Short communication

The Effect of Electromagnetic Field on the Heart Rate of Rabbits

B. LAŽETIĆ, B. NIKIN

1 *Faculty of Medicine, University of Novi Sad, Hajduk Veljkova 3, 21000 Novi Sad, Yugoslavia*
2 *Faculty of Technology, University of Novi Sad, 21000 Novi Sad, Yugoslavia*

Magnetic field of any origin influences both the individual parts of the body and the organism as a whole. Magnetic fields do not remain without effect on the human body either; data in the literature suggest magnetic field induced disorders in nervous, endocrine, vegetative, cardiovascular and other systems (Udincev and Hlinin 1980; Holodov 1982; Lažetić et al. 1982; Lažetić et al. 1984a; Milin et al. 1984).

Our previous investigations (Lažetić et al. 1984a) were concentrated on studying effect of a constant magnetic field on the heart rate of rats, the field being applied locally to the head region.

Further experiments dealt with the influence of whole body pulse electromagnetic field on rats, and their heart rate (Lažetić et al. 1984b).

The results of these investigations led us to construct an apparatus for the examination of effects of the electromagnetic field on rabbits under the conditions of whole body exposure to defined electromagnetic field.

Experiments were performed on 13 adult chinchilla rabbits of the Central European breed.

The animals were placed between Helmholz coils. Each coil had 2000 turns, a current with an intensity of 10 A was turned on. The coils were at 0.30 m from each other. This distance as well as cooling provided by water circulating through special pipes enabled that the animals were at room temperature. The cross section of the wire was 6 mm^2.

During the experiment, the animals were conscious and half-fixed; subcutaneous electrodes were used to record electrocardiogram (the second lead) on an EI Niš Hellige ECG apparatus (paper speed 50 mm/s).

Each electrocardiogram was recorded over a period of 150 minutes: 30 minutes prior to the exposure of the animal to the electromagnetic field; 60 minutes during the exposure and 60 minutes after the exposure. The electromagnetic field acting on a defined area of the thorax, had an intensity of 21.3 mT. Records were made during the last minute of every 5 minutes. The heart rates were calculated from heart cycles.

The statistical significance was tested using the Student *t* test.

Table 1. Mean values of heart rate in rabbits (n = 13)

Before the exposure to the magnetic field Time (min)	5	10	15	20	25
Mean	283.46	273.46	273.00	272.31	272.31
Standard deviation	14.34	8.99	8.55	8.32	8.32
2 Standard deviations	28.68	17.98	17.10	16.64	16.64

During the exposure to the magnetic field Time (min)	5	10	15	20	25	30	35	40	45	50	55	60
Mean	263.00	253.85	246.92	240.77	244.62	244.62	253.85	246.92	237.69	242.31	242.31	240.00
Standard deviation	17.97	14.31	11.64	18.80	19.73	9.46	14.31	13.36	14.81	22.79	22.79	12.20
2 Standard deviations	35.94	28.62	23.28	38.60	39.46	18.92	28.62	26.32	29.62	45.58	45.58	24.50

After the exposure to the magnetic field Time (min)	5	10	15	20	25	30	35	40	45	50	55	60
Mean	251.54	256.15	259.23	261.15	257.31	255.00	255.00	258.46	253.85	255.00	256.15	256.90
Standard deviation	13.90	22.47	20.80	22.93	25.13	22.91	22.91	22.21	20.73	20.31	18.05	17.90
2 Standard deviation	27.80	44.94	41.60	45.89	50.25	45.82	25.82	44.42	41.46	40.46	36.10	36.90

Table 2. Heart rates in rabbits during the exposure to the magnetic field

Time (min)	5	10	15	20	25	30	40	50	60
Measured values	263.00	253.85	246.92	240.77	244.62	244.62	246.92	242.31	240.00
Theoretical values	261.71	255.10	250.00	247.00	245.77	244.47	243.00	242.47	242.20

Table 3. Heart rates after the exposure to the magnetic field

Time (min)	5	10	15	20	25	30	40	50	60
Measured values	251.54	256.15	259.23	261.15	257.31	255.00	258.46	255.00	256.92
Theoretical values	257.00	257.10	256.91	256.64	256.36	256.07	255.50	254.94	254.42

Table 1 summarizes the results (mean values and standard deviations), obtained prior to, during, and after the exposure to electromagnetic field.

