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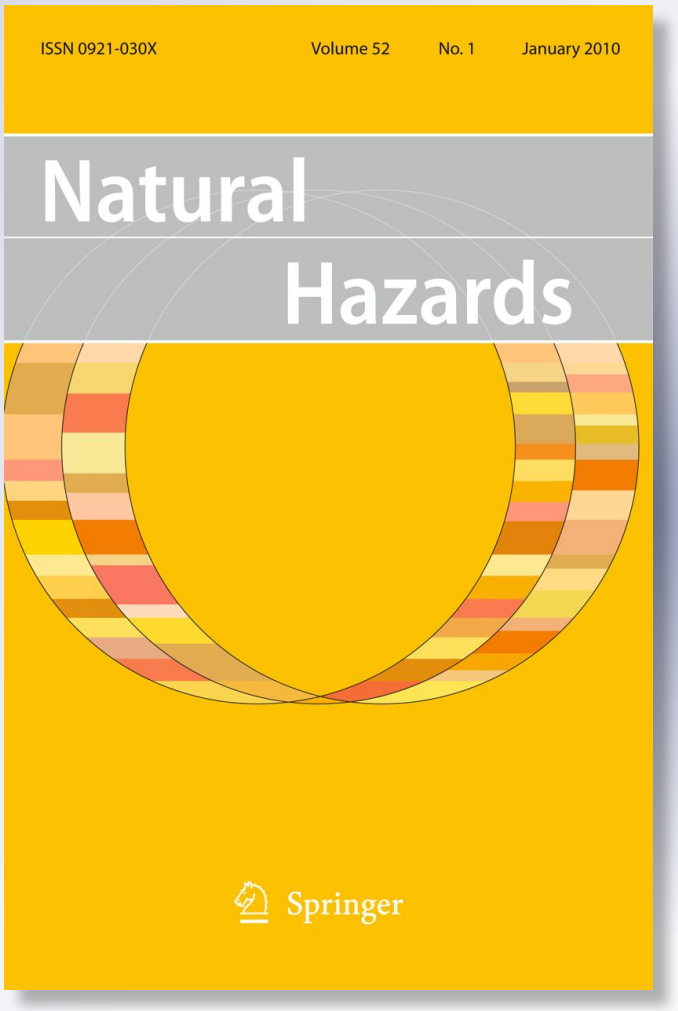

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ORIGINAL PAPER

Cosmic radiation influence on the physiological state of aviators

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Abstract Aviation personnel exposure to cosmic radiation and its biological effects has been an interesting subject for research over the last decade. In this study, scientific groups from Greece, Slovakia, and Bulgaria collaborated in order to examine the potential effects of cosmic radiation on the cardiovascular functionality of a group of Slovak aviators. Specifically, daily data concerning mean values of arterial diastolic and systolic blood pressure, which were registered during the medical examinations of the group of aviators, were related to daily variations of cosmic ray intensity, as measured by the Neutron Monitor Station on Lomnicky Stit. Statistical methods (analysis of variance—ANOVA and method of superimposed epochs) were applied in order to establish a statistical significance (p-values) of the effect of cosmic ray intensity variations on the aforementioned physiological parameters not only on the days of the events but also on the days preceding and following these events. Results reveal that diastolic and systolic blood pressure can be influenced by changes in cosmic ray activity.

Keywords Cosmic ray intensity · Cosmic ray decreases · Heart rate · Blood pressure

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1 Introduction

Cosmic rays are high energy particles (protons, α particles, and other heavier nuclei) that come from either the galactic or extragalactic area. According to its origin, cosmic radiation is divided to galactic cosmic rays and solar cosmic rays. Galactic cosmic rays come in permanently even though their intensity is modulated by solar activity. Solar cosmic rays, which consist of particles accelerated at the Sun, are more sporadic and are handled as individual events, on top of the usual particle flux from the remote Universe.

Once cosmic rays enter the upper atmosphere and before hitting the ground, they collide with atoms creating the secondary cosmic rays (protons, neutrons, muons, and electrons) that can be detected by ground-based particle counters. A large worldwide network of ground-based counters (neutron monitors) is used for measuring the neutron component (http://www.nmdb.eu).

