

The effect of cosmic ray intensity variations and geomagnetic disturbances on the physiological state of aviators

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Abstract. Over the last few years researches have resulted to the wide acceptance from the scientific community that cosmic ray variations and geomagnetic disturbances are related to the condition of the human physiological state. In this study medical data regarding 4018 Slovak aviators were analyzed in relation to daily variations of cosmic ray and geomagnetic activity. Specifically daily data concerning mean values of heart rate which were registered during the medical examinations of the Slovak aviators, were related to daily variations of cosmic ray intensity, as measured by the Neutron Monitor Station on Lomnický štít (<http://neutronmonitor.ta3.sk/realtime.php3>) and the high resolution neutron monitor database (<http://www.nmdb.eu>) and daily variations of Dst and Ap geomagnetic indices. All subjects were men in good health of age 18 – 60 yrs. This particular study refers to the time period from 1 January 1994 till 31 December 2002. Statistical methods were applied to establish a statistical significance of the effect of geomagnetic activity levels and cosmic ray intensity variations on the aforementioned physiological parameters for the whole group. The Pearson r-coefficients were calculated and the Analysis of Variance (ANOVA) method was applied to establish the statistical significance levels (p-values) of the effect of geomagnetic activity and cosmic ray intensity variations on heart rate up to three days before and three days after the respective events. Results show that there is an underlying effect of geomagnetic activity and cosmic ray intensity variations on the cardiovascular functionality.

1 Introduction

Cosmic ray intensity (CRI) and geomagnetic activity (GMA) variations can influence not only the performance and reliability

of space - borne or ground - based technological systems but also human life. Even though the scientific field concerning the responses of the human organism to CRI variations and GMA is relatively new, many interesting studies have been carried out with remarkable results (Cornelissen et al., 2002; Dzvonik et al., 2006; Stoupeľ et al., 2007). These results refer not only to the possible influence of GMA disturbances on the human cardiovascular state through variations of physiological parameters such as heart rate (HR) and arterial diastolic and systolic blood pressure (Dimitrova et al., 2009) but also on the central and vegetative nervous system through changes of the human brain's functional state and the psycho - emotional state (Babayev and Allahverdiyeva, 2007).

Some studies revealed that the most significant effects on myocardial infarctions, brain strokes, and traffic accidents were observed on the days of geomagnetic field disturbances accompanied with Forbush decreases (FDs) (Villoresi et al., 1994, 1995; Ptitsyna et al., 1998) and especially during the declining phase of FD (Villoresi et al., 1994, 1998; Dorman, 2005). At the same time it was shown that very low GMA could affect also adversely human cardio-vascular system (Stoupeľ et al., 2004, 2005, 2006, 2007) and that is why it is suggested that the role of environmental physical factors becoming more active in low GMA, like CR (neutron) activity, should be object of further studies (Stoupeľ, 2006).

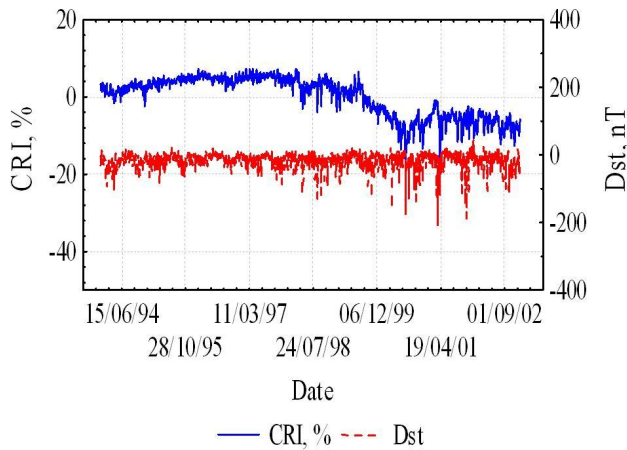
Different human physiological parameters have been used in recent studies in order to determine the relationship between cardio - health state and GMA and CR activity. For example, in Dimitrova et al. (2009) HR appeared to be a rather stable cardiovascular parameter and did not react statistically significantly under geomagnetic changes, whereas a statistically significant increment was revealed for arterial systolic and diastolic blood pressure during increased GMA. On the other hand Villoresi et al. (1995) showed that HR is better related to GMA. Moreover Mavromichalaki et al. (2008) showed that HR increased with GMA increase and the accompanied CRI decrease.



