELS AND THE NUMBER OF MEASUREMENTS OF CARDIOLOGIC PARAMETERS

Dst levels	I0	I	II	III	IV
Dst-index, nT	Dst ≥ 0	0<Dst<-20	-20 ≤ Dst<-50	100≤ Dst<-50	Dst<-100
Number of Measureme	494	966	208	5	0

TABLE II
AP-INDEX LEVELS AND THE NUMBER OF MEASUREMENTS OF CARDIOLOGIC PARAMETERS

Ap-index levels	I0	I	II	III	IV
Ap-index values	Ap<8	8 ≤ Ap<15	15 ≤ Ap<30	30 ≤ Ap<50	Ap ≥ 50
Number of Measureme	986	409	248	21	9

D. *Statistical methods*

The statistical method *ANalysis Of Variance* - ANOVA (statistical package STATISTICA, ver.6, StatSoft Inc., 2001), was applied to establish the statistical significance levels (*p*) of the effect of GMA and CRI variations on the HR (for the whole group and for each person in this group).

The effect of GMA and CRI variations up to three days before and after the respective events (the main phase of geomagnetic storms and CRI decreases and increases) on the examined parameter HR was investigated by the method of superimposed epochs and also by the help of ANOVA.

Significance levels (*p* – values) were calculated for the days before (-), during (0) and after (+) geomagnetic storms and CRI variations. The chosen level for statistical significance in the used data analysis software system STATISTICA is set to $p<0.05$ and the same value is used for interpreting the results.

3. RESULTS AND DISCUSSION

The time period under study is characterized mainly by low GMA levels and one important space weather event on 15 December 2006 (Fig. 1), nevertheless it is quite interesting to investigate how HR dynamics could be influenced by different (high and low level) variations in GMA and CRI.

ANOVA was used for obtaining the significance levels (*p-values)* of the effect of GMA level and the percentage of CRI variations on the HR for each person in the group separately and for the whole group (collective effect) for the days before (-), during (0) and after (+) geomagnetic storms and CRI variations. Table III shows *p*-values for CRI effect on HR for each examined person (p1-p7) and for the whole group.

Fig. 2a shows HR variations of one person (p4) of the group in relation to Ap-index levels (as they were gradated in Table II). Fig. 2b and 2c show HR variations for the same person under environmental physical activity, estimated by the Dst-index levels and CRI variations, respectively. Results show that high GMA levels (GMA increase, i.e. Ap-index values increase and Dst-index values decrease) and CRI decrease are associated to HR increase.

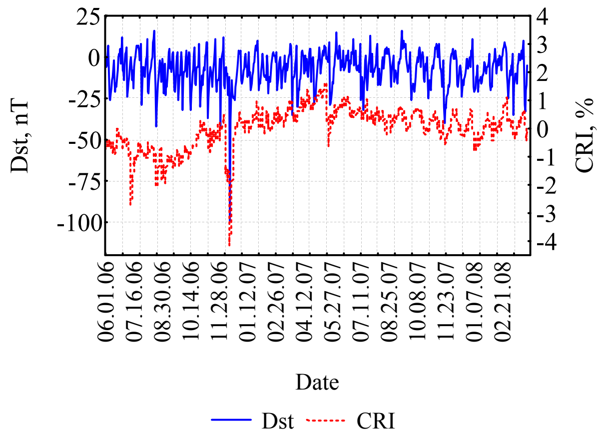

Fig. 1. Daily CRI (%) and Dst-index (nT) variations during experiments period from 15 July 2006 to 31 March 2008.

TABLE III
SIGNIFICANCE LEVELS (*P*-VALUES) OF CRI EFFECT ON HEART RATE (HR) FOR THE DAYS BEFORE (+), DURING (0) AND AFTER (-) CRI VARIATIONS (RESULTS MARKED WITH <*> ARE STATISTICALLY SIGNIFICANT; P1-P7 DENOTE THE PERSONS IN THE GROUP)

Day	p – values							
	HR group	**HRp_1**	**HRp_2**	**HRp_3**	**HRp_4**	**HRp_5**	**HRp_6**	**HRp_7**
-3	0.683	0.041*	0.456	0.513	0.0003*	0.386	0.833	0.600
-2	0.592	0.024*	0.461	0.297	0.0002*	0.512	0.339	0.034*
-1	0.952	0.219	0.302	0.106	0.003*	0.197	0.889	0.054
0	0.362	0.043*	0.627	0.041*	0.0003*	0.660	0.155	0.250
+1	0.700	0.111	0.714	0.002 *	0.00007*	0.712	0.149	0.045*
+2	0.411	0.054	0.308	0.112	0.00012*	0.074	0.048*	0.177
+3	0.692	0.165	0.339	0.072	0.0002*	0.455	0.029*	0.288

