ELSEVIER

Biomedicine & Pharmacotherapy 58 (2004) S???–S???

BIOMEDICINE & PHARMACOTHERAPY

www.elsevier.com/locate/biopha

Magnetic storm effect on the circulation of rabbits

S.M. Chibisov, G. Cornélissen*, F. Halberg*

People's Friendship University of Russia, Moscow, Russia
Halberg Chronobiology Center, University of Minnesota, Minneapolis, MN, USA

Abstract

The ultrastructure of cardiomyocytes of rabbits was found to be drastically altered at a time coinciding with strong magnetic storms by comparison with that usually observed during quiet geomagnetic conditions. The circadian characteristics of systolic and mean pressure in the left and right ventricles of Chinchilla rabbits were assessed and compared between quiet and stormy magnetic conditions. Experiments repeated during four consecutive seasons at the times of equinoxes and solstices in the absence of magnetic storms were also examined for any circannual and/or transannual variation. The results have been interpreted in the broader context of non-photic influences on the circulation, fully supporting the presence of non-photic effects. The recording of magnetic activity in the laboratory, and until this is possible, the consultation of the physicists' routine recording of geomagnetic indices should become a sine qua non, since, as shown herein, magnetic storms can override the effect of the usually dominant synchronizer, the alternation of light and darkness.

Keywords: Magnetic storm effect; Rabbit circulation; Light–darkness alternation effect; Altered circulation

1. Introduction

Magnetic storms have been shown in humans to affect the incidence of myocardial infarctions and strokes [1–9]. A putative underlying mechanism may involve an effect of magnetic storms on heart rate variability [8–11]. In the laboratory, electron-microscopic studies of rabbits have shown that magnetic storms are also associated with drastic alterations in the ultrastructure of cardiomyocytes [12,13]. Not only was the structure of the myocardium drastically altered, but the circadian rhythms in systolic and mean pressure in rabbit hearts were also phase-shifted. Limitations of earlier studies, the scarcity of data collected during quiet magnetic conditions, were overcome by the use of reference data, collected as part of an independent, though related investigation, reanalyzed herein from the viewpoint of circadian and circannual variations.

*Corresponding authors.
E-mail address: halbe001@umn.edu or corne001@umn.edu

2. Materials and methods

The experimental group consisted of 525 male Chinchilla rabbits with weights ranging from 2600 to 3500 g. Systolic and mean intracardiac pressure in the left and right ventricles were measured around the clock on groups of five rabbits sampled at 3-hour intervals for 24 hours in the fall of 1980 (September 23) during quiet conditions, and for 3 days every 3 months between June 1984 and March 1985, at the equinoxes and solstices. The groups starting on September 21, 1984 were studied at a time coinciding with the occurrence of two strong geomagnetic storms. Quiet geomagnetic conditions prevailed during the other experimental sessions.

Data from each session were analyzed by single cosinor [14,15] to assess the circadian variation. Rhythm detection was determined by means of the zero-amplitude (no rhythm) test. Point and interval estimates were obtained for the MESOR (midline estimating statistic of rhythm), a chronome-adjusted mean value, the double amplitude, a measure of the extent of predictable change within a day, and the acrophase, a measure of the timing of overall high values recurring each day. Circadian rhythm characteristics were compared between experimental sessions carried out during

