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THE POTENTIAL EFFECT OF COSMIC RAY INTENSITY VARIATIONS ON HUMAN CARDIOVASCULAR FUNCTIONALITY

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It is suggested from a series of studies that have been conducted during the last few years that cosmic ray activity and Forbush decreases in particular can possibly be connected not only with cardiovascular diseases (myocardial infarctions, brain strokes, ischemic heart diseases, etc) but also with variations of human physiological parameters (heart rate, arterial systolic and diastolic blood pressure, etc). In this particular study 1341 measurements concerning mean values of heart rate (beats/min) and arterial diastolic and systolic blood pressure (mmHg), obtained during the medical examinations of a group of Slovak aviators, are related to daily data of cosmic ray intensity, as measured by the Neutron Monitor Station on Lomnicky Stit (http://neutronmonitor.ta3.sk/realtime.php3). The data cover the time period from January 1, 1994 to December 31, 2002, during which strong cosmic ray intensity variations were registered (decreases up to −16 % and increases up to +8 %). For the analysis the statistical method ANalysis Of VAriance (ANOVA) combined with the method of superimposed epochs were used to determine the statistical significance (p-values) of the effect of cosmic ray activity on the aforementioned physiological parameters for the days before, during and after the event. As it is shown strong cosmic ray intensity variations could potentially affect the human cardiovascular state.

INTRODUCTION

The study of cosmic rays is of great importance, since they can provide a tool for exploring and understanding the Universe and its mechanisms, but they can also directly affect the Earth. Moreover, not only the performance and reliability of spaceborne or ground-based technological systems can be influenced during strong cosmic ray intensity (CRI) events but also human life [Dorman et al., 1999, 2001; Stoupel, 2002; Stoupel et al., 2007]. Many studies focus on the influence CRI variations may have on human physiological parameters [Dimitrova, 2008; 2009; Papailiou et al., 2011a; 2012; Mavromichalaki et al., 2012].

Specifically it is shown in [Dorman et al., 1999, 2001] that Forbush decreases are the most sensitive indicators of the relationship between geomagnetic disturbances and health parameters like the number of incidences of ischemic and brain strokes, myocardial infarctions and traffic accidents. Moreover [Dorman et al., 2001] mention that cardiovascular diseases are affected by space weather long-term (solar activity) but also short-term (Forbush decreases) parameters.

Another study by [Stoupel et al., 2007] focuses on the potential correlation between the number of acute myocardial infarctions and cosmic ray activity. This particular study was conducted in the Baku area using acute myocardial infarctions data from 21 first-aid stations during the years 2003– 2005. It is concluded that higher cosmic ray activity is predominant for acute myocardial infarction occurrence and pre-admission mortality.

In a study by [Styra et al., 2005] predictive correlation between hard cosmic ray flux near the Earth's surface and sudden increases in the number of cases of cardio-

vascular disease was studied in Vilnius city. Hard cosmic ray flux fluctuations were used as an indirect indicator of variations in the geomagnetic field, and a leap in cardiovascular disease cases was predicted 1–3 days following a change in the hard cosmic ray flux according to two criteria mentioned in the aforementioned paper. The predictive reliability of an increase in cardiovascular disease cases within 2–3 days exceeded 80 %, and within 1–2 days 70 %. Moreover [Styra et al., 2009] showed that the highest prognostic correlation between hard cosmic ray flux decrease and cardiovascular disease leaps within 1–2 days was from 64 to 76 %, the correlation within 2–3 days was lower and the correlation between atmospheric pressure decrease and leaps of cardiovascular disease in 1–2 days and on the same day was 25–44 %.

Furthermore in [Dimitrova, 2008, 2009] a group of 86 volunteers was examined during periods of maximum solar and geomagnetic activity. Results revealed that CRI decrease was associated to mean arterial systolic and diastolic blood pressure, pulse pressure and subjective psycho–physiological complaints increase [Dimitrova, 2009]. Moreover no significant changes were established in the heart rate of the examined persons under different cosmic rays intensities [Dimitrova, 2009].

On the other hand in the work by [Mavromichalaki et al., 2012] 1673 daily digital data of heart rate values and time series of beat-to-beat heart rate intervals (RR intervals), concerning functionally healthy persons, were registered for the time period from July 15, 2006 until March 31, 2008 and were studied in relation to different levels of cosmic ray activity. Results revealed heart rate increase and RR intervals variations were more pronounced for large CRI decreases, whereas very small or even minimum CRI variations did not affect heart rate dynamics.