To make a 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 space-borne or ground-based technological systems can be influenced during strong cosmic ray intensity (CRI) events but also human life. A recent review on the subject can be found, e.g., in paper (Singh et al. 2011).

The effect that CRI variations and geomagnetic activity (GMA) may have on the functionality of the human organism was already known a long time ago (Villoresi et al. 1994a, b; Ptitsyna et al. 1996, 1998; Dorman et al. 1999), but over the last years, many interesting studies have been carried out with remarkable results (Cornelissen et al. 2002; Dzvoník et al. 2006; Stoupel et al. 2007a, b; Dimitrova et al. 2009; Mavromichalaki et al. 2009; Papailiou et al. 2009).

Although the anticorrelation between the CRI and solar activity is very well known, and indications about solar activity and connected geomagnetic activity in the aspect of health are widely discussed in literature (e.g., recently by Mendoza and Sánchez de la Pena 2010; Diaz-Sandoval et al. 2011), there is some motivation to study the possible relationships between the CRI at Earth and health parameters too, namely due to the facts that (1) cross-correlation between cosmic ray time series and solar activity has extremum not exactly in time lag 0 and it is changing over long time periods (e.g., Usoskin et al. 2001 among others), and (2) Forbush decreases are not "one to one" with the Dst strong depression (e.g., Kudela and Brenkus 2004; Kane 2010).

Dorman et al. (1999) have shown that Forbush decreases (FDs) 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 infractions, and traffic accidents. Dorman et al. (2001) and Stoupel (2002) have shown that cardiovascular diseases are affected by space weather long-term (solar activity) but also short-term (FDs) parameters.

According to Stoupel et al. (2007a), the number of acute myocardial infarctions is correlated with cosmic ray activity. This was a result of a study conducted in the Baku area using acute myocardial infarctions data from 21 first aid stations during the years 2003–2005. Moreover, higher cosmic ray activity is predominant for acute myocardial infarction occurrence and pre-admission mortality (Stoupel et al. 2007a).

Another study concerning the monthly deaths distribution in a period of 192 months in the Republic of Lithuania in relation to solar, geomagnetic, and cosmic ray activity is the topic studied in Stoupel et al. (2007b). It is shown that cosmic ray activity is significantly correlated with monthly deaths number (total, stroke, non cardiovascular, and suicides) and

inversely correlated with monthly number of traffic accidents and is also related to monthly deaths' distribution.

This study is a result of a wide collaboration between three different scientific groups from Athens (Greece), Kosice (Slovakia), and Sofia (Bulgaria). The results that are being presented concern the potential influence CRI variations may have on the human physiological state through the variations of physiological parameters such as arterial systolic pressure (SP) and arterial diastolic pressure (DP).

2 Data and method

2.1 Cosmic ray data

Pressure corrected daily data of CRI were obtained from Lomnicky Stit Neutron Monitor (SNM-15) of the Department of Space Physics, Institute of Experimental Physics, Kosice, Slovakia (http://neutronmonitor.ta3.sk/realtime.php3). This station is located at 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/). CRI variations for the time period under examination are shown in Fig. 1. The largest decrease (−16%) was registered on April 12, 2001. The normalized CRI variations were calculated using the relation $\frac{I_i - I_{mean}}{I_{mean}}$, where I_i is the hourly CRI and I_{mean} is the average CRI for the time period under consideration. 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 DP and SP, were necessary. Cosmic ray activity was divided into six levels (−3, −2, −1, 0, +1, and +2) according to CRI (Table 1).