During the first 30 minutes, the average heart rate was approximately 270 bpm. Under the action of a constant electromagnetic field (21.3 mT) applied to the thorax the heart rate decreased reaching a minimum after 45 minutes of exposure. The minimum was by 12.9 % lower than the initial value ($p < 0.001$).

It is apparent from the results shown in Table 1 that after field was turned out, the heart rate increased within 15—20 minutes and remained almost constant thereafter; yet the pre-exposure values were not reached even after 60 minutes.

Further analysis was based on the assumption that electromagnetic field affects the heart function in a significant manner and that the exposure induced heart rate change whit can be expressed (Lažetić et al. 1984a) as

$$\left[\frac{\mathrm{d}f}{\mathrm{d}t}\right]_B = -g(B) \tag{1}$$

where f means heart rate and B magnetic induction. In our experiments the electromagnetic field was produced by direct current (10 A).

However, the animal organism posseses compensation mechanism which operate against field-induced heart rate changes. The role of these mechanisms can be expressed as

$$\left[\frac{\mathrm{d}f}{\mathrm{d}t}\right]_C = \frac{1}{\Theta}(f_0 - f) \tag{2}$$

where C means compensation mechanism and Θ is the time constant dependent only on compensation mechanism.

The resulting change in heart rate is the sum of both actions,

$$\left[\frac{\mathrm{d}f}{\mathrm{d}t}\right] = \left[\frac{\mathrm{d}f}{\mathrm{d}t}\right]_B + \left[\frac{\mathrm{d}f}{\mathrm{d}t}\right]_C \tag{3}$$

or

$$\left[\frac{\mathrm{d}f}{\mathrm{d}t}\right] = -g(B) + \frac{1}{\Theta}(f_0 - f) \tag{4}$$

By solving the linear differential equation obtained, we yield a general solution

$$f = f_0 + \mathrm{A}\mathrm{e}^{-\frac{t}{\Theta}} - \Theta g(B) \tag{5}$$

where A is the integral constant. In accordance with the initial conditions, $t = 0$ and $f = f_0$, the constant A in the general solution has the form

$$\mathrm{A} = \Theta g(B)$$

Hence the particular solution (the particular integral) can be written as

$$f = f_0 - \Theta g(B)[1 - e^{-\frac{t}{\Theta}}] \tag{6}$$

The experimentally obtained results could be computed from the particular solution for $\Theta = 12$ and $g(B) = 2.5$.

This is true for the exposure period only. The reference date are shown in Table 2.

After the magnetic field has been turned off the value of $g(B)$ is zero, and the heart rate at that moment is f_1. For this time interval characterized as the period of heart rate recovery the integration constant A can be calculated from the initial conditions, i.e., $t = 0$, and $f = f_1$,

$$\mathrm{A} = -(f_0 - f_1)$$

The particular solution to the differential equation for this time period will take the form

$$f = f_0 - (f_0 - f_1) \tag{7}$$

However, data obtained experimentally show that the value of Θ is not constant during this latter time interval (see Table 3).

The values of the time-dependent function Θ were determined by statistical methods (Table 4). Using the least squares method we get a second degree parabola.

Normal equations are:

$$\begin{aligned} 497 &= 11a_0 + 0a_1 + 110a_2 \\ 913 &= 0a_0 + 111a_1 + 0a_2 \\ 5149 &= 110a_0 + 0a_1 + 1598a_2 \end{aligned}$$

The coefficients calculated from the above system are

$$a_0 = 43.1; \quad a_1 = 8.30; \quad a_2 = 0.21$$

The parabola is given by

$$\Theta(x) = 43.1 + 8.30x + 0.21x^2 \tag{8}$$

To introduce time we put

$$x = \frac{t - 30}{5}$$

and thus

$$\Theta(t) = 0.008t^2 + 1.18t + 0.5 \tag{9}$$

This function $\Theta(t)$ roughly yields the values of Θ that appear in Table 3,

Table 4. Statistical data for 0

Time (min)	X	Measured $0(X) = Y$	X^2	X^3	X^4	XY	X^2Y
5	−5	12	25	−125	625	−60	300
10	−4	12	16	−64	256	−48	192
15	−3	18	9	−27	81	−54	162
20	−2	20	4	−8	16	−40	80
25	−1	30	1	−1	1	−30	30
30	0	50	0	0	0	0	0
35	1	60	1	1	1	60	60
40	2	50	4	8	16	100	200
45	3	80	9	27	81	240	720
50	4	80	16	64	256	320	1280
55	5	85	25	125	625	425	2125
	$\Sigma X = 0$	$\Sigma Y = 497$	$\Sigma X^2 = 110$	$\Sigma X^3 = 0$	$\Sigma X^4 = 1958$	$\Sigma YX = 913$	$\Sigma X^2Y = 5149$