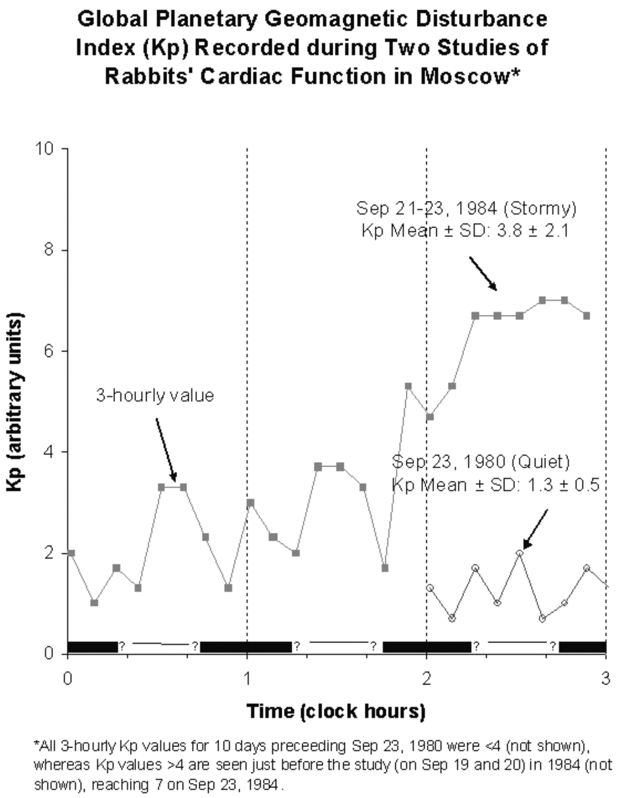

Fig. 1. The geomagnetic situation in September 1980 vs September 1984: the former was a calm span with a low planetary geomagnetic index K_p, whereas in 1984 a storm buildup is visible from increasing K_p values that are relatively high toward the end of the study. © Halberg.

strong magnetic storms or quiet conditions by means of parameter tests [16]. Cosine curves with trial periods of 1.0 and 1.3 years were fitted by least squares to the circadian MESORs determined in each season to assess any circannual or transannual variation.

3. Results

Fig. 1 displays the 3-hourly values of the planetary index of geomagnetic disturbance, Kp, in experiments conducted during the autumn equinox in 1980 and 1984. It can be seen that geomagnetic conditions were quiet in September 1980, whereas in September 1984, strong magnetic activity coincided with the data collection.

Fig. 2 shows the changes in systolic pressure in the left ventricle of rabbits studied in the fall of 1980 and 1984. A prominent circadian variation observed during the first day of study is progressively dampened as the Kp index increases. A circadian rhythm is also demonstrated in 1980 during quiet conditions. There is a large difference in circadian acrophase observed between the two experiments, however. Similar results are observed for the systolic pressure in the right ventricle of rabbits (Fig. 3).

The statistical significance of the phase difference between studies in 1980 and 1984 is apparent from the non-overlapping 95% confidence intervals (Fig. 4). This near-antiphase of circadian rhythms in systolic and mean intracardiac pressure, in the left and right ventricles of rabbit hearts during a magnetic storm (fall 1984) and quiet conditions (fall 1980) suggests a geomagnetic effect on the circulation.

Without further evidence that the circadian acrophase remains stable during quiet geomagnetic conditions, these

Table 1
Circadian rhythm characteristics of intra-cardiac pressure of rabbits studied for 3 days at equinoxes and solstices (June 1984–March 1985)

Seas	K	PR	P	MESOR		Amplitude		Acrophase	
		Mean pressure in left							
Summer	1.3	1	0.528	135.7	2.9	4.63	4.08	-	51
Autumn	3.	13	<0.001	119.6	2.9	17.22	4.07	-	14
Winter	2.	4	0.091	105.6	2.7	8.40	3.80	-	26
Spring	1.	1	0.418	116.8	2.0	3.80	2.87	-	43
		Systolic pressure in left							
Summer	1.	5	0.039	206.0	2.3	8.23	3.18	-	22
Autumn	3.	5	0.045	208.7	2.4	8.48	3.37	-	23
Winter	2.	8	0.010	182.3	3.0	13.16	4.27	-	19
Spring	1.	6	0.023	199.7	2.4	9.62	3.44	-	20
		Mean pressure in right							
Summer	1.	1	0.646	25.3	0.5	0.65	0.69	-	62
Autumn	3.	6	0.024	22.2	0.4	1.62	0.58	-	21
Winter	2.	1	0.648	21.4	0.4	0.52	0.56	-	61
Spring	1.	2	0.382	23.1	0.4	0.73	0.52	-	41
		Systolic pressure in right							
Summer	1.	2	0.377	46.6	0.8	1.64	1.16	-	40
Autumn	3.	5	0.046	40.3	0.7	2.52	1.00	-	23
Winter	2.	4	0.116	39.9	0.7	1.95	0.93	-	27
Spring	1.	1	0.721	43.5	0.7	0.81	1.00	-	71

Kp: Planetary index of geomagnetic disturbance averaged over study span in each season; PR: percentage rhythm, the proportion of variability accounted for by fitted 24-hour cosine curve; MESOR (midline estimate statistic of rhythm), a chronome-adjusted mean value; amplitude: a measure of half the extent of predictable change within a day; acrophase: a measure of the timing of overall high values recurring each day, expressed in (negative) degrees, with 360°=24 hours and 0°=00:00. SE: standard error.