2.2 Medical data

The DP and SP measurements used in this study refer to a group of 4018 Slovak aviators and were provided during their periodical medical checks at ground level. The group consisted only of men (from 18 to 60 years old), all in good health state according to the requirements for the aviators stuff. Daily mean values of DP and SP (mmHg) for the group were registered. More specifically, the measured parameters were as follows:

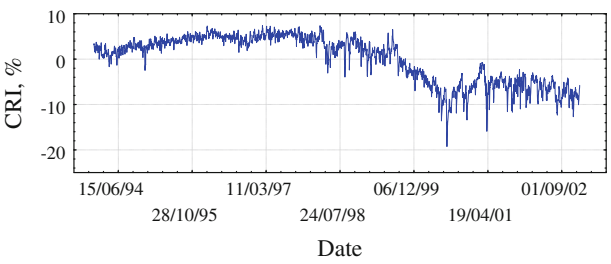

Fig. 1 Normalized daily CRI variations during the experiments period from January 1, 1994 to December 31, 2002

Table 1 CRI levels and the corresponding number of days

CRI levels	CRI (%)	Number of days
−3	$-16 \leq CRI \leq -11$	25
−2	$-11 < CRI \leq -6$	271
−1	$-6 < CRI \leq -1$	273
0	$CRI = 0$	32
1	$1 \leq CRI \leq 4$	435
2	$4 < CRI \leq 8$	305

- DP and SP in rest without load (DPR and SPR);
- DP and SP in 1st degree of load (DPFDL and SPFDL—sitting on a stationary bike and pedaling at a power of 50–100 Watts);
- DP and SP in 2nd degree of load (DPSDL and SPSDL—sitting on a stationary bike and pedaling at a power of 100–150 Watts);
- Maximum DP and SP achieved by load (DPMAX and SPMAX—sitting on a stationary bike and pedaling at maximum power).

Each physiological parameter value represents the mean daily 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 1341. The data refer to the time period from January 1, 1994 until December 31, 2002.

2.3 Statistical method

The statistical method, the *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 DP and SP parameters. The effect of CRI variations up to 3 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. 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

Diastolic pressure and systolic pressure variations have been analyzed 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 DP and SP parameters. p-values were calculated for the days before (−), during (0), and after (+) CRI variations.

Table 2 shows p-values for CRI effect on all the parameters under study. For SP parameters, only SPFDL was statistically significantly affected by CRI variations on all of the days before (−), during (0), and after (+) the event, while SPMAX was affected only during and before the event (days 0, −1st, and −3rd). Furthermore, for DP parameters, statistically significant results were obtained only for DPSDL (except on day 0) and DPFDL (for day 0).

SPFDL and DPFDL variations in relation to CRI levels (as they were gradated in Table 1) are shown in Fig. 2. As it is seen, SPFDL decrease is associated with strong CRI

Table 2 Significance levels (p-values) of CRI effect on the physiological parameters under study for the days before (−), during (0), and after (+) CRI variations

Day	p-values (CRI)							
	SPR	SPMAX	SPFDL	SPSDL	DPR	DPMAX	DPFDL	DPSDL
−3	0.36380	0.02550*	0.00385*	0.63225	0.35838	0.05468	0.42203	0.00196*
−2	0.31961	0.09411	0.01305*	0.86791	0.39709	0.32002	0.44713	0.00633*
−1	0.29558	0.00166*	0.00385*	0.33590	0.28481	0.08942	0.34159	0.00907*
0	0.47034	0.04547*	0.00326*	0.28520	0.58137	0.18252	0.00183*	0.11839
+1	0.52325	0.23876	0.00602*	0.82745	0.53935	0.15069	0.12549	0.00073*
+2	0.69084	0.23215	0.00559*	0.76853	0.38358	0.31278	0.33813	0.00197*
+3	0.62430	0.05270	0.00421*	0.97634	0.27194	0.44875	0.39805	0.01767*

Results marked with <*> are statistically significant

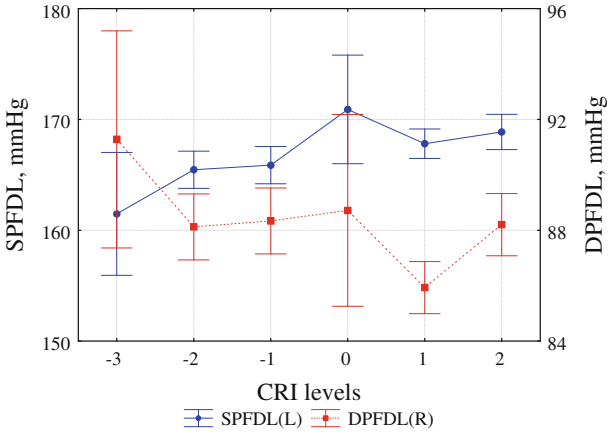

Fig. 2 CRI variations effect on SPFDL and DPFDL (date 0) (±95% CI)

decreases. A similar behavior is also noticed for the rest of the SP parameters under study (SPR, SPMAX, and SPSDL). Their minimum values are noticed for levels −2 and −3 of the CRI gradation. On the other hand, DPFDL maximum value is obtained during strong CRI events (level −3) as it is seen in Fig. 2. The same effect is also noted for DPR, DPMAX, and DPSDL.

