

The State of the Cardiovascular System Under the Action of Industrial Electromagnetic Fields

G. V. Gazya¹, V. V. Eskov², M. A. Filatov²,

¹Federal Science Center Scientific-research Institute for System Studies of the Russian Academy of Sciences, Moscow, Russian Federation

²Surgut State University, Surgut, Russian Federation

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Abstract—The influence of industrial low-frequency electromagnetic fields on the human body is currently insufficiently studied. However, such fields are quite common in modern automated production, where various electric drives are used, and they significantly affect the quality of human life. This is especially evident in the conditions of the North, where special ecological factors cause significant changes in the systems of regulation of the body's functions. This study examines the influence of such fields on the parameters of the cardiovascular system of female workers in the oil and gas industry in Russia. Four groups of women were studied, differing in age and electromagnetic field exposure. As a result, the effects of influence of the fields were revealed, especially for the older age group.

Keywords—Industrial electromagnetic fields, cardiointervals, chaos, Eskov-Zinchenko effect.

I. INTRODUCTION

THE influence of industrial electromagnetic fields (EMF) of low frequency and low intensity on the human body is a poorly studied problem of human biophysics and ecology. The study of this problem is especially relevant for workers in the oil and gas sector in the Far North [1-3].

In the North, under the influence of extreme environmental factors (sharp changes in air temperatures, extremely low humidity in rooms in winter, long winters and the influence of polar factors - (cosmic radiation, etc.), significant changes occur in the parameters of various human functions. all it concerns the state of the cardiovascular system (CVS), and various psychiatric disorders (insomnia, lethargy, cognitive impairment, etc.). All of these factors significantly affect the quality and length of human life in the North [3-5].

In our studies, we studied the state of CVS parameters, which is very sensitive to the action of special environmental factors of the North and to the influence of EMF on production. The combination of these two factors also affects changes in CVS parameters. This is what we dedicate our

study to in terms of age-related changes in CVS parameters in oil and gas workers. spheres of Russia.

We conducted these studies for two aged groups in order to research the effects of both weak electromagnetic fields, and study possible age-related changes. It should be noted that age-related aspects (the influence of environmental factors, and electromagnetic fields) have been poorly studied in modern biomedicine [6, 12-16]. Now we are paying special attention to this problem, since the increase in the life expectancy of the visiting population in the North is an important issue of medicine in all countries accessing to the Northern Territories.

II. OBJECT AND METHODS

100 women were examined, oil and gas workers, i.e. living and working in the Khanty-Mansiyski Autonomous Okrug - Yugra (North of Russia). These 100 people were divided into 4 groups (25 people in each): 1st group - women under 35 years old without the effect of EMF on the body, 2nd group - women over 35 years old, without the effect of EMF; Group 3 - women under 35 years old (under the action of EMF) and the 4th group - over 35 years old (under the action of EMF). All four groups were examined according to 6 CVS parameters (using the patented Elox-01 device) Samples were registered at least 5 minutes, according to the recommendation of the European Association of Cardiology: x_1 - SIM - parameter of the state of the sympathetic autonomic nervous system (ANS); x_2 - PAR - the state of the parasympathetic ANS; x_3 - SSS - heart rate parameters; x_4 - SDNN - deviation standard for cardiointervals (CI, RR); x_5 - IBN - CVS tension index (according to R.M. Baevsky); x_6 - parameters of cardiointervals (msec). All these 6 diagnostic features were calculated for each subject (in each group of 25 people) to medians (Me). The obtained samples of 25 Me (for each x_i , in each group) were processed statistically, also up to Me, but for the whole group (of 25 people). Let us explain that in each sample of CI (and other x_i) there were at least 300 values of x_i .

In other words, this was a sufficient sample of cardio intervals and this data should have been representative.

However, the calculations of these samples identified a number of problems that were associated with the further use of statistics in such calculations.

As a result, samples were obtained for five parameters x_i of the entire state vector of the CVS in the form $x = x(t) = (x_1, x_2, \dots, x_6)^T$ in a six-dimensional phase state space (FPS). Further, statistical comparisons were made for each $x_i(t)$ in paired comparisons of samples of all four groups using the Mann-Whitney test. The summary matrix of all paired comparisons of samples (all x was calculated), in which the p values were entered. If $p \geq 0.05$, then these two samples were considered statistically coincident (they could have a common general population). At $p < 0.05$, the samples were considered different, i.e. they do not have a common population.

