

Influence of geomagnetic activity on recurrence quantification indicators of human electroencephalogram

I. E. Kanunikov, B. V. Kiselev

Saint-Petersburg State University, Russia
E-mail: igorkan@mail.ru

Abstract: The investigation deals with the revealing of influence of a geomagnetic field on human electroencephalogram by means of recurrence quantification analysis (RQA). The EEG base of 10 subjects was processed. The database included electroencephalogram records carried out from 16 points under three background conditions. Each subject took part in 15–50 experiments. EEG was registered from frontal, temporal, central, parietal and occipital areas of the left and right hemispheres. For every subject for each of 16 points of EEG registration 9 recurrent measures of EEG were calculated (RR, DET, L, DIV, ENTR, RATIO, LAM, TT, CLEAN). Then the factor of correlation of these measures with a planetary index of geomagnetic activity of Ap and local daily K-index in a day of carrying out experiment was calculated. As a result of this research the following conclusions were received.

1. Significant influence of intensity of a geomagnetic field on recurrent EEG dynamics indicators is shown. Thus the relationship between recurrent EEG measures and indexes of local intensity of a geomagnetic field appeared higher than with planetary indexes.
2. Existence of significantly bigger number of relations between geomagnetic activity and recurrent measures of the left hemisphere EEG is shown.
3. The conclusion suggests that the geomagnetic field makes the main impact on a chaotic component of EEG.

Keywords: Nonlinear methods, Recurrence quantification analysis, Electroencephalogram, Geomagnetic field, Magnitobiology.

1. Introduction

The investigation deals with the revealing of influence of a geomagnetic field on human electroencephalogram by means of recurrence quantification analysis (RQA). In contrast with chaos method, an important advantage of RQA is that it can deal with a noisy and short time series.

2. Methods and experiments

Recurrence Plots are introduced by Eckmann et. al. (1987) as a tool for visualization of recurrence of states X_i in phase space. This approach enables us to investigate the m -dimensional phase space through a two-dimensional representation of its recurrences.

Zbilut and Webber (1992, 1994) developed RQA for definition of numerical indicators. They offered the measures using density of recurrent



points and diagonal structures of the diagram: indicator of similarity (RR), determinism (DET), maximum length of diagonal lines (L), the maximal length of diagonal structures or its inversion — the divergence (DIV), entropy (ENTR), the ratio between DET and RR (RATIO). Slightly after Marwan et.al. (2004, 2007) offered the measures based on horizontal (vertical) structures of recurrent diagrams: laminarity (LAM) and indicator of a delay (TT). V.B.Kiselev (20007) suggests the indicator CLEAN which shows influence of a stochastic component of process, thus prevalence of the stochastic component leads to increase of CLEAN value.

Expressions for RQA measures are shown below.

The simplest measure of the RQA is the recurrence rate (RR) or percent recurrences which is a measure of the density of recurrence points in the recurrent points. Note that it corresponds to the definition of the correlation sum.

The ratio of recurrence points that form diagonal structures (of at least length l_{min}) to all recurrence points is introduced as a measure for determinism (DET) (or predictability) of the system. The threshold l_{min} excludes the diagonal lines which are formed by the tangential motion of the phase space trajectory.

L is the average time that two segments of the trajectory are close to each other. This measure can be interpreted as the mean prediction time.

Another RQA measure considers the length L_{max} of the longest diagonal line found in the recurrent points, or its inverse, the divergence, $DIV=1/L_{max}$. These measures are related to the exponential divergence of the phase space trajectory. The faster the trajectory segments diverge, the shorter are the diagonal lines and the higher is the measure DIV.

ENTR refers to the Shannon entropy of the frequency distribution of the diagonal lines lengths. This measure reflects the complexity of the deterministic structure in the system.

RATIO is the ratio between DET and RR. This measure is useful to discover transitions when RR decrease and DET does not change at the same time.

LAM is analogous to the definition of determinism. This measure is the ratio between the recurrence points forming the horizontal structures and the entire set of recurrence points. The computation of LAM is realized for horizontal line length that exceeds a minimal length V_{min} .

