Radiat Environ Biophys (1996) 35: 199–204

ORIGINAL PAPER

L. Korpinen · J. Partanen

Influence of 50-Hz electric and magnetic fields on human blood pressure

Received: 6 June 1994 / Accepted in revised form: 11 March 1996

Abstract This investigation studied the effects of 50-Hz electric and magnetic fields on the pulse rate and blood pressure in humans. Electrocardiograms (ECG) and the blood pressure of 41 male volunteers were recorded using ambulatory methods. Twenty-six subjects were measured in and outside real fields and 15 subjects in and outside 'sham' fields. The results of the ECG recordings have been presented earlier. This article deals with the analysis of the blood pressure measurements. Measurement took 3 hrs. First, the subjects spent 1 h outside the fields, then 1 h in real or 'sham' fields, followed by 1 h outside the fields. The electric field strength varied from 3.5 to 4.3 kV/m and the magnetic flux density from 1.4 to 6.6 μT. When analysing the blood pressure, which was measured with a noninvasive cuff method, it could not be shown that the fields (<4.3 kV/m and <6.6 μT) affected diastolic or systolic blood pressure.

Introduction

The physiological effects of electric and magnetic fields on humans have been studied at Tampere University of Technology. One aim of the studies was to examine the electric and magnetic fields of transmission lines and to evaluate their possible biological effects on workers.

An earlier investigation at Tampere University of Technology studied the effect of 50-Hz electric and magnetic fields on the human heart in 53 male subjects. In this study the ECG analysis indicated that there were no extrasystoles or arrhythmias. In some cases a small decrease in heart rate was observed during exercise (walking) outside the field after the exposure[1, 2].

L. Korpinen (✉)
Power Engineering Group, Tampere University of Technology, Box 692, FIN-33101 Tampere, Finland

J. Partanen
Power Engineering, Lappeenranta University of Technology, Box 20, FIN-53581 Lappeenranta, Finland

The effect of the electric and magnetic fields on blood pressure has been investigated earlier. When monkeys were exposed to a 1.5-T static (stationary) field, no changes in their arterial pressure were demonstrable [3]. In another study dogs were exposed to field strengths over 10 kV/m, and transient increases in blood pressure were detected [4]. Studies of blood pressure measurements on human volunteers exposed to 50/60-Hz electric and magnetic fields have not yet been performed. However, in addition to blood pressure, heart rate is important when assessing the effect of the fields on the human cardiovascular system.

Some studies by Graham et al. [5] suggest that power-frequency electric and magnetic fields influence the human cardiovascular system. They evaluated exposure effects on over 200 healthy young men at several levels of field strength, and under both intermittent and continuous exposure conditions. The laboratory studies showed that compared with sham exposure, field exposure had a significant effect on the human cardiovascular system. A slowing response was observed in four studies in which fields of 9 kV/m and 200 mG (20 μT) were used, arising after 2 h and 6 h of exposure. The response did not occur in two studies of exposure to stronger fields, 12 kV/m and 300 mG (30 μT), nor when subjects were exposed to weaker fields, 6 kV/m and 100 mG (10 μT). The cardiac slowing response does not appear to be cumulative, and the effect is not a function of exposure duration or field strength. Their results indicate that there might be amplitude 'windows' in which effects on the heart are observed [5, 6].

In addition, Graham et al. [6] observed that periods of short intermittent field exposure could induce both speeding and slowing of the human heart rate, when the field strengths were 9 kV/m and 200 mG. Additional analyses indicated that the pre-exposure heart rate (HR) was a significant ($P \leq 0.01$) predictor of subject's individual cardiac reactivity. Those with slower baseline HR showed both speeding and slowing of HR during exposure, whereas those with faster baseline HR showed only a slowing effect. Graham et al. did not measure blood pressure [5, 6].

The aim of the study

In our earlier study during the analysis of the ECG recordings [7], we found a decrease in pulse rate after exposure in some cases, but it is possible that the changes in pulse rate were caused by small changes of physical load [1]. Therefore, we designed a new study, the main aim of which was to investigate the possible changes in the pulse rate when the subjects were exposed to 50-Hz electric and magnetic fields. In addition, we wished to study other possible changes in the whole cardiovascular system, in order to elucidate possible reasons for the pulse changes. For example, changes in blood pressure may affect the pulse rate. Therefore, blood pressure was also measured.

Some of the results, namely the influence of the fields on pulse rate, have been published already [7].