III. RESULTS AND DISCUSSIONS

We note right away that the statistical comparison of all cardio-vascular system's parameters between all four groups of women showed a rather high percentage of statistical coincidences between the samples. In this case, the Mann-Whitney test for the i -th and j -th samples (for this pair) shows $p_{ij} \geq 0.05$. In other words, this pair can have one (common) general population. We emphasize that all CI samples and other parameters were initially checked for normal distribution. It turned out that 1.5-2% of samples could show a normal distribution, while for the rest of the samples, we obtained an abnormal one; therefore, nonparametric tests were used to analyze the data obtained (for example, the Mann-Whitney test).

Initially, we have built a table to calculate Me medians for the parameters of the cardio intervals. Table 1 with all 25 median cardio intervals for each group is demonstrated. Recall that each such median was obtained from a sample of 300 CI values for each subject.

For each column containing 25 Me, their total Me^C was calculated and a centile estimate was given for each such column Me^C (their mean values were found for 5% and for 95%). While processing this table, we made a pairwise comparison of all 4 samples Me for cardio intervals. As a result, six different pairs were obtained, which showed a very low percentage of statistical differences: $P_i < 0.05$ was less than 50% of all six comparison pairs. In the issue, we decided to check all the other five comparison pairs for their statistical differences.

Table 1. The results of the final statistical processing of 25 medians of individual (for each of 25 subjects) samples of cardiointervals of four groups of women, not exposed (groups 1, 2) and exposed (groups 3, 4) to industrial low-frequency electromagnetic fields, presented in Me, 5% and 95% (percentiles)

Num ber	Group											
	1			2			3			4		
	<i>M</i>	5%	95%	<i>Me</i>	5%	95%	<i>Me</i>	5%	95%	<i>Me</i>	5%	95%
1	59	54	66	71	65	77	73	67	79	73	64	77
	0	0	5	0	0	5	0	0	5	0	5	0
2	78	68	86	83	75	89	74	61	85	83	76	91
	0	5	5	0	0	0	0	5	0	0	0	0
3	75	68	84	74	70	81	73	68	79	79	70	84
	0	5	0	0	0	0	0	0	0	0	5	0

4	83	77	92	73	64	82	69	61	81	69	62	75
	5	0	0	0	0	0	0	5	5	0	5	0
5	84	74	93	78	69	85	67	57	78	72	64	82
	0	5	5	0	5	0	0	0	0	0	0	0
6	74	66	82	86	80	92	72	66	77	10	94	11
	0	5	0	0	0	0	0	0	0	50	0	40
7	71	63	78	90	82	94	77	71	83	74	69	77
	0	0	0	0	5	0	0	0	0	0	0	0
8	63	57	69	80	74	86	65	59	73	66	60	72
	0	0	5	0	5	5	5	0	0	0	0	0
9	63	58	76	83	73	91	76	62	88	80	69	84
	0	0	0	0	0	0	0	5	0	0	0	5
10	85	72	99	98	87	10	62	52	68	86	81	90
	0	5	0	0	5	70	0	0	5	0	0	5
11	71	60	77	70	58	82	63	57	70	76	71	84
	0	5	0	0	0	0	0	5	0	0	0	0
12	87	73	10	66	60	71	67	60	75	70	61	75
	0	0	10	0	0	0	0	0	0	5	0	0
13	68	61	75	87	82	93	69	60	79	93	88	98
	0	0	0	0	0	0	0	0	0	0	0	0
14	58	52	68	81	69	90	56	52	63	64	56	71
	0	0	0	0	0	0	0	0	0	0	5	0
15	79	71	87	95	87	10	72	64	87	76	68	83
	0	0	0	0	0	20	0	0	0	0	5	5
16	85	77	94	60	52	68	67	61	73	59	53	64
	0	0	0	0	0	0	0	0	0	0	0	0
17	80	65	91	74	64	79	78	68	89	55	52	59
	0	5	0	0	0	5	0	0	0	0	0	0
18	72	66	79	66	60	76	62	57	69	61	55	67
	0	0	0	0	0	0	0	0	0	5	0	0
19	70	58	81	10	98	10	73	64	79	86	80	93
	0	0	0	40	0	95	0	0	5	0	0	0
20	81	73	88	90	77	98	83	77	89	76	67	82
	0	0	0	0	5	5	0	0	0	0	5	0
21	73	64	78	88	75	96	10	93	11	71	66	78
	0	5	5	0	5	0	50	5	20	0	0	0
22	74	66	80	61	54	72	65	60	71	78	72	82
	0	0	0	0	5	0	0	0	0	0	0	5
23	87	80	94	72	65	80	69	63	78	79	73	85
	0	0	0	0	0	0	0	0	0	0	0	0
24	82	69	94	71	62	77	76	69	86	74	71	79
	0	0	5	0	5	0	5	0	0	0	0	0
25	83	77	95	79	75	85	89	81	97	70	66	75
	0	0	0	0	0	0	0	0	5	0	0	0
Me	75	59	86	79	62	98	71	61	89	74	58	93
	6	7	9	5	5	1	9	2	2	5	5	2