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Table 1. CRI and GMA levels and the corresponding number of days

Ap levels	Ap-index values	Number of days	Dst levels	Dst-index values (nT)	Number of days	CRI levels	CRI, %	Number of days
I0	$Ap < 8$	597	I0	$Dst \geq 0$	178	-3	$-15 \leq CRI \leq -11$	16
I	$8 \leq Ap < 15$	306	I	$-20 < Dst < 0$	640	-2	$-11 < CRI \leq -6$	225
II	$15 \leq Ap < 30$	232	II	$-50 < Dst \leq -20$	340	-1	$-6 < CRI \leq -1$	294
III	$30 \leq Ap < 50$	67	III	$-100 < Dst \leq -50$	55	0	$CRI = 0$	25
IV	$Ap \geq 50$	21	IV	$Dst \leq -100$	10	+1	$1 \leq CRI \leq 4$	261
						+2	$4 < CRI \leq 8$	402

**Fig. 1.** Normalized daily CRI (%) and Dst-index (nT) variations from 1 January 1994 to 31 December 2002.

This study is a result of the collaboration of three different scientific groups, from Athens (Greece), Kosice (Slovakia) and Sofia (Bulgaria). The results that are presented concern mainly the influence that CRI changes and geomagnetic disturbances might have on the human cardio-health state of aviators and specifically on HR variations.

2 Data and method of analysis

The HR measurements used in this study refer to a group of 4018 Slovak aviators and were obtained during their periodical medical checks at ground level. The group consisted only of men (from 18 to 60 yrs old), all in good health. Daily mean values of the group of the examined aviators HR (beats/min) in rest without load (HRR), HR in 1st degree of load (HRFDL - sitting on a stationary bike and pedaling at a power of 50 – 100 W), HR in 2nd degree of load (HRS DL - sitting on a stationary bike and pedaling at a power of 100 – 150 W), maximum HR achieved by load (HRMAX - sitting on a stationary bike and pedaling at maximum power)

were registered. Each HR value represents the mean daily HR value of all the aviators, who were examined during that day. On some days (weekends, holidays, etc) no medical data were available. The total number of the days of measurements is equal to 1223. The data refer to the time period from 1 January 1994 until 31 December 2002.

Pressure corrected daily data of the hadronic component of the CRI were obtained from Lomnický Stit Neutron Monitor (SNM-15) of the Department of Space Physics, Institute of Experimental Physics, Kosice, Slovakia. This station is located 2634 m above sea level and detects particles with a cut-off rigidity of 3.84 GV. It has been operational since December 1981 providing high quality data (archive, current data) through the Internet in digital form (<http://neutronmonitor.ta3.sk/>). The normalization of the CRI data was based on the assumption that the 100% level was reached in September 1986, when the CRI minimum of the previous solar cycle had occurred. CR activity was divided into six levels (-3, -2, -1, 0, +1, +2) according to CRI (Table 1). In this way no further corrections due to long or short term cosmic ray modulation, such as solar cycle variation or FDs which can possibly influence the average HR, were necessary.

The GMA of the days, for which medical data were available, was also analyzed. The geomagnetic index Dst data were obtained from the World Data Centre for Geomagnetism, Kyoto (<http://swdcwww.kugi.kyoto-u.ac.jp/>). Ap-index data were obtained from Space Weather Prediction Centre at NOAA, Boulder, (http://www.swpc.noaa.gov/ftpmenu/indices/old_indices.html). GMA was divided into five levels (I0, I, II, III, IV) according to Dst-index and Ap-index (Table 1).

