Effect of Geomagnetic Activity on Rat Resistance to Hypoxia

M. L. Khachatur'yan and L. A. Panchenko*

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Resistance to acute hypoxia in rats was evaluated by the life span after elevation to an altitude of 11,500 m at 13.00-21.00 (local time) in different seasons of one year. Geomagnetic activity was evaluated using local *K* index for Moscow and planetary *Kp* index. Total 24-h geomagnetic activity had a great impact on the life span of rats. The effects of local and planetary geomagnetic activities coincided in about 70% cases. An increase in geomagnetic activity was responsible for prolongation, decrease (2-3 times more often than prolongation), and phase changes in the life span of rats, which were the most pronounced in the case of medium geomagnetic activity, during the second half of the year (in summer and particularly in autumn), in the middle and end of the day, in rats with low resistance to hypoxia.

Key Words: *resistance to hypoxia; geomagnetic activity*

Geomagnetic storms are associated with exacerbations of cardiovascular diseases, 1.1-2.5-times increase in the incidence of myocardial infarction [5], angina pectoris attacks and arrhythmias [4], brain strokes [4,5], and 1.2 times increase in total mortality [5]. Hypoxia underlies the pathogenesis of these diseases. However the effects of geomagnetic activity (GMA) on resistance to hypoxia has never been studied. We elucidated the effects of GMA on resistance to acute hypoxia in rats.

MATERIALS AND METHODS

Male Wistar rats (150-180 g) were elevated in a pressure chamber to an altitude of 11,500 m above sea level during 60 sec. The experiments were carried out at 13.00-21.00 (local time) in different seasons of the same year (38-336 rats for different GMA). The time of investigation was divided into 3 periods: beginning (13.00-15.00), middle (16.00-18.00), and end (19.00-21.00) of the day.

Resistance to acute hypoxia was evaluated by the duration of life in a pressure chamber after elevation until reversible respiration arrest, after which the animals were descended [3]. In order to detect the range of LS for rats with low, medium, and high resistance to hypoxia (LR, MR, HR rats, respectively) for each hour of the day, the type of LS values distribution was determined using Kolmogorov—Smirnov's consensus test (with Lilliforce and Shapiro—Wilks' supplement), after which 34 and 66% quantiles ($C_{0.34}$ and $C_{0.66}$) were estimated for the resultant distribution. We assumed that LS of LR rats was no more than $C_{0.34}$, of MR rats $C_{0.34}$-$C_{0.66}$, and of HR rats more than $C_{0.66}$, *i. e.* $C_{0.34}$ and $C_{0.66}$ divided the probable LS range into 3 equal parts (ranges). The median served as the characteristic of the center of LS distribution for all rats.

GMA was characterized by indexes (in points): local *K* for Moscow and planetary *Kp* for median latitudes of the Earth per hour (identical GMA). Maximum indexes for 24 h (maximum GMA) and total indexes for 24 h (total GMA) were registered for the period during which LS was determined. *K* (*Kp*) less than 3 (30) at low GMA, from 3 (30) to 5 (50) at medium GMA, and more than 5 (50) points at high GMA corresponded to identical and maximum GMA. *K* (*Kp*) at low GMA no more than 18 (160), more than 18 (160) and less than 30 (287) at medium GMA, and at least 30 (287) points at high GMA corresponded to total GMA.

Statistical nonparametric methods were used: bifactorial dispersion analysis and Dunn's method of

Department of Experimental Laboratory Models, Russian State Medical University; *Department of General Ecology, Biological Faculty, Moscow State University

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multiple comparisons for study of the relationship between GMA and LS; Spearman's analysis of correlations for detecting the correlations between GMA and LS; Pearson's χ^2 test for comparing the incidence of the effects of different types of GMA on LS of all groups of rats. The zero hypotheses were rejected in all cases at α=0.05.

The results were statistically processed using Statistica 5.0 software.

RESULTS

The effect of GMA on rat LS depended on GMA, interval between GMA increase and evaluation of LS, type of resistance to hypoxia, time of the day, and season. In summer and autumn LS of all rats depended on the time of the day and all GMA parameters; both factors are highly significant for the life span of MR rats (p<0.05-0.01). The effects of planetary and local GMA on rat LS coincided in 70% cases, the number of coincidences being greater in the spring and summer than in autumn; total GMA values also coincided (p<0.05). Total GMA had a greater impact on LS than maximum (1.6 times higher, p<0.05) and identical GMA (1.9 times higher, p<0.01; at high GMA 6.4 times higher, p<0.05). An increase of GMA caused changes in LS of 50-60% of all rats, these changes being more often observed in LR rats (2.2 times) and MR rats (2.4 times, p<0.05) than in HR rats. It is noteworthy that medium GMA had a greater (2-fold, p<0.05) impact on LS (of all rats and MR rats) than high GMA. Changes in LS resultant from increased GMA are shown in Fig. 1. Decreases, increases, and changes in LS were phasic, decreases being observed 2-3 times more often than increases, mainly in autumn in LR rats (p<0.05). An increase of GMA at 13.00-21.00 led to a decrease in LS of all rats during all seasons (for example, in autumn), of LR rats in summer (Table 1) and autumn, of MR rats in spring (Table 1), and of HR rats in autumn; in summer LS was increased in all rats, while in MR rats in autumn (in case of total GMA increase). Changes in rat LS resultant from GMA increase during different periods of the day in different seasons are summed up in Tables 1 and 2.