Table 2
Population-mean cosinor summary of circadian rhythm in intra-cardiac pressure of rabbits during magnetic storms and geomagnetic quie

		Magneti conditio	k	PR	*P*	MESO	Amplitud	(95	CI	Acrophas	(95	CI
Fall	original	Stor	4	7.	0.46	97.	6.5		)	–	(	)
1984-	"	Quie	1	3.	0.06	95.	3.3		)	–	(	)
1984-	"	Quie	4	5.	0.09	173.	8.5		)	–	(	)
Fall	A=	Stor	4	7.	0.02	97.	0.8	(0.50	1.15	–	(–	–
1984-	"	Quie	1	3.	0.34	95.	0.3		)	–	(	)
1984-	"	Quie	4	5.	0.01	173.	0.8	(0.58	1.12	–	(–	–

k: number of data series (four series available during magnetic storms; 12 series available during magnetic quiet, statistical significance of circadian variation being reached in for of them); PR: percentage rhythm, average proportion of variance accounted for by 24-hour cosine fit to each data series; *P*: *P*-value from test of zero-amplitude (no-rhythm) assumption; MESOR (midline estimating statistic of rhythm), a chronome-adjusted mean value; Amplitude: half the extent of predictable change within a day; acrophase: measure of timing of overall high values recurring each day, expressed in (negative) degrees, with 360°=24 hours and 0°=00:00. CI: confidence interval.

results are insufficient, however, to associate the difference in acrophase with the occurrence of a magnetic storm. In 1984–85, additional profiles were collected, one in each season, each for 3 days, allowing the examination of the extent of stability of the circadian acrophase of intracardiac pressure in rabbits during quiet geomagnetic conditions.

Table 1 summarizes the circadian characteristics of systolic and mean pressure in the left and right ventricles of rabbits during each season between June 1984 and March 1985. A summary by population-mean cosinor of results in winter, spring and summer, in the absence of magnetic storms, Table 2 is in keeping with the data obtained in the fall of 1980, with an average acrophase of –49° (P=0.062).

A comparison of acrophases (considered irrespective of the amplitude, set equal to 1) for series showing a statistically significant circadian rhythm during quiet conditions (N=4; P=0.019) vs those in the fall of 1984 (P=0.023) confirms the near-antiphase, namely –267° (95% CI: –206 to –311) during storms vs –58° (95% CI: –3 to –101) during quiet conditions.

The MESORs of circadian studies conducted in each season in 1984–1985 were further used as imputations to assess any circannual or other variation. As seem from Table 3, results are highly statistically significant (P<0.001), at both trial periods of 1.0 and 1.3 years. An about 1.3-year component may be anticipated as a counterpart to a similar feature in solar wind speed [17,18]. Although the data cover too short a span to distinguish between the two sources of variation, corresponding to photic and/or non-photic environmental influences, it is interesting to note that three of the four amplitudes are numerically larger and acrophases are more tightly clustered at the 1.3-year than at the 1.0-year trial period, covering 36° vs 46°, 360° representing 1.0 and 1.3 years, respectively.

4. Discussion

The repeated mapping of the circadian variation of intracardiac pressure of rabbits on added occasions in the laboratory under quiet geomagnetic conditions yields consistent results, with an acrophase between 03:00 and 04:00. This timing is more or less opposite that observed in the fall of 1984, a time coinciding with two strong magnetic storms. Unfortunately, the lighting and magnetic as well as other conditions, such as environmental temperature, were not

Table 3
Circannual and transannual variation in intra-cardiac pressure of rabbits

Variable	PR	*P*	MESO	S	Amplitude	(95%	Acrophase	(95%
	Summary at trial period of 1.0							
Mean LV	1	<0.001	119.5	1.4	15.05	(11.3, 18.80)	–	(–352, –
Systolic LV	9	<0.001	199.3	1.3	12.59	(8.93, 16.25)	–	(-5, -39)
Mean RV	9	<0.001	23.0	0.2	1.98	(1.40, 2.57)	–	(–331, –
Systolic RV	1	<0.001	42.6	0.4	3.76	(2.74, 4.78)	–	(–320, –
	Summary at trial period of 1.3							
Mean LV	12	<0.001	123.2	1.5	16.48	(12.06, 20.89)	–	(–311, –
Systolic LV	6	<0.001	201.2	1.5	10.75	(6.71, 14.79)	–	(–315, –
Mean RV	9	<0.001	23.7	0.2	2.46	(1.72, 3.20)	–	(–296, –
Systolic RV	10	<0.001	44.0	0.4	4.90	(3.57, 6.23)	–	(–290, –

PR: percentage rhythm, proportion of variability accounted for by fitted cosine curve with period of 1.0 or 1.3 years; MESOR (midline estimate statistic of rhythm), a chronome-adjusted mean value; amplitude: a measure of half the extent of predictable change within one cycle; acrophase: a measure of the timing of overall high values recurring during each cycle, expressed in (negative) degrees, with 360°=period length (1.0 or 1.3 years) and 0°=00:00 on 21 June 1984. SE: standard error; CI: confidence interval.