Cosmic ray intensity and geomagnetic activity variations are not independent. Low CRI is related to strong GMA during FDs, while strong GMA may also weaken the geomagnetic shielding and increase CRI and therefore cause magnetospheric effects (Belov et al., 2005; Chilingarian and Bostanjyan, 2009). CRI and Dst-index variations for the time period under examination are presented in Fig. 1. As it is shown in this figure the strongest decrease of CRI (-15%)

Table 2. Correlation coefficients between GMA and CRI parameters and physiological parameters under examination (Results marked with * are statistically significant)

	Ap	Ap level	Dst	Dst level	CRI, %	CRI level
HRR	-0.0389 p = 0.174	-0.0585* p = 0.041	0.0681* p = 0.017	-0.0591* p = 0.039	0.0325 p = 0.257	0.0288 p = 0.315
HRFDL	-0.0368 p = 0.199	-0.0545 p = 0.057	0.0804* p = 0.005	-0.0695* p = 0.015	0.2480* p = 0.000	0.2470* p = 0.000
HRSDL	-0.0665* p = 0.020	-0.0732* p = 0.011	0.0987* p = 0.001	-0.0959* p = 0.001	0.2324* p = 0.000	0.2343* p = 0.000
HRMAX	-0.0637* p = 0.026	-0.0568* p = 0.047	0.0903* p = 0.002	-0.0721* p = 0.012	0.3140* p = 0.000	0.3245* p = 0.000

was registered on 12 April 2001 when Dst-index had a value of -118 nT.

The statistical method the 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 CRI and GMA levels on HR. The effect of CRI and geomagnetic variations up to three days before and after the respective events (geomagnetic storms development - considering the number of days of the length of the storms and CRI decreases and increases) on the examined parameter HR was also investigated by the help of ANOVA and superimposed epoch method. The p-values were calculated for the days before (-), during (0) and after (+) geomagnetic storms and CRI variations.

3 Results

Heart rate variations have been analyzed in regard to CRI, Ap- and Dst- indices variations. At first the correlation coefficients between GMA and CRI parameters and physiological parameters under examination were calculated and they are presented in Table 2. It is seen that there are significant correlation coefficients although small by value, especially for GMA. It is supposed that the relationship between the examined parameters is nonlinear and that is why furthermore gradation of the factors was applied and the effects were studied by ANOVA.

The ANOVA method of analysis was used for obtaining the significance levels (p-values) of the effect of CRI and GMA level on HR for the days before (-), during (0) and after (+) CRI variations and geomagnetic storms. Table 3 shows p-values for Dst-index and CRI effect on some of the parameters under examination.

Results from ANOVA revealed that high GMA levels (GMA increase, i.e. Ap-index values increase and Dst-index values decrease) and CRI decrease are associated to HR decrease. As it is seen in Figs. 2 and 3 HRR, HRFDL, HRSDL and HRMAX take their minimum value for CR level

Table 3. Significance levels (p-values) of CRI and GMA effect on HR for the days before (-), during (0) and after (+) geomagnetic storms and CRI variations (Results marked with * are statistically significant)

Day	p-values (Dst-index)			p-values (CRI)	
	HRFDL	HRSDL	HRMAX	HRFDL	HRSDL
-3	0.02306*	0.01543*	0.000*	0.000*	0.000*
-2	0.00292*	0.00022*	0.000*	0.000*	0.000*
-1	0.18812	0.16068	0.000*	0.000*	0.000*
0	0.85449	0.94855	0.000*	0.000*	0.000*
+1	0.93407	0.74775	0.000*	0.000*	0.000*
+2	0.65690	0.60194	0.000*	0.000*	0.000*
+3	0.99546	0.82501	0.000*	0.000*	0.000*

-3 (strongest decreases in CRI) as well as for level IV for Dst-index classification (Fig. 4) and Ap-index classification (Fig. 5). Results from ANOVA observed in the figures coincide with the correlation coefficients. It is clearly seen that for the significant and highest correlation coefficients (CRI and HRSDL and HRMAX) there is a gradual decrease of the physiological parameters with the decrease of CRI (Fig. 3). On the opposite, for the smallest correlations as for Ap-index, HRFDL and HRSDL kept almost the same values up to major storms (IV level) however then they sharply decreased, Fig. 5.