Hence, we detected a phasuc effect of GMA on rat LS in the course of the day and year. This effect was observed as a result of GMA increase during one term and was more pronounced in all rats and LR animals: at medium GMA rat LS decreased at 13.00-21.00 in all rats in summer and at 19.00-21.00 in LR rats, increased in autumn in all rats at 13.00-15.00, in MR rats at 19.00-21.00, and in spring in LR rats at 13.00-15.00, while at high GMA LS did not differ from that at low GMA. Phase changes in LS were more expressed on the days of the season with different GMA at 13.00-21.00. At medium GMA in spring LS of all rats decreased and of HR rats increased, but at high GMA LS was similar to that at low GMA. Phase pattern of LS changes was the most pronounced in summer in all rats (Fig. 1, *a*): LS remained stable as long as GMA remained low, while at medium GMA LS was liable to change and, in general, decreased; at high GMA it increased and reached LS level at low GMA. Similar time course of LS during increase of GMA was observed in LR rats in summer, but the

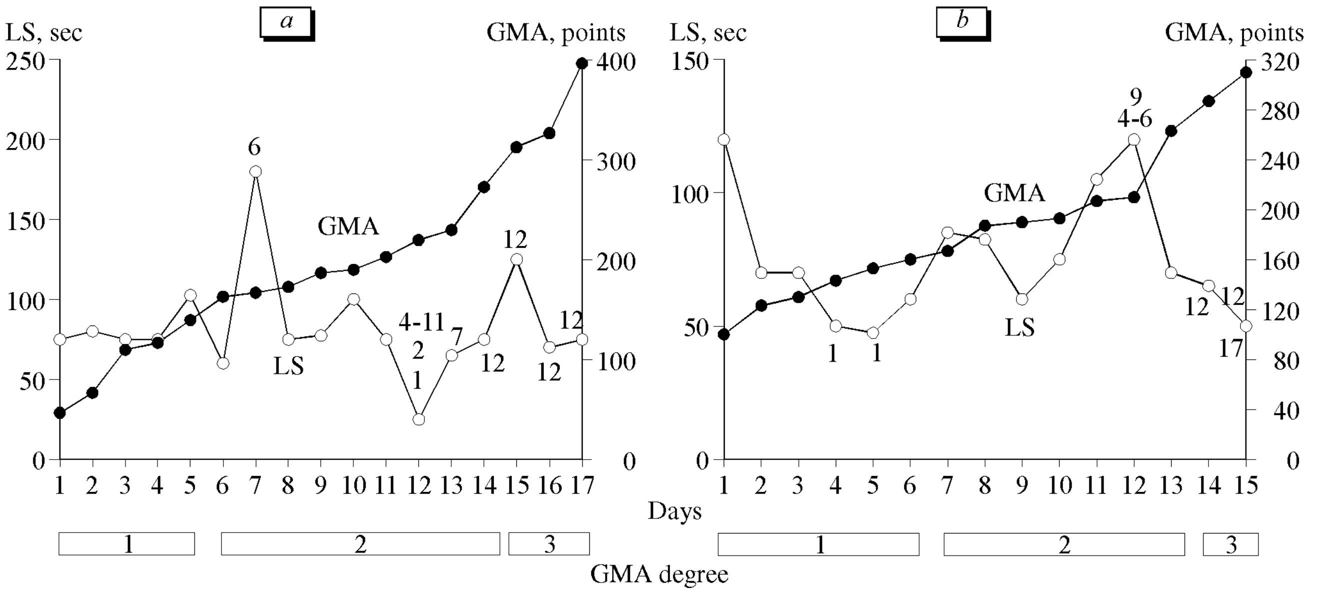

Fig. 1. Phase changes in the life span (LS) of all rats on the days with different total geomagnetic activity (GMA) evaluated by the *Kp* index in points at 13.00-21.00 in summer (*a*) and autumn (*b*). GMA: *1*) low; *2*) medium; *3*) high. Figures near markers: days for which the differences are significant (p<0.05-0.01, Dunn's test).

fluctuations in this parameter were less manifest, and LS remained lower at high GMA than at low GMA. Fluctuations in LS were the maximum in autumn (Fig. 1, *b*): LS of all rats decreased as low GMA progressed, increased at medium GMA, and again decreased at high GMA (2.4 times lower than at low GMA), that is, LS was the maximum at medium GMA. On the whole, LS values changed 1.7-7.2 times (p<0.05-0.01) at GMA increase.