Groups 1 and 2 - women not exposed to electromagnetic fields under 35 and over 35, respectively; groups 3 and 4 - women exposed to electromagnetic fields under 35 years old and over 35 years old, respectively.

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In Table 1 we present a typical result for CI, where for the 1st age group (without EMF) $Me_1^C = 756$ msec; for the 2nd group (without EMF) $Me_2^C = 795$ msec; for the 3rd group $Me_3^C = 719$ msec (with exposure to EMF) and for the 4th group of women $Me_4^C = 745$ ms (with exposure to EMF). From this table 1 it follows that the effect of EMF (in the 3rd and 4th groups) leads to a significant decrease in the median CI. Moreover, the smallest value $Me_3^C = 719$ msec can be interpreted as a result of the stress factor in the form of a traditional increase in heart rate and a decrease in the value of CI, respectively. Obviously, $Me = 745$ msec. for the first group, that it is similar to the third, but the 1st group has no weak electromagnetic field. In the third group, the CI values are significantly lower, which is also typical for the 4th group (see Table 1)

In physiology and medicine, this phenomenon is recorded as the action of a stress agent. Stress usually decreases the CI value. In our case, this is a stable reaction, because the

measurements of the CVS parameters were carried out within the framework of the professional examination, i.e. on a non-working day. This proves the stability of the reaction to a decrease in the CI values, since the subjects did not work that day and were not exposed to EMF. In other words, the low values of CI medians for Me sample of each P are caused precisely by the action of weak electromagnetic fields, which sharply reduced the CI value (from Me1 = 756 msec. To Me3C = 719 msec.). Moreover, the fourth Me4C = 745 msec. did not even approach the value of Me1 of the younger age group (Without exposure to weak electromagnetic field). All this proves the real effect of EM field on the parameters of CVS of women - working in the oil and gas industry of Russia.

Let us emphasize that the 4th group (over 35 years old, under the influence of EMF) demonstrates the value of Me₄^C = 745 msec, which is less than Me₁^C (for the younger group without EMF). It should be noted that the CI value increases with age (heart rate falls), but our older group (with EMF) does not reach the values of the Me₁^C younger group (without EMF). This clearly reflects the state of the CI and the entire CVS.

As a result, we performed similar calculations for all 5 parameters x_i(t) and obtained tables for the remaining four x_i, which are similar to Table 1. In all cases, the women of the third and fourth groups significantly differed in the medians of 25 samples x_i(t) in comparison with women of the first and second groups (without the effect of EMF).

We will not present all four other tables, but present the final results of pairwise comparison of all five x_i(t) for all four groups of women. The results of such a pairwise comparison of samples are given in the summary Table 2. Here are the results of calculating the Mann-Whitney test p_{ij} for all i-x and j-x pairs of all x_i(t). This is a generalized table for five x_i(t).

Recall that the samples of 25 Me were compared for each parameter x_i(t). If p_{ij} ≥ 0.05, then such a pair of samples Me for x_i(t) can have one common general population. In this case, such a pair may statistically coincide. The general calculation of all Mann-Whitney criteria p_{ij} showed that out of all 30 different pairs of comparisons, exactly 13 pairs showed p_{ij} ≤ 0.05. These pairs are statistically different (see Table 2).

The other 17 comparison pairs showed p_{ij} ≥ 0.05, i.e. they can statistically coincide (they can have a common general population). In this case, we represent such a situation as the first type of uncertainty (FTU). For FTU, statistics show predominant coincidences of pairs of samples, which in reality may not be [6-9].