TT shows average length of laminar states in the system.

In periodical systems fluctuations and noise influence leads in separate points and very short diagonals. The measure *cleanness* (CLEAN) is the ratio between recurrence points in diagonals with lengths less than l_{min} and recurrence points in diagonal lines with lengths equal or more than l_{min} . The measure quantifies influence of noise and fluctuations on system trajectory and should be used if studied system shows periodic behavior.

In this work the EEG base of ten clinically normal subjects (six males and four females in the age range 20– 65 years) was processed. The database included records of electroencephalogram, carried out from 16 sites under

three background conditions: two with open eyes and one with close eyes. During background condition with open eyes subject has to look passively at a picture or thumb through the book. During close eyes subject has to consider drops which were modelled by phonostimulator. In our opinion such simple activity more will balance subjects with each other in comparison with a standard background condition at which it is impossible to check internal state of the subject.

Each subject took part in 20-50 experiments which are carried out to the period of time from half a year till two years. Registration of EEG was carried out in the international system 10/20 in frontal (Fp1, Fp2, F3, F4, F7, F8), temporal (T3, T4, T5, T6), central (C3, C4), parietal (P3, P4) and occipital (O1, O2) sites of the left and right hemispheres. The length of record EEG was about 1 minutes for each of three backgrounds, EEG was quantized with frequency of 250 times a second. The constant of time was 0.3 seconds, and the top frequency of a cut equaled 30 Hz.

3. Results

Before data processing all records were filtrated to escape EEG from different artifacts. For every subject for each of 16 sites and the 3rd background conditions 9 recurrent measures of EEG were calculated (RR, DET, L, DIV, ENTR, RATIO, LAM, TT, CLEAN). Then the coefficient of correlation of these measures with an index of geomagnetic activity was calculated. The coefficient of correlation was calculated on two rows: one row corresponded to defined EEG indicator, and the second – represented values of an index of geomagnetic activity in day of carrying out experience.

As a result of carrying out one experiment about 500 values of recurrent measures (9x16x3) turned out. Two geomagnetic indexes were thus used: planetary Ap and local daily K-index which undertook from a site of the Finnish observatory (Sudancula). At calculation of coefficients of correlation with an index of geomagnetic activity value of correlation were averaged on three background conditions. Tests were significant at $P < 0.05$.

At the first analysis stage significant correlations of 9 recurrent measures of EEG were compared with indexes of planetary and local geomagnetic activity. It appeared that all measures significantly correlated with geomagnetic activity. Total number of significant interrelations for all 10 subjects made in relation to a planetary index was 271, and in relation to a local indicator - 347. Considering that fact that the local index of geomagnetic activity was more sensitive to recurrent EEG measures in comparison with a planetary index, in further calculations it was used only. Thus the maximum quantity of correlations made 44 (for an indicator of DIV), and the minimum number equaled 32 (for a TT indicator). Statistically significant distinctions between quantity of correlations for each of measures it was revealed not. On this basis in the subsequent analysis data on all measures were averaged.

In table 1 are submitted data by number of statistically significant coefficients of correlation between recurrent measures of EEG and local K-

indexes of geomagnetic activity. First, the fact of individual differences in number of correlations which are in range from 14 to 57 attracts attention.

Table 1. Quantity of significant correlations of recurrent measures of EEG with local K-index

Subjects	RR	DET	L	DIV	ENTR	RATIO	LAM	TT	CLEAN	Summa
1	5	4	5	7	5	7	4	5	4	46
2	2	1	4	4	3	1	1	3	0	19
3	11	4	2	8	7	7	9	1	8	57
4	2	2	1	2	1	1	3	0	2	14
5	1	4	3	3	3	4	2	4	4	28
6	4	5	7	9	8	3	3	5	3	47
7	1	5	2	5	3	4	8	3	5	36
8	4	8	5	1	5	2	6	5	7	43
9	1	5	5	4	6	7	4	5	5	42
10	3	1	1	1	1	3	1	1	2	14
Summa	34	39	35	44	42	39	41	32	40	346

The second interesting result consisted that all recurrent measures were characterized by a large amount of correlations for EEG of the left hemisphere in comparison with right. However statistically significant differences took place only for DET measure ($P < 0.02$). As a whole, when averaging all 9 recurrent EEG measures differences between the left and right hemisphere were statistically high-significant ($P < 0.001$).