This particular work is the outcome of a wide collaboration between three scientific groups from Athens (Greece), Kosice (Slovakia) and Sofia (Bulgaria). An attempt is made to study the potential effects of CRI variations on the human physiological state through the variations of physiological parameters such as heart rate, arterial systolic pressure and arterial diastolic pressure. Some preliminary results regarding heart rate parameters were discussed in [Papailiou et al., 2011b]. An extended version of the database and more thorough analyses were performed and more accurate results are presented in this article.

1. DATA AND METHODS

1.1. Medical data

The heart rate (HR), arterial systolic (SP) and diastolic (DP) blood pressure measurements refer to a group of 4018 Slovak aviators and were taken during their periodical medical checks at ground level. In total 1341 measurements, which refer to the time period from January 1, 1994 until December 31, 2002, were analyzed. The group consisted only of men of age from 18 to 60 years, all in good health. Daily mean values of the group for HR (beats/min) and SP and DP (mmHg) were registered. More specifically the measured parameters were as follows:

- HR, SP and DP in rest without load (HRR, SPR, DPR);
- HR, SP and DP in 1st degree of load (HRFDL, SPFDL, DPFDL — sitting on a stationary bike and pedaling at a power of 50...100 W);
- HR, SP and DP in 2nd degree of load (HRSDL, SPSDL, DPSDL — sitting on a stationary bike and pedalling at a power of 100...150 W);
- maximum HR, SP and DP achieved by load (HRMAX, SPMAX, DPMAX — sitting on a stationary bike and pedalling at maximum power).

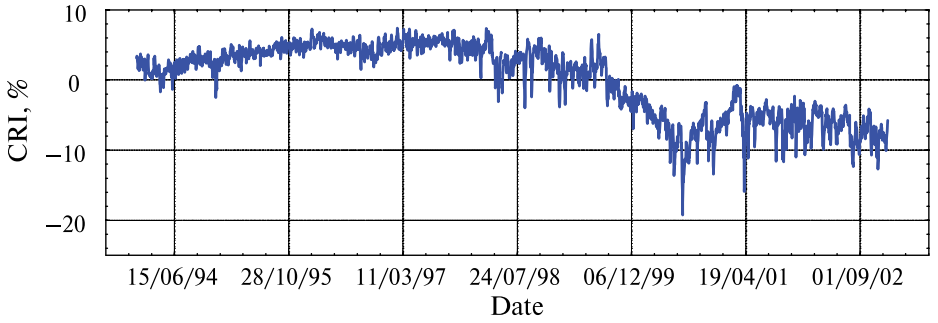

Figure 1. Normalized daily CRI (%) variations during experiments period from January 1, 1994 to December 31, 2002

1.2. Cosmic ray data

Pressure corrected daily data of the hadronic component of the CRI were obtained from Lomnický Štít Neutron Monitor (SNM-15) of the Department of Space Physics, Institute of Experimental Physics, Košice, 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/). Cosmic ray activity was divided into six levels (−3, −2, −1, 0, +1, +2) according to CRI [Papailiou et al., 2012].

CRI variations for the time period under examination are shown in Figure 1. The largest decrease (−16 %) was registered on April 12, 2001. The normalized CRI variations were calculated using the relation $(I_i - I_{mean})/I_{mean}$, where I_i is the hourly CRI and I_{mean} is the average CRI for the time period under consideration.

1.3. Statistical method

The statistical method *ANalysis Of VAriance* (ANOVA), (statistical package STATISTICA (ver.6, StatSoft Inc., 2001), was applied to establish statistical significance levels (p) of the effect of CRI variations on the HR, SP and DP. The effect of CRI variations up to three days before and after the respective events (CRI decreases and increases) on the examined parameters was also investigated by the help of ANOVA and superimposed epoch method. p-values were calculated for the days before (−), during (0) and after (+) these events.

2. RESULTS

Heart rate and arterial blood pressure variations have been analysed in regard to CRI variations. ANOVA was used for obtaining the significance levels (p-values) of the effect of the percentage of CRI variations on the HR, SP and DP parameters. p-values were calculated for the days before (−), during (0) and after (+) CRI variations. In table, p-values for CRI effect on those of the parameters for which significant effects on some of the days around the events were established are shown.