which also shows the corresponding experimental values. This suggests that after the electromagnetic field has stopped acting, the compensatiom mechanism acts to bring heart rate to pre-exposure values. The dipendence of the post-exposure heart rate changes can be expressed by the following analytical expression:

$$f = f_0 - (f_0 - f_1)\,e^{\frac{-125t}{t^2 + 147t + 62.5}} \tag{10}$$

which reasonably fits the experimentally obtained values shown in Table 3.

The present results are very similar to those obtained previously with electromagnetic fields with different characteristics and with different biological objects (Lažetić et al. 1984a; Lažetić et al. 1984b). This further supports the view that electromagnetic fields may have significant effect on biosystems. Regarding the explanations of the mechanisms through which the fields exert effects upon the heart rate, we believe that the most appropriate interpretation of the mechanisms of action of electromagnetic fields is provided by the theory as applied to biological system by Anokhin (1973). The principal assumptions of the theory of functional system can be summarized as follows.

By its nature, the physiological auto-regulation is an automatic process, in which the agents causing disturbing effects on an organism, and the forces directed towards the elimination of the disturbing effects, always show definite quantitative relationship. In a normal organism under normal conditions the regulating mechanisms are always stronger than agents inducing disturbing effects. It follows from the above that the electromagnetic field as an external disturbing agent induces disturbances to the equilibrium of a living organism. The heart rate as one physiological parameter, in particular at rest, is well known to be determined by two components: The parasympathetic and sympathetic system when the other regulating mechanisms are ignored. In our previous studies (Lažetić et al. 1984a) a decrease in the QRS complex voltage and increased or decreased T waves were observed in addition to bradycardia. The decreased heart rates observed in the present experiments allow the conclusion that the electromagnetic field effects are due to enhanced vagotony which cannot be adequately balanced by the tonus of the sympathetic system. This is further supported by the observation of heart rate oscillations in particular during the exposure to the electromagnetic field. The factors in the organism which had been exhausted by opposing the effects of the external disturbing agent, were not able, during 60 minutes of the recovery period to counterbalance the disturbance and to bring the system back to its starting position.

We denoted Θ the ability of the compensation mechanisms to resist the effects produced by the electromagnetic field, and hence to oppose shifts from the optimal state of the functional system. From Table 3 one can see that Θ is smallest during the first few minutes after the action of the field had been interrupted, and increases thereafter.

We believe that information on functional ability of compensation mechanisms can be obtained from the initial values of the heart rate and the intensity of the field using the above mathematical models.

Although results of similar experiments appear quite frequently this approach requires investigations as does the the interpretation of the mechanisms involved in the action of magnetic fields on biological systems.

References

Anohin P. K. (1973): Principles of System Organisation of Functions. Nauka, Moscow (in Russian)

Holodov J. A. (1982): The Brain in Electromagnetic Fields. Nauka, Moscow (in Russian)

Lažetić B., Milutinović B., Pavlov M., Bajić M. (1984a): Effect of constant magnetic field on heartbeat rate in rats. Proceedings of Natural Sciences. Matica Srpska **66**, 107—117

Lažetić B., Pavlov M., Šovanj Ž., Bajić M. (1984b): Of pulsed magnetic field of heartbeat rate in rats. Proceedings of Natural Sciences, Matica Srpska. **67**, 15—31

Milin J., Bajić M., Lažetić B., Pavlov M. (1984): Morphodynamic response of the pineal gland to an initial magnetic field action. Eur. Rev. Med. Pharmacol. Sci. **6**, 5—18

Udintsev N. A., Hlynin S. M. (1980): Influence of Magnetic Fields on Tests. Publishing House of the Tomsk University, (in Russian)

Final version accepted March 28, 1988