Graded response of heart rate variability associated with an alteration of geomagnetic activity in subarctic area

S Oinuma[1], Y Kubo[1], K Otsuka[1], T Yamanaka[1], S Murakami[1], O Matsuoka [1],
• @S Ohkawa[1], G Cornelissen[2], A Weydahl[3], B Holmeslet[4], C Hall[4], F Halberg[2]
on behalf of the "ICEHRV" Working Group

1. Department of Medicine, Tokyo Women's Medical University, Daini Hospital, Tokyo, Japan
2. Chronobiology Laboratories, University of Minnesota, Minneapolis, Minnesota
3. Finnmark University College, Alta, Norway
4. Auroral Observatory, University of Tromso, Tromso, Norway

Postral address: Kuniaki OTSUKA, M.D.
• @• @• @• @• @• @• @• @• @• @• @• @• @• @ Department of Medicine, Tokyo Women's Medical University,
• @• @• @• @• @• @• @• @• @• @• @• @• @• @ Daini Hospital,
• @• @• @• @• @• @• @• @• @• @• @• @• @• @ Nishiogu 2-1-10, Arakawa-ku, Tokyo, 116-8567, Japan
• @• @• @• @• @• @• @• @• @• @• @• @• @• @ FAX 81-3-3894-0282• @• @ E-mail: frtotk99@ba2.so-net.ne.jp

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Summary :

Background: It is becoming recognized that geomagnetic activity may influence biological processes, including the incidence of various human diseases. There is evidence that heart rate variability (HRV) may serve not only as an index of autonomic coordination of the circulation, but also as a powerful predictor of risk in apparently healthy subjects. This study focuses on any effect of geomagnetic disturbance on HRV, by comparing different indices of HRV of young, healthy men living in a subarctic area on days of low (ap; 0-7), middle (ap; 7-20), and high (ap; 20-45) geomagnetic activity.• @ *Subjects and Methods*: The effect of geomagnetic disturbance on HRV is examined herein on the basis of 7-day records by Holter ECG, obtained longitudinally on 5 clinically healthy men, 21-31 years of age, in Alta, Norway (70 degree N). Frequency- and time-domain measures of HRV were analyzed for each subject on separate 24-hour spans.• @ *Results*: A graded alteration of HRV endpoints was found in association with increased geomagnetic activity. As time-domain measures of HRV, SDNNIDX and the 90% length of the Lorenz plot decreased statistically significantly on days with increased geomagnetic disturbance (p=0.0144 and p=0.0102, respectively). A graded decrease in frequency-domain HRV measures was also validated statistically for the total spectral power (decrease of 18.1% and 31.6% on days when 7<ap<20 and 20<ap<45 versus days when ap<7; p=0.0013). The decrease in spectral power was found primarily at frequencies below 0.04 Hz, in the "ultra-low-frequency" (0.0001-0.003 Hz; 18.1% and 27.5% decrease, respectively; p=0.0102) and "very-low-frequency" (0.003-0.04 Hz; 12.9% and 28.6% decrease, respectively; p=0.0209) regions of the spectrum. The decrease in spectral power was much less pronounced around 10.5 sec ("low frequency"; N.S.) and around 3.6 sec ("high frequency"; N.S.). *Conclusions*: Evidence is provided herein that HRV decreases on magnetically disturbed days, and that it does so in a dose-dependent fashion, HRV being depressed more on days when 20<ap<45 than on days when 7<ap<20, by comparison with days when ap<7. This graded response of HRV to geomagnetic activity should encourage us to search for human magnetoreceptors and for a better understanding of putative mechanisms of magnetoreception.

Introduction

• @• @ Influences of geomagnetic activity on biological processes [1-4] and the incidence of various human diseases [5-10] have been reported. Putative associations between geomagnetic storms and myocardial infarction or stroke are of particular interest and constitute active areas of current research [11, 12]. In Minnesota, mortality from myocardial infarction is increased by 5% at times of maximal solar activity [12], when geomagnetic disturbances occur more frequently. Susceptible individuals may then be at an increased cardiovascular disease risk.

• @• @ Heart rate variability (HRV) has been known as a powerful predictor of vascular disease risk in apparently healthy people, as evidenced in an elderly cohort [13], as well as in patients suffering from coronary artery disease, valvular heart disease, and congestive heart failure [14, 15]. In this study, clinically healthy men who live in a subarctic area provided Holter ECG records for 7 days to determine whether geomagnetic activity affected various measures of HRV. Geomagnetic activity was gauged by the ap index of geomagnetic disturbance. This index is based on local K indices determined in different geographic locations. Each local K index is based on the measured amplitude of variation of the local geomagnetic field over consecutive 3-hour intervals. Corrections for local effects are applied to yield world ap indices. Measures of HRV assessed over separate 24-hour spans were compared among days of low, middle and high geomagnetic activity, defined as days with ap values <7, 7-20, and 20-45, respectively.