Statistically significant results concern all HR parameters for the days before, during and after CRI variations, apart from HRR. The last parameter changed significantly only on days 0 and $+1^{st}$. For SP parameters only SPFDL was statistically significantly affected by CRI variations on all of the days before, during and after the event while SPMAX was affected only during and before the event (days 0, -1^{st} and -3^{rd}). Furthermore for DP parameters statistically significant results were obtained only for DPSDL (except on day 0) and DPFDL (only on day 0).

Significance levels (p-values) of CRI effect on the physiological parameters under study for the days before (−), during (0) and after (+) CRI variations (results marked with <*> are statistically significant)

Day	*p*-values (CRI)							
	HRR	**HRMAX**	**HRFDL**	**HRSDL**	**SPMAX**	**SPFDL**	**DPFDL**	**DPSDL**
−3	0.55187	0.0000*	0.0000*	0.0000*	0.02550*	0.00385*	0.42203	0.00196*
−2	0.19592	0.0000*	0.0000*	0.0000*	0.09411	0.01305*	0.44713	0.00633*
−1	0.13180	0.0000*	0.0000*	0.0000*	0.00166*	0.00385*	0.34159	0.00907*
0	0.01508*	0.0000*	0.0000*	0.0000*	0.04547*	0.00326*	0.00183*	0.11839
+1	0.02587*	0.0000*	0.0000*	0.0000*	0.23876	0.00602*	0.12549	0.00073*
+2	0.19773	0.0000*	0.0000*	0.0000*	0.23215	0.00559*	0.33813	0.00197*
+3	0.11558	0.0000*	0.0000*	0.0000*	0.05270	0.00421*	0.39805	0.01767*

Variations of the human physiological parameters under examination in relation to different CRI levels are shown in Figures 2. Statistical significant (see table) decrease of parameters HRFDL, HRSDL (Figure 2*c*) and HRMAX for strong CRI decreases (levels −2 and −3 of the CRI classification) is registered. Similar behavior is noticed for parameters SPR, SPMAX as for SPFDL and SPSDL (Figure 2*a*), which take their minimum values for CRI level −3. However, for DP parameters (Figure 2*b*) the maximum value is obtained for level −3, during strong CRI events [Papailiou et al., 2012].

The dynamic of SPFDL, DPR and HRFDL in dependence of CRI classification on the days preceding, during and following the events is shown in Figures 3 respectively. Physiological parameters' changes are more pronounced mostly for level −3 of the CRI classification. For strong CRI decreases, level −3, SPFDL decreased from -2^{nd} day until day 0 (minimum value) and increased from there on until $+3^{rd}$ day after the event (Figure 3*a*). As it is seen in Figure 3*b*, DPR values decreased on -2^{nd} and -1^{st} days before the strongest registered CRI event and increased from there on until $+3^{rd}$ day after the event [Papailiou et al., 2012]. HRFDL decreased from -1^{st} day until day 0 and increased from there on until day $+2^{nd}$ after the event (Figure 3*c*).

CONCLUSIONS

The potential relation between human health state and space weather parameters is a subject that has been widely investigated [Cornelissen et al., 2002; Stoupel, 2006; Babayev, Allahverdiyeva, 2007; Dimitrova, 2009].