HR variations for the whole group on the days before (-), during (0) and after (+) geomagnetic storms with different intensities are shown in Fig. 3a (estimated by Ap-index), Fig. 3b (Dst-index) and Fig. 3c (CRI variations). It appears that HR varies significantly for increased GMA: levels III and IV for Ap-index classification and levels II and especially III according to Dst-index classification as well as for the largest CRI decreases (from -4% to -2%), which were registered during the considered time period.

Regarding the two highest GMA levels (III and IV), described by the Ap-index, HR started increasing 3 days before geomagnetic storms, having the highest values for level III from -2nd to 0 day and slowly returned to its basic values. Meanwhile, being increased on the day before the event, denoted as level IV, HR decreased to its basic values on 0 and +1st day and obtained peak values on +2nd and +3rd days (Fig. 3a).

Concerning the Dst-index for level II, there was again HR increment from -3rd to 0 day and, after that, recovering of the values. For IV level, there were peak increments on some of the days under consideration (-3rd, -1st, +1st and +3rd day) (Fig. 3b).

It is evident from Fig. 3c that HR of the group had peak values on the days before (-3, -2, -1), during (0) and after (+1, +2, +3) CRI decreases from -2% to -4%.

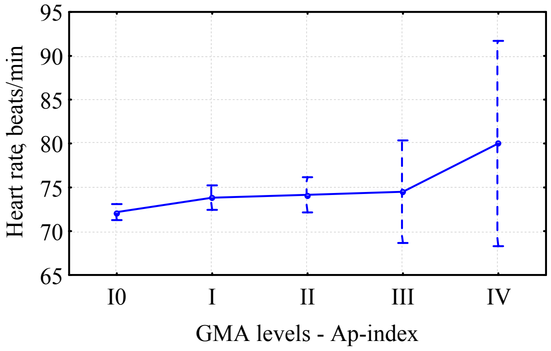

Fig. 2a. Effect of GMA (estimated by Ap-index) on heart rate (±95% CI) for the person p4 in the group.

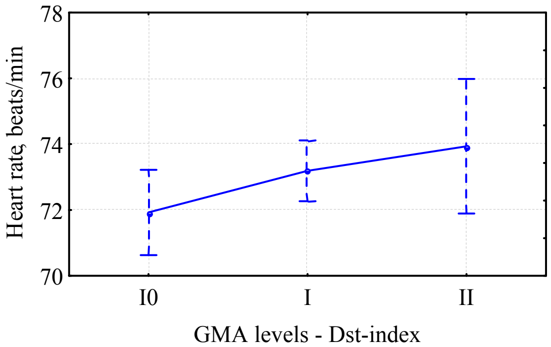

Fig. 2b. Effect of GMA (estimated by Dst-index) on heart rate (±95% CI), for the person p4 in the group.

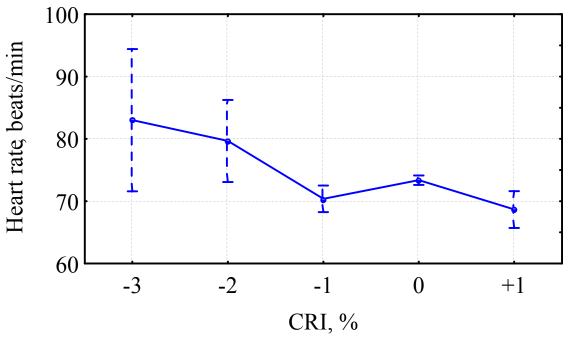

Fig. 2c. CRI effect on heart rate (±95% CI) for the person p4 in the group.

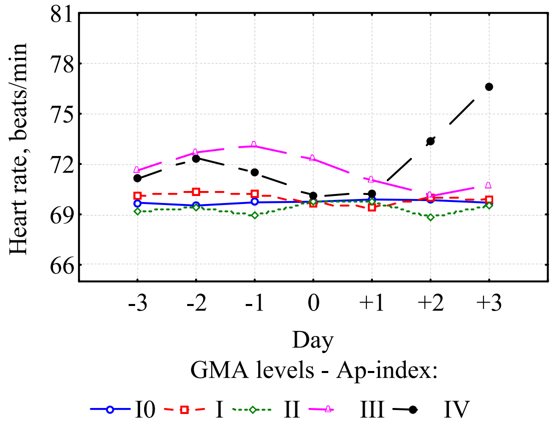

Fig. 3a. Effect of GMA (estimated by Ap-index) on heart rate for the whole group before (-), during (0) and after (+) geomagnetic storms.