Subjects and Methods

• @• @ The effect of geomagnetic disturbances on HRV endpoints is examined herein on the basis of 7-day records by Holter ECG, obtained longitudinally on 5 clinically healthy students of Finnmark University College (5 men, 21 to 31 years of age), in Alta, Norway (70 degree N). Days of low, middle, and high geomagnetic activity were classified in terms of the ap index as follows: low; 0-7, middle; 7-20, and high; 20-45. Days of low, middle, and high geomagnetic activity were selected individually from each 7-day record. HRV endpoints were compared among the 3 classes thus formed.

• @• @ The 24-hour ECG records were obtained with an ambulatory two-channel Holter recorder (SM-28, Fukuda-Denshi, Tokyo). The analog signals were digitized by means of an analyzer (SCM-280-3, Fukuda-Denshi, Tokyo), R-R interval counter, and a built-in A/D converter. The interval resolution was 8 msec. Analyses were carried out on smoothed R-R intervals resampled at 4 Hz.

• @• @ As time-domain measures, CVNN, SDNNIDX, r-MSSD, NN50, pNN50 and Lorenz plot indices (Length90%, Width90%, L/W) were computed, as well as heart rate (HR) and the mean cycle length of the normal-normal RR intervals (NN). These indices were averaged over consecutive 5-min intervals to cover the entire 24-hour ECG recording. Frequency-domain measures were obtained by the maximum entropy method (MEM). Calculations were done with the MemCalc/CHIRAM program [15,16] (Suwa Trust Co., Ltd., Tokyo Japan). 5-min NN interval time series were processed consecutively, and the spectral power in the very low frequency (VLF, 0.003-0.04 Hz), low frequency (LF, 0.04-0.15 Hz) and high frequency (HF, 0.15-0.40 Hz) regions of the spectra were assessed, from which the LF/HF ratio was calculated. 180-min NN interval time series were processed consecutively, progressively displaced by 5 min, to estimate the ultra-low frequency (ULF, 0.0001-0.003 Hz) component and the slope of 1/f fluctuations of NN intervals (ƒÀ, 0.0001-0.01 Hz). Normalized spectral power in the ULF, VLF, LF and HF regions of spectra was obtained by dividing these HRV endpoints by the total spectral power (0.0001-0.50 Hz).

• @• @ Group comparisons were done by Tukey's test and two-way ANOVA. Results were considered to be statistically significant at p<0.05.

Results

• @• @ Table 1 summarizes the graded response of HRV endpoints to geomagnetic activity. There is a tendency for HR to increase on geomagnetically active days, but the trend is not statistically significant. SDNNIDX and the 90% length of the Lorenz plot, however, both show a statistically significant decrease on magnetically disturbed days as compared to quiet days (p=0.0144 and 0.0102, respectively). CVNN, r-MSSD, NN50, pNN50, the width of the Lorenz plot and the Length/Width ratio, however, did not change statistically significantly as a function of days with increased magnetic disturbance.

• @• @ A decrease in frequency-domain measures of HRV on days with 7<ap<20 and 20<ap<45 versus days with ap<7 is validated with statistical significance for the TF power (by 18.1% and 1.6%, respectively; p=0.0013). The decrease in spectral power was found primarily in the "ultra-low-frequency (ULF)" (by 18.1% and 27.5%, respectively; p=0.0102) and in the "very-low-frequency (VLF)" (by 12.9% and 28.6%; p=0.0209) regions of the spectrum. The decrease in spectral power around 10.5 seconds ("low frequency (LF)") (by 9.9% and 24.23%; p=0.1234) and around 3.6 seconds ("high frequency (HF)") (N.S.) was of much lesser extent and was not statistically significant. There was no statistically significant change either in LF/HF, ULF/TF, VLF/TF, LF/TF and HF/TF. The power-law scaling of the spectra (ƒÀ, that is the slope of 1/f fluctuations of NN intervals) showed a tendency toward a less steep slope in association with increasingly disturbed days, but the trend was not statistically significant, suggesting that geomagnetic activity may not influence the fractal scaling of HRV.