DPR and SPFDL vary significantly on the days before (−3rd, −2nd, and −1st), during (0), and after (+1st, +2nd, and +3rd) CRI decreases (levels −3, −2, −1, 0, 1, 2 according to the CRI classification) as it is shown in Figs. 3 and 4, respectively.

Regarding DPR, strong variations were noticed mostly for level −3 (the biggest registered CRI decreases), described by the CRI classification (Fig. 3). DPR decreased on −2nd and −1st days before the CRI event and increased from there on until +3rd day after the event. The same decrease on −2nd day before the event is also noticed for parameters DPMAX, DPFDL, and DPSDL. However, the increase phase for parameters DPMAX and DPFDL is completed on day 0, whereas for DPSDL, the increase lasts until day +2nd (similar to DPR).

The dynamic of SPFDL in dependence of CRI classification for different CRI variations and days is shown in Fig. 4. SPFDL changes are more pronounced mostly for level −3 of

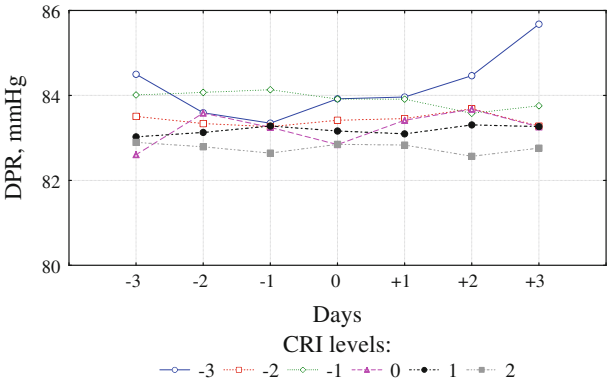

Fig. 3 CRI effect on DPR before (−), during (0), and after (+) the corresponding variations

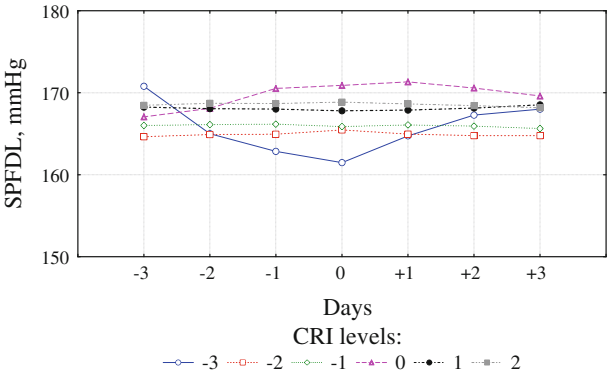

Fig. 4 CRI effect on SPFDL before (−), during (0), and after (+) the corresponding variations

the CRI classification. Minimum value of SPFDL, for level −3 of the CRI classification, was noticed on the day of the event (day 0). This physiological parameter decreased from −2nd day until day 0 and increased from there on until +3rd day after the event. The same behavior is also noticed for SPR, SPSDL, and SPMAX.

4 Discussion and conclusions

The effects of geomagnetic and cosmic ray activity on the SP and DP parameters, for the specific group of aviators, were examined separately since geomagnetic storms and FDs are two phenomena that are connected but could also evolve independently (Kudela and Brenkus 2004; Kane 2010). FDs are created by disturbances in the heliosphere, while Dst variations depend on the local situation in the magnetotail near the Earth (Kane 2010). Usually, high cosmic ray activity (strong decreases in CRI) is related to strong GMA (corresponding Dst depressions); however, as it is already mentioned, CRI decreases are not always accompanied by strong GMA variations and, respectively, large Dst depressions are not marked by CRI decreases (Kudela and Brenkus 2004).