Analysis of correlations showed phasic changes in LS, which depended on the interval between GMA increase and LS evaluation: the increase in the planetary GMA (particularly medium) often promoted a decrease in LS of all rats early (3-12 h) after the increase during all seasons and LS increase at later periods after the increase (15 h-3 days in spring and summer). Progress of low GMA promoted an increase in LS of all animals in spring-autumn and its decrease in winter. Progress of low and medium GMA often promoted an increase of LS in MR and HR rats and its decrease in LR rats (in winter, summer, and autumn). LR and MR rats were more sensitive to the effects of GMA in winter and summer, while HR rats more sensitive in spring and autumn.

GMA can be a factor organizing the functional systems determining organism resistance to hypoxia. This is in line with assimilation of the frequency of low-frequency magnetic fields by the organism [2], direct effect of low-frequency magnetic fields on the cells (sections of mouse cerebellum), which results in the decrease of their resistance to hypoxia [1]. Through magnetoreceptors [5] the field modulates the activity of the suprachyasmatic nucleus regulating the endocrine functions, cardiovascular system, motor activity, and secretion of epiphyseal hormone melatonin [10], hypothalamo-adrenal system [5], sympathoadrenal system, causing the development of stress reactions in humans [7] and rats [8]. It mediates an increase of resistance to hypoxia, *i. e.* leads to manifestation of the urgent cross-adaptation effect. This is in line with a decrease of stress hypokinesia reaction by the alternating magnetic field, close by its characteristics to geomagnetic field during the storm [8]. Increase of norepinephrine concentration during stress stimulates the synthesis of melatonin [14] (which increases stress resistance [11] and, probably, resistance to hypoxia) during the light hours of the day, while during the dark hours inhibits it [14] and decreases the resistance. Magnetic perturbations are responsible for decrease of melatonin concentrations at night [13]. This correlates with different effect of GMA increase on rat LS during different seasons at different time of the day. In addition, melatonin is a potent natural antioxidant [12]. Reduction of its concentration decreases the antioxidant status of the organs; an increase of GMA can directly activate LPO in tissues [13], thus shifting LPO and antioxidant system balance in tissues towards predominance of LPO activity. This is associated with low resistance to hypoxia [9] and can lead to its reduction during GMA increase. A magnetic storm causes the development of hypoxia [5], when the predominance of NAD-dependent oxidation in LR rats, succinate oxidase oxidation in the myocardium in HR rats, and higher resistance of NAD-dependent oxidation to oxygen deficiency in the brain of HR rats [6] can contribute to impairment of resistance to hypoxia in LR

TABLE 1. Changes in LS of Rats during GMA Increase Evaluated by *Kp*

Rat group	Season	Time, h	LS (sec) in GMA		
			low	medium	high
LS decrease					
All rats	Autumn	13.00-21.00	95	70*	50*+
LR	Summer	13.00-21.00	55	45*	40*
MR	Spring	13.00-21.00	87.5	90	70+
HR	Autumn	19.00-21.00	140	115*	95
LS increase					
All rats	Summer	16.00-18.00	75	75	105*+
MR	Summer	16.00-18.00	75	85*	92.5*
HR	Summer	16.00-18.00	135	145	205*
Phase changes in LS					
All rats	Summer	19.00	100	50*	77.5+
All rats	Autumn	13.00-15.00	60	92.5*	75

Note. p<0.05-0.01 according to Dunn's test: *compared to low GMA, +compared to medium GMA.

TABLE 2. Changes in rat LS during the Day at GMA Increase during Different Seasons

Rat group	Season	Time of the day, h	
		LS decrease	LS increase
All rats	Spring	13.00-18.00	19.00-21.00
	Summer	19.00-21.00	16.00-18.00
	Autumn	16.00-21.00	13.00-15.00
LR	Spring	13.00-15.00 (T, M)	13.00-15.00 (I)
	Summer	16.00-21.00	—
	Autumn	16.00-21.00	13.00-15.00
MR	Spring	13.00-15.00, 19.00-21.00	16.00-18.00
	Summer		16.00-18.00
	Autumn		19.00-21.00
HR	Spring		19.00-21.00
	Summer		16.00-21.00
	Autumn	16.00-21.00	

Note. I: identical; M: maximum; T: total GMA.

rats. Phasic changes in resistance to hypoxia during GMA increase can be due to phasic patterns of neuronal activity [1], activity of the sympathoadrenal system [7], energy production in the myocardium [5], and attest to phasic changes in urgent cross-adaptation.

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