Discussion

• @• @ The results herein provide further evidence that HRV decreases on geomagnetically disturbed days as compared with quiet days. A graded response is suggested, the extent of HRV decrease depending on the degree of geomagnetic activity, as gauged by ap. This statistically significant association between the decrease in HRV and ap was found in 7-day ECG records from 5 clinically healthy young men living above the arctic circle. Not all HRV endpoints were affected by geomagnetic disturbances. Results were not statistically significant for indexes related to the autonomic cardiovascular function, including time-domain measures such as CVNN, r-MSSD, NN50, pNN50 and the width of the Lorenz plot, and frequency-domain measures such as the spectral power centered around 10.5 and 3.6 seconds ("LF" and "HF" components). Those HRV indices that were affected by geomagnetic disturbances were the prognostic indices such as SDNNIDX, "TF", "ULF" and "VLF". SDNNIDX was decreased by 8.7% and by 16.9% on days when 7<ap<20 and 20<ap<45 (vs. days when ap<7), respectively. Similarly, "TF" was decreased by 18.1% and 31.6%, "ULF" by 18.1% and 27.5%, and "VLF" by 12.9% and 28.6%, respectively.

• @• @ One feature of this study is that it was carried out on healthy young subjects, who may more readily respond in terms of their HRV endpoints to both phasic and tonic environmental stimuli [16]. The extent of the HRV response may have been further amplified by the fact that the subjects lived in a subarctic area, where geomagnetic disturbances tend to be stronger and can affect biological systems more directly, notably the cardiovascular system, by comparison with other populations living at lower latitudes. Another feature of this study is that it focused on geomagnetics-associated HRV alterations assessed on 24-hour ECG records in order to account for the circadian variation that characterizes both the HRV endpoints and the geomagnetic fluctuations.

• @• @ Human HRV endpoints have been known not only as a measure of the autonomic coordination of the circulation, but also as a powerful predictor of vascular disease risk in an apparently healthy elderly cohort [13] as well as in patients with coronary artery disease, valvular heart disease and congestive heart failure [14, 15]. In this investigation, different measures of HRV, including time-domain, geometrical, frequency-domain and nonlinear endpoints, were compared for each subject among days of low- (ap; 5.35), middle- (ap;12.20) and high- (ap; 28.65) geomagnetic activity. The results indicate that HRV decreases in a graded fashion as a function of the level of geomagnetic disturbance. A more prominent relationship is observed for HRV measures that reflect long-term HR fluctuations ("TF", "ULF" and "VLF") than for HRV measures associated with short-term HR fluctuations, such as "LF" and "HF" usually related to the cardiovascular parasympathetic activity. As an impaired HRV has been shown to serve as a predictor of mortality among patients with a variety of other vascular diseases, the results herein may point to some underlying physiological mechanism responsible for the physiological response to changes in magnetic activity other than the parasympathetic nervous system.

• @• @ Electromagnetic field exposure effects on biological and clinical phenomena have been previously reported [17-23]. It is known that electromagnetic fields act not only at the cellular level [22-25], but also through the central nervous system [1, 17, 26], predomonantly the hypothalamus. But such induced biological responses are usually associated with field intensities in the range of 10^{-6} to 10^{-4} tesla [19, 20, 22]. Physiological responses in association with geomagnetic storms, however, involve much weaker fields of only 10^{-7} to 10^{-6} tesla. The graded response of HRV endpoints to geomagnetic disturbances observed herein suggests that a receptor-associated mechanism may be responsible for picking up the geomagnetic information.

• @• @ Birds are able to use the geomagnetic field as a compass to find direction. In the search for sensory mechanisms of magnetoreception, research focused on direct magnetic responses to magnetic stimuli [27]. Aquatic bacteria, Aquaspirillum, exhibit magnetotactic behavior. Each bacterium contains a chain of about twenty single-domain magnetite particles. This discovery elicited a search for magnetoreceptors in a variety of animal species, and mechanoreceptors were noted to act as magnetoreceptors. Phillips and his colleagues [28, 29] proposed a new hypothesis that an animal's photoreceptor can pick up geomagnetic information, and a light-dependent magnetoreception mechanism was reported in newts. Our previous study confirmed the possibility of this hypothesis in the human [30]. In the recent year, Nemec et al. [31] constituted evidence for the involvement of a specific mammalian brain structure in magnetoreception. The search for human magnetoreceptors and/or for a mechanism of human magnetoreception may be rekindled by the results presented herein.

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The members of the "ICEHRV" Working Group are as follows:

Otsuka K, Omori K., Kubo Y., Shinagawa M., Yamanaka T., Murakami S., Watanabe Y., Ohkawa S. (Department of Medicine, Tokyo Women's Medical University, Daini Hospital), Ichimaru Y. (Department of Chrononutrition, University of Tokyo Domestic Science), Kumagai Y. (Kitasato Univesity, East Hospital), Yamashina A.