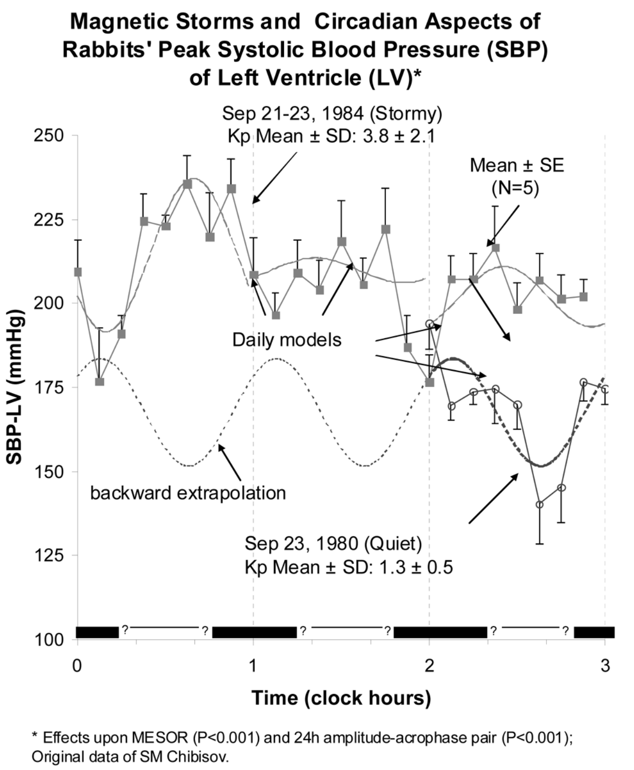

Fig. 2. A 1-day profile of systolic pressure in the left ventricle of rabbits during a calm span in 1980 is compared with the 3-day profile during a stormy span. During the buildup of a storm in 1984, shown by K_p values in Fig. 1, a relatively large amplitude is seen first with a very great difference in phase, if one compares the timing of the peak with that on a calm day in 1980. © Halberg.

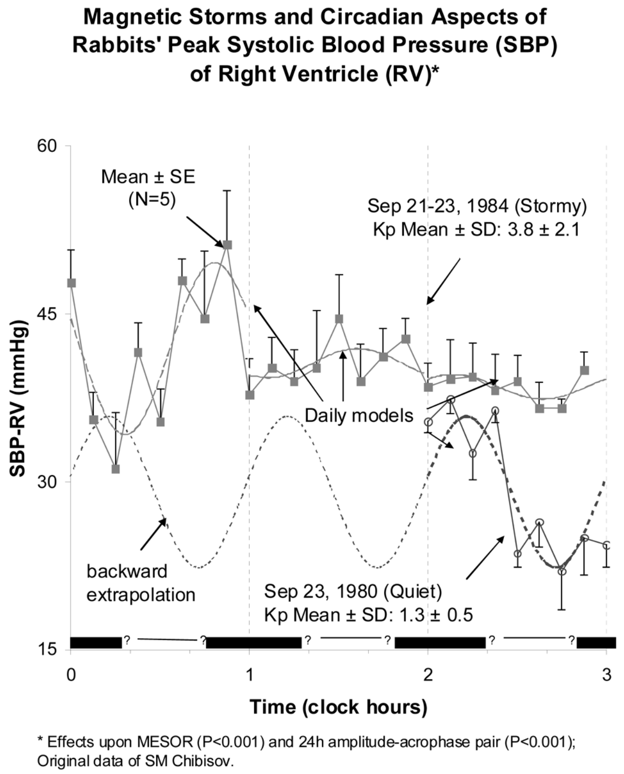

Fig. 3. A large difference in acrophase and a progressive reduction in the circadian amplitude are features also observed for the systolic pressure in the right ventricle of rabbits studied during quiet and stormy geomagnetic conditions, similar to those found in the left ventricle, as shown in Fig. 2. A large phase-shift with a peak originally during the build-up of the storm during the light span is seen, with a gradual damping of rhythm as the storm gains in intensity. © Halberg.