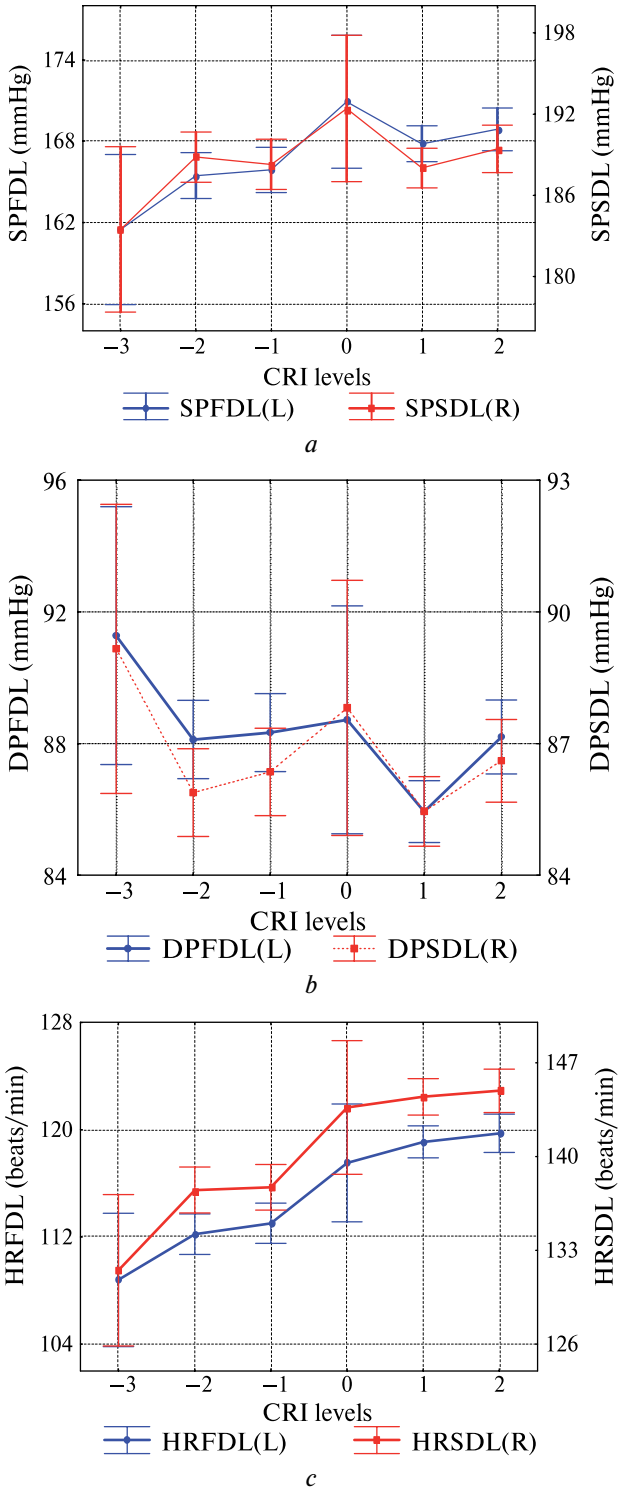

Figure 2. CRI variations effect (day 0) (±95 % CI): *a* — SPFDL and SPSDL; *b* — DPFDL and DPSDL; *c* — HRFDL and HRSDL