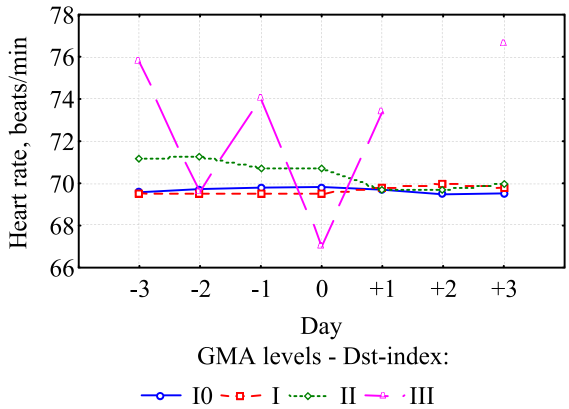

Fig. 3b. Effect of GMA (estimated by Dst-index) on heart rate for the whole group before (-), during (0) and after (+) geomagnetic storms.

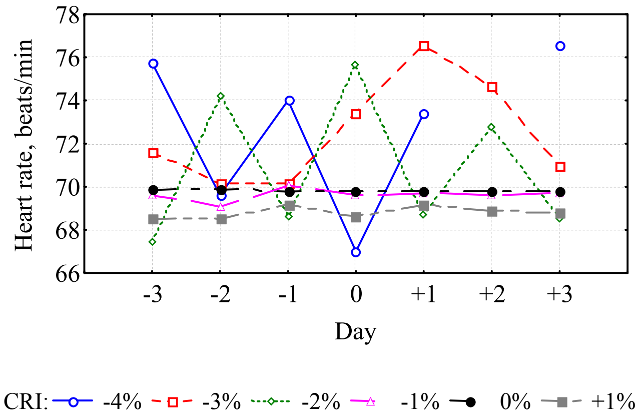

Fig. 3c. CRI effect on heart rate for the whole group before (-), during (0) and after (+) CRI variations.

Figures 4a, 4b, 5a and 5b show HR variations before (-), during (0) and after (+) geomagnetic disturbances with different intensities and CRI variations but refer to different individuals of the group. It was revealed that HR of different persons had peak increments on some of the days before, during and after days with high GMA and CRI decreases (more than -2%).

The most interesting and common result of our study is that HR variations appear to be connected to geomagnetic disturbances and CRI variations. The effects of HR increase are more pronounced for high levels of GMA (especially when geomagnetic storms occur) and large CRI decreases. However, researches of this sensitive subject must be continued on regional and global scales.

Changes in the GMA level are related to fluctuations in solar activity and conditions in the interplanetary and near-Earth space and are involved in climate regulation and various animal and human behaviors. The biological effects of GMF have emerged in recent years as an important factor. A number of studies have shown that the GMF has a major influence on the orientation of migratory birds and other vertebrates, protein synthesis and branching in plants and human physical and mental states. Various animals utilize the GMF for migrational and direction-finding purposes with precision along definite geographical routes. Many living organisms (e.g. various bacteria, homing pigeons, skates, honey-bees, probably sharks, rays, etc.) have been reported to have the ability to detect small fluctuations in the GMF and react to the Earth's magnetic field and its variations [36], [37].

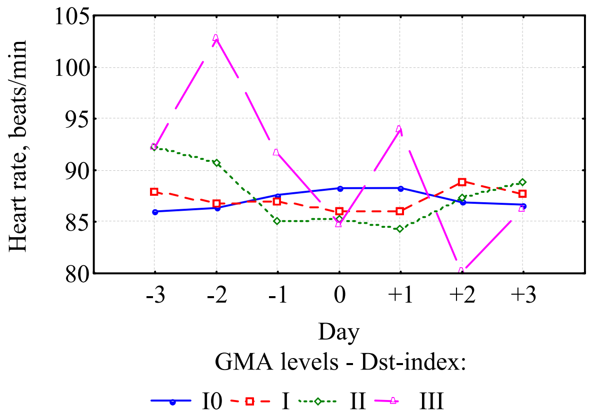

Fig. 4a. Effect of GMA (estimated by Dst-index) on heart rate before (-), during (0) and after (+) geomagnetic storms for the person p1 in the group.