HRFDL and HRMAX vary significantly on the days before, during and after increased GMA (levels III and IV according to the Ap-index and Dst-index classification) as it is shown in Figs. 6 and 7 respectively. These parameters have peak values on the days before (-3rd, -2nd, -1st), during (0) and after (+1st, +2nd, +3rd) geomagnetic storms.

HRFDL variations for different levels of GMA (according to the Ap-index classification) are shown in Fig. 6. Important

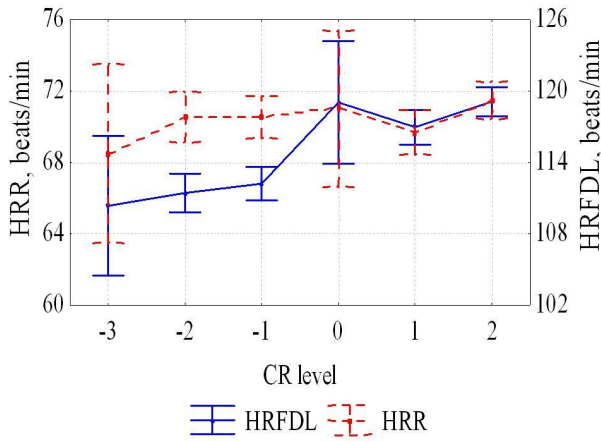


Fig. 2. CRI variations effect on HRR and HRFDL ($\pm 95\%$ CI).

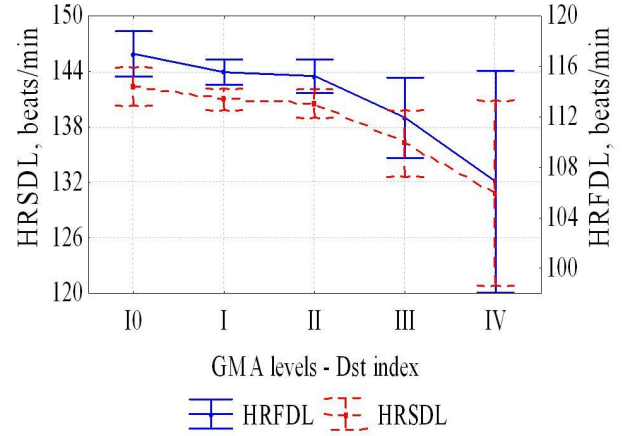


Fig. 4. GMA effect, estimated by Dst-index, on HRSDDL and HRFDL ($\pm 95\%$ CI).

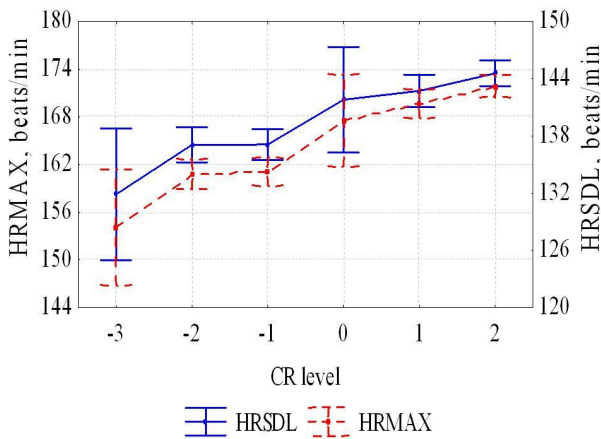


Fig. 3. CRI variations effect on HRMAX and HRSDDL ($pm95\%$ CI).