In a previous study by Papailiou et al. (2011b), the results concerning SP and DP behavior during strong geomagnetic storms, for the same group of aviators, were presented. In order to estimate GMA, daily values of the geomagnetic indices Ap and Dst were used and classified into four levels. As it was shown, the SP parameters decreased for high GMA (levels III and IV of the Ap- and Dst-indices classification), which is in agreement with the decrease in these parameters during strong CRI decreases. However, for the DP parameters, results are not so clear since these parameters decrease during high GMA (levels III and IV of the Ap- and Dst-indices classification) but increase during strong CRI decrease (levels -3 and -2 for the CRI classification). Concerning the behavior of SP and DP parameters on the days before, during, and after strong geomagnetic storms and large CRI decreases, a decrease in these parameters on the days before strong events is usually followed by an increase in the days after the events, apart from cases where peak increases and decreases on different days for the same levels of GMA were registered, mostly for DP parameters.

There is an increasing number of studies connecting human health state to space weather parameters (Cornelissen et al. 2002; Stoupel 2006; Babayev and Allahverdiyeva 2007; Dimitrova et al. 2009). A large amount of these investigations focuses mainly on the influence cosmic ray activity may have on the human physiological state (Stoupel et al. 2007a, b; Mavromichalaki et al. 2009; Papailiou et al. 2009, 2011a) since cosmic ray activity could be considered as one of the regulating external/environmental factors in human homeostasis (Stoupel et al. 2006).

The most important results are not only those concerning cardiovascular diseases and diseases of the nervous system, especially strokes, myocardial infarctions, and traffic accidents (Villoresi et al. 1994a, b; Ptitsyna et al. 1996, 1998; Dorman et al. 1999) but also those concerning human physiological parameters variations such as heart rate and arterial systolic and diastolic pressure (Dimitrova 2008; Dimitrova et al. 2009; Papailiou et al. 2011a). More specifically, in Dimitrova (2008), a group of 86 volunteers was examined during periods of high solar and geomagnetic activity. It was shown that CRI decrease was associated with mean arterial systolic and diastolic blood pressure, pulse pressure, and subjective psycho–physiological complaints increase, while in Papailiou et al. (2011a), CRI decrease is associated with heart rate decrease.

Stoupel et al. (2005) have shown that the monthly number of acute myocardial infractions is significantly related to cosmic ray (positive correlation) and solar and geomagnetic (negative correlation) activity. Moreover, the sudden cardiac death mortality has also been investigated in relation to periodical changes of solar, geomagnetic, and cosmic ray activity (Stoupel et al. 2006). As it was revealed, days with increased number of sudden cardiac deaths were accompanied by higher cosmic ray activity. Additionally, the monthly number of sudden cardiac deaths was positively linked to cosmic ray activity level.

Monthly data of myocardial infarctions, brain strokes, and car accident incidences as well as two types of train accidents (caused by man-related factors or technological factors) of the Siberian Railways for the period 1986–1993 were analyzed in relation to space weather changes (Dorman et al. 2001). It was shown that during FDs, the average number of traffic accidents and cardiovascular diseases, as myocardial infractions and brain strokes, was higher. These results were in agreement with other studies (Villoresi et al. 1994a, b; Ptitsyna et al. 1996). Moreover, train accidents (caused by man-related factors) can also be influenced by FDs events (Dorman et al. 2001).

In this study, the effect of CRI variations on the physiological parameters of aviators was examined. Results reveal that strong CRI decreases (Forbush decreases) are associated with arterial blood pressure variations. The SP parameters have a minimum value for CRI

decreases (levels −3 and −2) on the days of CRI events. The opposite behavior is noticed for the DP parameters under examination. Moreover, results, concerning the variations of the physiological parameters on the days before and after CRI decreases, show that mainly for the biggest registered CRI decreases during the period of examination (level −3 of the CRI classification), a decrease, noticed on the days before the CRI decreases, is usually followed by an increase in the days after the CRI decreases.

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