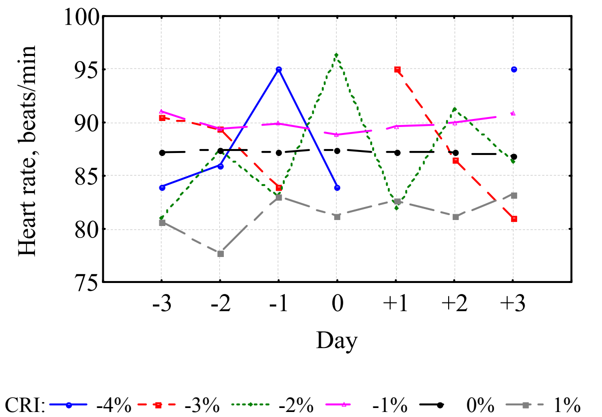

Fig. 4b. CRI effect on heart rate before (-), during (0) and after (+) CRI variations for the person p1 in the group.

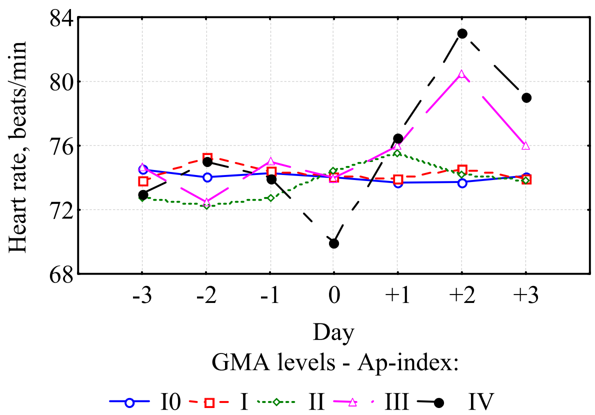

Fig. 5a. Effect of GMA (estimated by Ap-index) on heart rate before (-), during (0) and after (+) geomagnetic storms for the person p6 in the group.

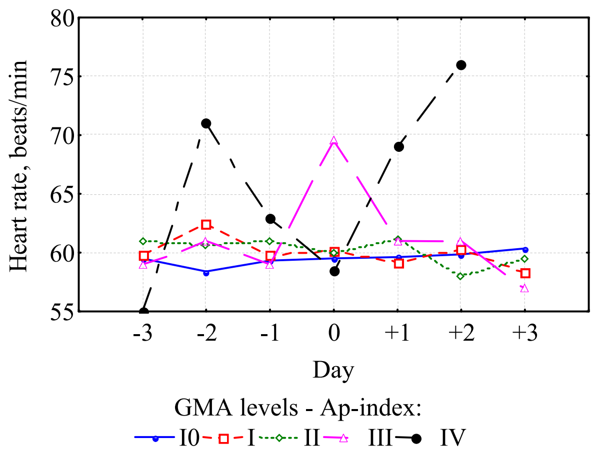

Fig. 5b. Effect of GMA (estimated by Ap-index) on heart rate before (-), during (0) and after (+) geomagnetic storms for the person p7 in the group.

What becomes clear in all these studies is that the living beings, including man, have adapted to normal variations in GMA [34]. But, any deviations from this normal level, either extremely high or low level fluctuations in GMA, will undoubtedly affect biological systems through their brain, cardio-vascular, nervous and other systems.

The human heart has an autonomous rhythm of activity but variations of the HR can be changed and adjusted to variations of external factors such as ionization, temperature and pressure of the environment and the GMF which, through the autonomous nervous system, influence the nervous and muscular strings and can alter the amplitude of HR frequency.

4. CONCLUSIONS

This paper is an outcome of collaboration of three different research groups, and focuses on the possible relation between geomagnetic activity and cosmic ray intensity changes, and human cardio-health state through measured parameters in middle latitudes. CRI decreases, like those during the big event recorded in December 2006, together with Ap- and Dst-indices variations, has been analysed in regard to HR variations. This study shows that human beings' heart rate dynamics can be affected by space weather changes like variations in geomagnetic activity and cosmic ray intensity.

Results have revealed that heart rate increased with geomagnetic activity increase and accompanied cosmic ray intensity decrease.

Heart rate increased on the days before, during and after geomagnetic storms with high intensities and on the days preceding and following cosmic ray intensity decreases.

Further studies should be performed at different latitudes and longitudes to confirm the obtained results and to clarify biophysical mechanisms of these effects.

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