Table 2. Results of pairwise comparison of the mean values of the ranks of the admissible level of significance of the parameters of heart rate variability of the examined groups 1 - 4 using the nonparametric U criterion Mann - Whitney

Parameter	Values of the criterion p in pairwise comparison					
	1 - 2	1 - 3	1 - 4	2 - 3	2 - 4	3 - 4
SIM	0.052	0.045 *	0.000 *	0.778	0.001 *	0.005 *
PAR	0.304	0.793	0.000 *	0.516	0.003 *	0.001 *
SSS	0.352	0.109	0.749	0.023 *	0.224	0.202
SDNN	0.084	0.050	0.000 *	0.655	0.037 *	0.108
IBN	0.107	0.084	0.000 *	0.808	0.001 *	0.007 *

Women under 35 years old without exposure to EMF sources, 2 - women over 35 years old without exposure to EMF sources, 3 - women under 35 years old under the influence of EMF sources, 4 - women over 35 years old under the influence of EMF sources; p is the achieved level of significance (at the critical level p < 0.05); * - groups p statistically belong to different general populations.

Women under 35 years old without exposure to EMF sources, 2 - women over 35 years old without exposure to EMF sources, 3 - women under 35 years old under the influence of EMF sources, 4 - women over 35 years old under the influence of EMF sources; p is the achieved level of significance (at a critical level < 0.05); * - the groups statistically belong to different general populations.

First type of uncertainty shows low efficiency of statistics and here other methods of calculating and assessing differences in CVS parameters are needed. One of these methods is the use of artificial neural networks (ANNs). These ANNs can distinguish the sample and then the FTU can be allowed and the samples will differ [2, 14-16].

Application of FTU, i.e. the prevalence of the absence of statistical differences in the samples of CVS parameters in our case is interpreted in two aspects. First, the effect of EMF and age-related changes in CVS parameters are so insignificant that it is difficult for traditional statistics to demonstrate them. On the other hand, statistics really show low efficiency, since ANN solves this problem [2, 10-12].

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All physiology and biomedicine have now approached a certain threshold, after which the sensitivity of calculation methods should be increased and new methods for assessing changes in the parameters of not only CVS, but also other life support systems (including brain neural networks) should be created [10-12]. Within the framework of the new theory of chaos-self-organization (TCS), we have now shown the lack of statistical stability of samples of various parameters of the functions of the human body [1-3, 6-19]. This is now referred to as the Eskov-Zinchenko effect (EES) [1-3, 5, 6, 13-16].

This means that any sample of any parameter x_i(t) of the functions of the human body can be unique, it is not statistically repeatable (two times in a row). W. Weaver wrote about this more than 70 years ago, but little attention was paid to his work [20]. As a result, we proved the Eskov-Zinchenko effect (EEZ), which in TCS is defined as type 2 uncertainty (lack of statistical stability of the sample x_i(t)) [1-3, 5, 6, 13-19].

In TCS, new methods and models have been developed that ensured the resolution of type 1 uncertainty (see above) and type 2 uncertainty. These new methods and models made it possible to bring biomedicine to a completely new level in assessing the state of various functions of the human body. In TCS, the concept of a pseudo-attractor (PA) is introduced,

which allows one to get rid of the second type of ambiguity both in the study of CVS and in the study of the neuromuscular system, in the study of neural networks of the brain and all electrophysiology.

IV. CONCLUSION

Studies of four different (by age and exposure to EMF) groups of women workers in the oil and gas sector in the North of the Russian Federation have shown that the influence of the environmental factors of the North and the effects of industrial EMF causes statistical differences in the parameters of CVS. Significant changes in the direction of decreasing CI values showed by medians of cardiointervals of two age groups of women in conditions of EMF exposure.

However, further study of the samples of all five CVS parameters showed the presence of the first type of uncertainty. Most of the pairs of comparison of all five parameters showed statistical coincidence according to the Mann-Whitney test (17 pairs out of 30). They showed statistical coincidence of the Me samples. We interpret this as type I uncertainty. It can be solved by applying new methods using artificial neural networks. Within the framework of statistics, uncertainties of the 1st and 2nd types cannot be resolved. New TCS methods also open up new opportunities in biomedicine.

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