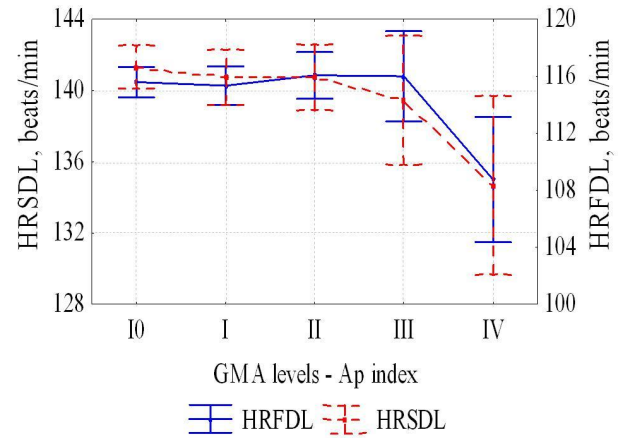


Fig. 5. GMA effect, estimated by Ap-index, on HRSDDL and HRFDL ($\pm 95\%$ CI).

variations were noticed only for levels III and IV of the Ap-index classification. For level IV HRFDL decreased on -1st day before the event and after that increased until +1st day after the event. For level III the increase was from -2nd to +1st day.

HRMAX variations for the different levels of Dst-index classification are shown in Fig. 7. Specifically for level III HRMAX seems to increase from -2nd day before the event until +1st day after the event when the highest value of HRMAX was registered. For level IV of Dst-index classification, HRMAX increases from day -3rd until day -1st before the event. HRMAX keeps almost the same value from day -1st before the event until day +1st after the event.

Values of HRMAX in relation to levels I0, I and II of the Dst-index classification (Fig. 7) are higher in comparison to the values concerning the rest of their respective levels.

4 Conclusions

A series of recent studies prove that solar and geomagnetic conditions may be responsible for a number of responses of the human organism and may be connected to many diseases, mostly cardiovascular diseases and diseases of the nervous system, especially strokes, myocardial infarctions, etc. (Dorman et al., 2001; Stoupel et al., 2007; Dimitrova, 2008; Dimitrova et al., 2009; Papailiou et al., 2009).

This study focuses on the possible relation between GMA and CR activity and human cardiologic parameters. The most interesting result is that HR variations appear to be connected to geomagnetic disturbances and CRI variations. The effects are more interesting for high levels of GMA (when geomagnetic storms occur) and strong CRI decreases. However, because the possible space weather conditions influence on human health is a rather sensitive subject, further research is required.

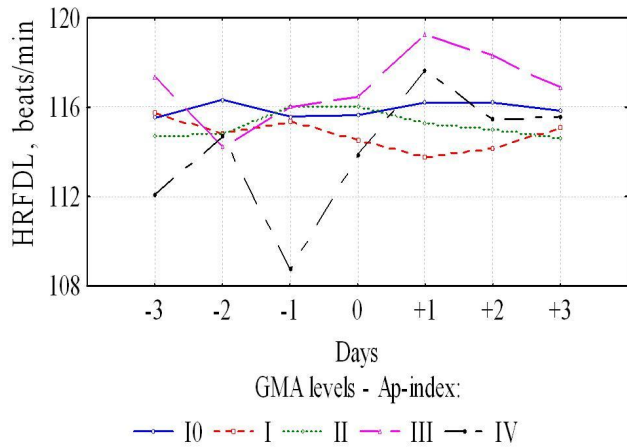


Fig. 6. GMA effect, estimated by Ap-index, on HRFDL before (-), during (0) and after (+) geomagnetic storms.

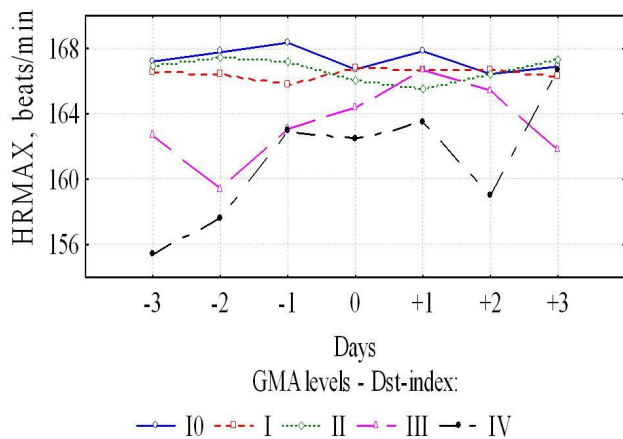


Fig. 7. GMA effect, estimated by Dst-index, on HRMAX before (-), during (0) and after (+) geomagnetic storms.

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