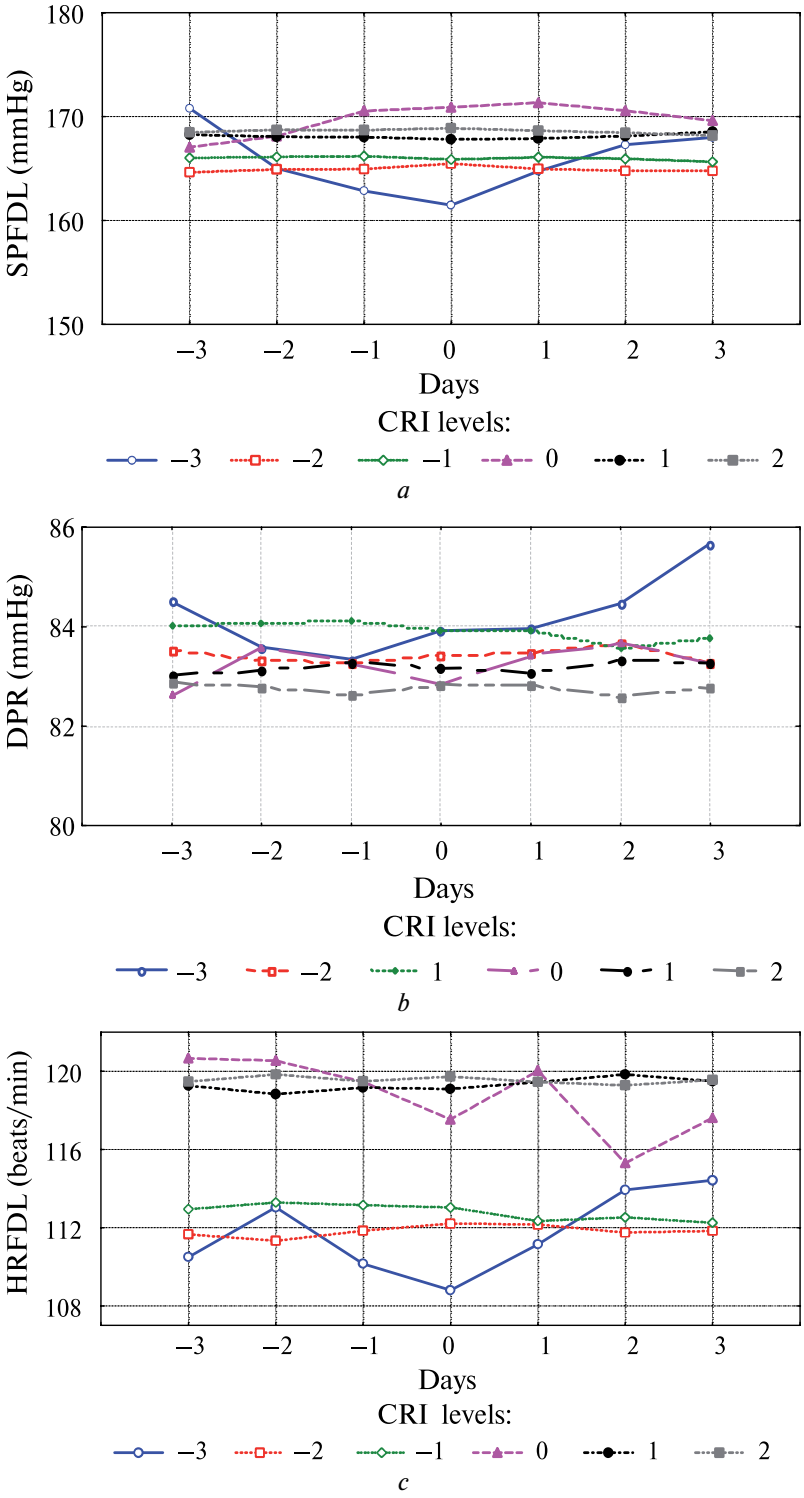

Figure 3. CRI effect before (−), during (0) and after (+) the corresponding variations: *a* — SPFDL; *b* — DPR; *c* — HRFDL

Many studies focus mainly on the influence cosmic ray activity may have on the human physiological state [Stoupel et al., 2007; Papailiou et al., 2009; Mavromichalaki et al., 2012] since cosmic ray activity could be considered as one of the regulating external/environmental factors in human homeostasis [Stoupel et al., 2006].

This study focuses on the possible relation between cosmic ray activity and human cardiologic parameters. Heart rate and arterial systolic and diastolic blood pressure have been analysed in regard to CRI variations. The most interesting results of this study are the following:

1. Strong CRI decreases (levels −2 and −3 of the CRI classification) are associated to HR and SP decrease. DP parameters take their maximum value for level −3 of the CRI classification.
2. HR, SP and DP vary significantly on the days before (−), during (0) and after (+) CRI decreases (levels −3, −2, −1 according to the CRI classification).
3. For level −3 of the CRI classification a decrease of HR, SP and DP parameters, noticed on the days before and/or during CRI decreases, is usually followed by an increase on the days after CRI decreases.
4. The effects are more pronounced for the cardiologic parameters registered under some load.

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ВОЗМОЖНОЕ ВЛИЯНИЕ ВАРИАЦИЙ ИНТЕНСИВНОСТИ КОСМИЧЕСКИХ ЛУЧЕЙ НА СЕРДЕЧНО-СОСУДИСТЫЕ ПОКАЗАТЕЛИ ЧЕЛОВЕКА

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На основании исследований, проведённых в течение последних нескольких лет, предполагается, что активность космических лучей и форбуш-эффект в частности могут быть связаны не только с сердечно-сосудистыми заболеваниями (инфарктом миокарда, инсультом мозга, ишемической болезнью сердца и т. д.), но и с вариациями

физиологических параметров человека (частотой сердечных сокращений, систолическим и диастолическим артериальным давлением и т. д.).

В данном исследовании 1341 измерение средних значений частоты сердечных сокращений (уд./мин) и диастолического и систолического артериального давления (мм рт. ст.), полученное в ходе медицинского обследования группы словацких авиаторов, сопоставлялось с ежедневными данными об интенсивности космических лучей, измеряемых нейтронным монитором на станции Ломницкий Штит (http://neutronmonitor.ta3.sk/realtime.php3). Данные охватывают период с 1 января 1994 г. по 31 декабря 2002 г., в течение которого были зарегистрированы сильные вариации интенсивности космических лучей (уменьшения до 16 % и возрастания до +8 %).

Использовались статистические методы анализа вариаций (ANOVA) в сочетании с методом наложенных эпох для определения статистической значимости (*p*-значения) влияния космических лучей на вышеупомянутые физиологические параметры за один день до, во время и после событий. Как очевидно, сильные вариации интенсивности космических лучей потенциально могут влиять на сердечно-сосудистую систему человека