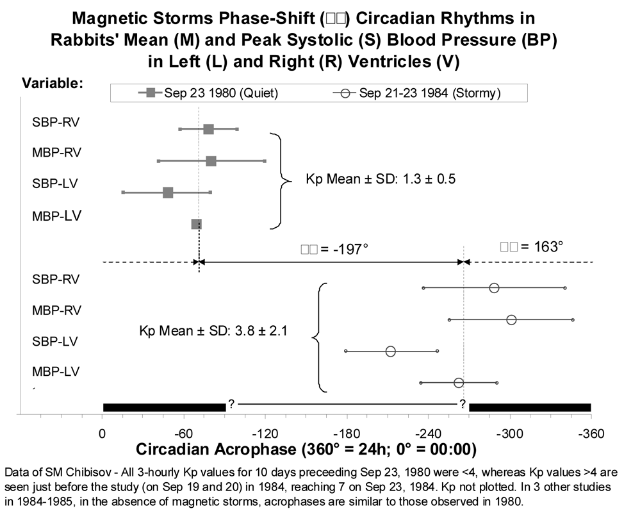

Fig. 4. Acrophase chart of systolic and mean pressure in the left and right ventricles of rabbits studied in the fall of 1980 during quiet conditions and in the fall of 1984 when stormy conditions prevailed. Results are in almost antiphase, the statistical significance of the difference in circadian acrophase being documented by the non-overlap of 95% confidence intervals. The likely association of the difference in circadian acrophase and the occurrence of strong magnetic storms is supported by the relative stability of the circadian acrophases during quiet conditions, as determined in additional experiments conducted in the winter, spring and summer of 1984–1985 (see Tables 1 and 2). © Halberg.

recorded, and this should be done in the future. With this qualification, the added results strengthen the proposition that magnetic storms were associated with a changed circadian variation of circulatory variables in rabbits. Altered circadian rhythms were also reported in a 7-day electrocardiographic record on a clinically healthy man, obtained in part during a magnetic storm, consisting mainly of a decreased prominence of the circadian component, the spectral peak being shifted away from 24 hours [10,12].

The statistically significant 1.3-year component, found to be numerically more prominent than a component with a precise 1.0-year period deserves further investigation. This result is noted only to point to the need for longer time series. Continued studies in laboratory animal chambers controlled for lighting and temperature and preferably controlled for and compensated for changes in magnetic fields could help determine the relative prominence of photic and non-photic influences on circulatory variables.

The results presented herein on rabbits complement the invariably statistically significant transyear detected in longitudinal series of human blood pressure and heart rate covering up to 38 years [19,20], as well as in transverse series from hundreds of human babies, in which case the transyear predominates over the calendar year [21]. Neonatal blood pressure and heart rate had earlier been shown to be characterized by an about 11-year cycle similar to the solar activity cycle and by prominent about 7-day (circaseptan) variations correlating with circaseptans in the local geomagnetic index K [22].

5. Acknowledgments

This study was supported by the US National Institutes of Health (GM-13981) (to FH) and by the Dr. h.c. Earl Bakken Fund (to GC, FH).

References

[1] Halberg F, Breus TK, Cornélissen G, Bingham C, Hillman DC, Rigatuso J, et al., for the International Womb-to-Tomb Chronome Initiative Group: Chronobiology in space. Keynote, 37th Ann. Meeting, Japan Soc. for Aerospace and Environmental Medicine, Nagoya, Japan, November 8–9, 1991. University of Minnesota/Medtronic Chronobiology Seminar Series No. 1; 1991.

[2] Breus TK, Cornélissen G, Bingham C, Hillman DC, Halberg E, Guillaume F, et al. Cardiovascular and other chronoepidemiology via ambulance calls versus geomagnetic and sunspot variability. In: Halberg F, Watanabe H, Eds. Proc. Workshop on Computer Methods on Chronobiology and Chronomedicine, Tokyo, Sept. 13, 1990. Tokyo: Medical Review; 1992. p. 203–31.

[3] Breus T, Cornélissen G, Halberg F, Levitin AE. Temporal associations of life with solar and geophysical activity. Ann Geophys 1995;13:1211–222.