At the following analysis stage interhemisphere differences of coefficients of correlation for each pair of sites (tab. 2) were considered. Except for pair of sites of C3 and C4 where in the right hemisphere the quantity of correlations was higher, than in left, and in T5, T6 sites where it was equal, in all other pairs of EEG sites the number of correlations at the left was higher than in right. However statistically significant difference was observed only between temporal sites T3 and T4.

Table 2. Quantity of significant correlations of 9 recurrent measures of EEG in different sites with local K-index of geomagnetic activity (data were averaged on 10 subjects)

C3	C4	F3	F4	F7	F8	Fp1	Fp2
24	34	16	14	22	12	37	19
O1	O2	P3	P4	T3	T4	T5	T6
32	21	10	6	35	12	26	26

Research of changes of classical rhythms EEG (α , β , θ) in reply to changes of a geomagnetic field hasn't revealed significant interrelations with K

index. On the other hand primary not filtered signal EEG has revealed such relationship.

4. Discussion

The fact of existence of a large number of correlations between various recurrent EEG measures and index of geomagnetic activity appeared the most important. It testifies that the nonlinear component of EEG for which analysis the RQA method was used, is very sensitive to changes of a geomagnetic field. Carruba et.al. (2007) show that magnetosensory evoked potentials weren't detected when the EEGs were analyzed by time averaging, indicating that the evoked potentials were nonlinear in origin. Obviously, the geomagnetic field influences electric activity of a brain in a nonlinear way. This fact can cause failures in search of reflections in EEG of influences from a geomagnetic field.

That fact that a local index was more closely connected with recurrent EEG measures in comparison with a planetary index is explained by that a local index more precisely, in comparison with planetary, reflects a condition of a geomagnetic field in St. Petersburg being on close longitude.

The fact of very high individual differences found in work concerning quantity of correlations of various recurrent EEG measures with geomagnetic activity, was explained obviously, existence of individual differences concerning sensitivity of subjects to influence on the central nervous system of changes of a geomagnetic field. It should be noted that subjects differed concerning that what by sites EEG significantly correlated with indicators of geomagnetic activity. At the 4th of 10 subjects correlated mainly frontal and temporal sites, at 4 subjects significant correlations were observed practically for all sites, at 2 subjects correlated either frontal, or temporal sites. Similar individual differences were observed in the work of Carruba et.al. (2007). They show that magnetosensory evoked potentials so strongly differ at various subjects that when the results obtained within subjects were averaged across subjects, evoked potentials couldn't be detected.

The most interesting fact concerns high-significant differences concerning number of correlations with recurrent EEG measures of the left and right hemispheres. This result based on a tendency to excess of number of correlations with every recurrent measures of the left hemisphere in comparison with right, and on the high-significant difference received at averaging of all recurrent measures of EEG. The question of why the bigger number of EEG sites of the left hemisphere correlates with changes of a geomagnetic field, remains open. We know that the right hemisphere is closely connected with adaptation processes. So, for example, V.P. Leutin and E.I.Nikolayeva (1988) on the basis of numerous experimental studies drew a conclusion that right brain hemisphere activation is decisive factor, providing adaptation to extreme climate conditions. In our experiments devoted to studying of influence of a geomagnetic field on an indicator of spatial synchronization of EEG, it was

shown that in reply to changes of a geomagnetic field activation of the right hemisphere authentically increases. We connected this result with the stress reaction caused by changes of a geomagnetic field.

In the real experiments more sensitive in relation to variations of a geomagnetic field there was a nonlinear component of EEG of the left hemisphere. The understanding of this result will require further researches.

5. Conclusions

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