(2nd Department of Medicine, Tokyo Medical University), Burioka N. (3rd Department of Medicine, Tottori University), Sato Y. (Medical Institute of Bioregulation, Kyushu University), Tsunomura S. (Kakioka Magnetic Observatory, Japan Meteorological Agency), Akioka M. (Communications Research Laboratory, Ministry of Posts and Telecommunications, Japan), Kamide Y. (Solar-Terrestrial Environment Laboratory, Nagoya University), Weydahl A. (Finnmark University College, Alta, Norway), Holmeslet B., Hall C, Hansen T.L. (Auroral Observatory, University of Tromso, Tromso, Norway), Tarquini R. (Institute of Internal Medicine, Univesity of Florence, Italy), Perfetto F. (Institute of Internal Medicine, Univesity of Florence, Italy), Carandente F. (University of Milan, Italy), Delyukov A.A. (Institute of Physics, National Academy of Sciences, Ukraine), Gorgo Y. (Department of Human and Animals Physiology, Kiev National Taras Shevchenko University, Ukraine), Wang Z. (Cardiology and Cardiovascular Pharmacology, West China University Medical School, P.R.China), Zhao Z. (Institute of Materia Medica, Shandong Academy Medical Sciences, P.R.China), Zhou Rui-Hai (Department of Health Care Affiliated Hospital of Shandong Medical University, P.R.China), Singh R.B. (Medical Hospital and Research Centre, Heart Research Laboratory and Centre of Nutrition, India), Shankaraiah K. (Department of Biology, University of Asmara, Eritrea (N.E. Africa), Mitsutake G. (Department of Psychology, University of Manitoba, Canada), de la Pena S.S. (IMSS, Mexico City, Mexico), Borer K.T. (University of Michigan), Cornelissen G.G., Schwartzkopff O., Halberg F. (Chronobiology Laboratories, University of Minnesota).

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Table 1. Heart rate variability parameters on days of low, middle and high geomagnetic activity in healthy subjects (n=5).

	Low		Middle		High		2-way
	Mean	SD	Mean	SD	Mean	SD	ANOVA
ap	5.35	1.37	12.20	4.95	28.65	8.16	p-value
Average HR	63.18	6.89	63.89	7.07	67.73	5.43	N.S.
NN	1005.13	108.72	995.92	110.12	934.05	76.29	N.S.
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CVNN	10.97	1.10	10.20	1.31	10.17	1.55	N.S.
SDNNIDX	107.16	22.64	97.89	20.44	89.01	13.63	0.0144
r-MSSD	72.55	29.02	63.31	18.81	55.38	11.23	N.S.
NN50	87.89	26.70	81.04	17.83	72.71	15.65	N.S.
pNN50	36.86	12.67	33.01	9.36	27.52	5.75	N.S.
Length 90%	498.56	111.08	457.23	98.36	419.68	75.99	0.0102
Width 90%	197.90	97.61	164.71	63.13	147.45	48.18	N.S.
Length/Width	3.1075	0.9197	3.3072	0.6979	3.4054	0.3501	N.S.
ƒÀ (1/f)	-1.0133	0.1053	-0.9641	0.1099	-0.9236	0.1670	N.S.
TF	19870.99	9433.06	16300.58	8548.13	13594.99	6750.35	0.0013
ULF	9619.19	4764.94	7874.47	5507.11	6969.53	5184.13	0.0102
VLF	6302.54	2869.74	5489.85	2288.11	4497.39	1597.39	0.0209
LF	2080.00	998.54	1874.63	693.81	1576.80	430.25	N.S.
HF	1307.31	1350.66	950.17	790.46	692.18	304.77	N.S.
LF/HF	3.5943	1.6091	4.0682	1.6339	3.9495	1.2558	N.S.
ULF/TF	0.4950	0.0612	0.4706	0.0597	0.4827	0.0941	N.S.
VLF/TF	0.3213	0.0229	0.3391	0.0411	0.3265	0.0507	N.S.
LF/TF	0.1100	0.0110	0.1261	0.0245	0.1259	0.0322	N.S.
HF/TF	0.0710	0.0633	0.0614	0.0408	0.0618	0.0387	N.S.

Average HR = 24-hour average of heart rate (bpm); ƒÀ(1/f) = slope of power-law regression line of HR variability between 10^{-2} and 10^{-4}, CVNN = coefficient of variation of NN intervals (%); HF; high frequency spectral component (msec^2); Length90% = 90% length of Lorenz plot (msec); L/W = Length90% to Width90% ratio; LF = low frequency spectral component (msec^2); NN50 = number of difference between adjacent normal cycle intervals >50msec computed over the entire 24-hour ECG recordings; pNN50 = percent of difference between adjacent normal cycle intervals >50msec computed over the entire 24-hour ECG recordings (%); r-MSSD = root mean square successive difference (msec); SDNNIDX = mean of the SDs of all NN intervals for all 5-min segments of a 24-hour ECG recording (msec); TF = total frequency spectral component (msec^2); ULF = ultra-low-frequency spectral component (msec^2); VLF = very-low-frequency spectral component (msec^2); Width90% = 90% width of Lorenz plot (msec).• @• @• @• @• @