[4] Villoresi G, Breus TK, Iucci N, Dorman LI, Rapoport SI. The influence of geophysical and social effects on the incidences of clinically important pathologies (Moscow 1979–1981). Phys Med 1994;10:79–91.

[5] Villoresi G, Kopytenko YA, Ptitsyna NG, Tyasto MI, Kopytenko EA, Iucci N, et al. The influence of geomagnetic storms and man-made magnetic field disturbances on the incidence of myocardial infarction in St. Petersburg (Russia). Phys Med 1994;10:107–17.

[6] Cornélissen G, Breus TK, Bingham C, et al. Beyond circadian chronorisk: worldwide circaseptan–circasemiseptan patterns of myocardial infarctions, other vascular events, and emergencies. Chronobiologia 1993;20:87–115.

[7] Cornélissen G, Wendt HW, Guillaume F, Bingham C, Halberg F, Breus TK, et al. Disturbances of the interplanetary magnetic field and human pathology. Chronobiologia 1994;21:151–4.

[8] Cornélissen G, Halberg F, Breus T, Syutkina EV, Baevsky R, Weydahl A, et al. Non-photic solar associations of heart rate variability and myocardial infarction. J Atmos Solar Terr Phys 2002;64:707–20.

[9] Halberg F, Cornélissen G, Otsuka K, Watanabe Y, Katinas GS, Burioka N, et al., for the International BIOCOS Study Group. Cross-spectrally coherent ~10.5- and 21-year biological and physical cycles, magnetic storms and myocardial infarctions. Neuroendocrinol Lett 2000;21:233–58.

[10] Cornélissen G, Halberg F, Schwartzkopff O, Delmore P, Katinas G, Hunter D, et al. Chronomes, time structures, for chronobioengineering for 'a full life'. Biomed Instrument Technol 1999;33:152–87.

[11] Otsuka K, Cornélissen G, Weydahl A, Holmeslet B, Hansen TL, Shinagawa M, et al. Geomagnetic disturbance associated with decrease in heart rate variability in a subarctic area. Biomed Pharmacother 2001;55(Suppl. 1): 51–6.

[12] Breus TK, Pimenov KY, Cornélissen G, Halberg F, Syutkina EV, Baevsky RM, et al. The biological effects of solar activity. Biomed Pharmacother 2002;56(Suppl. 2):S273–83.

[13] Breus TK, Chibisov SM, Baevsky RM, Schebzuhov KV. The chronostructure of heart biorhythms under effects of external environment factors. Moscow: RUPF; 2002. 231 pp.

[14] Halberg F. Chronobiology. Annu Rev Physiol 1969;31:675–725.

[15] Cornélissen G, Halberg F. Chronomedicine. In: Armitage P, Colton T, Eds. Encyclopedia of biostatistics, vol 1. Chichester, UK: John Wiley; 1998. p. 642–9.

[16] Bingham C, Arbogast B, Cornélissen Guillaume G, Lee JK, Halberg F. Inferential statistical methods for estimating and comparing cosinor parameters. Chronobiologia 1982;9:397–439.

[17] Richardson JD, Paularena KI, Belcher JW, Lazarus AJ. Solar wind oscillations with a 1.3-year period. Geophys Res Lett 1994;21:1559–60.

[18] Mursula K, Zieger B. The 1.3-year variation in solar wind speed and geomagnetic activity. Adv Space Res 2000;25:1939–42.

[19] Halberg F, Cornélissen G, Schack B, Wendt HW, Minne H, Sothern RB, et al. Blood pressure self-surveillance for health also reflects 1.3-year Richardson solar wind variation: spin-off from chronomics. Biomed Pharmacother 2003;57(Suppl. 1):S58–76.

[20] Cornélissen G, Masalov A, Halberg F, Richardson JD, Katinas GS, Sothern RB, et al. Multiple resonances among time structures, chronomes, around and in us. Is an about 1.3-year periodicity in solar wind built into the human cardiovascular chronome? Hum Physiol 2004;30(2):86–92.

[21] Masalov AV, Syutkina EV. Magnetic storms and neonatal blood pressure and heart rate chronomes. Neuroendocrinol Lett 2003;24 (Suppl. 1):111–16.

[22] Syutkina EV, Cornélissen G, Yatsyk G, Studenikin M, Baranov A, Halberg F. Over a decade of clinical chrononeonatology and chronopediatrics in Moscow. Neuroendocrinol Lett 2003;24 (Suppl. 1):132–38.