Subjects and methods

Subjects

There were two groups: group 1, 26 male volunteers, were measured in real fields and group 2, 15 male volunteers, in 'sham' fields. Group 1 consisted of two subgroups: 18 subjects were measured outdoors and 8 in tents. In group 1 the men were 21–41 years old; the mean age ± standard deviation (SD) was 28.2 ± 5.2 years. Group 2 included 22- to 48-year-old men, and the mean age ± SD was 27.9 ± 6.4 years.

The subjects did not have any known illnesses nor were taking long-term medication. Other factors (e.g. activity prior to the test) were not analysed.

Test environment

The subjects of group 1 spent first 1 h outside the field, then 1 h inside, exposed under a 400-kV transmission line, and then again 1 h outside the field. There were also 110-kV transmission lines beside the 400-kV transmission line. When entering and exiting the real field (under the transmission lines), the subjects of group 1 had to walk a short distance (200 m). This 5-min period has been taken into account in the evaluation of results.

As sham exposure was not possible under 400-kV transmission lines, a 33-kV outdoor testing station was used for group 2. The 'sham' field was switched on and off by opening and closing the manually operated disconnector, which the subjects were able to see. In practice, there was no voltage or current even when the disconnector was closed, but the subjects were not aware of this fact. The background fields were below 0.01 kV/m and 0.01 μT. Under the circumstances, we could not make the subjects walk, because we wanted the test situation to be as real as possible.

Methods

ECG, blood pressure and EEG were measured using ambulatory methods. The blood pressure was measured every 10 min, except in the orthostatic tests, in which additional measurements were taken. The test protocol (Fig. 1) of both groups was similar. In the protocol, periods 1 and 3 (before and after the fields) were the same. First the subjects were sitting down (0–30 min) and then (31–60 min) they executed some cardiovascular autonomic function tests: orthostatic test, Valsalva manoeuvre and deep breathing [8, 9]. During the field exposure, period 2, the subjects were sitting down and, in order to maintain mental activity, performed some Ruddel's mental arithmetic tasks. In period 3 (after the fields) they were sitting down (120–150 min) and then (151–180 min) they executed the cardiovascular autonomic function tests again.

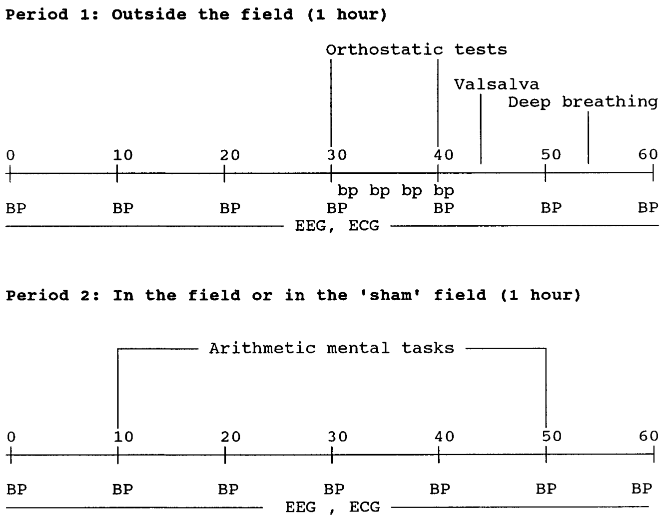

Fig. 1 Test protocol; BP, systematic blood pressure measurement; bp, manual blood pressure measurement; ECG, electroencephalogram; EEG, electrocardiogram

Ambulatory blood pressure measurement

For the blood pressure measurements systolic and diastolic blood pressures and average heart rate were registered by means of an automatic, non-invasive cuff method as follows. An ordinary cuff is placed around the upper left arm. The compressor fills the cuff with air every 10 min. The cuff is also equipped with a microphone to record arterial sounds on a recorder with a microprocessor. The recorder is on the subject's waist. If the measuring fails, the recorder repeats the measurement. After the whole measuring procedure, the results are printed out on paper.

Electric and magnetic field measurement

The electric fields were measured with a modified spheroidal dipole meter designed and made by Imatran Voima (IVO). The spheroidal dipole includes two hemispheres which deform electric fields in a known way, and the current between them is the measure of electric field strength. According to the IEEE standard [10], electric fields are measured near transmission lines at a height of 1 m. The distance between the operator and the meter must be at least 2.5 m, otherwise, the operator affects the results. Under these conditions the measurement error caused by the operator is 1.5–3%.

The standard recommends measuring the magnetic field with a screened loop antenna. The measuring height is the same as for electric fields. The operator does not affect the measurement results, as in measuring electric fields. The magnetic field was also measured with a meter made by IVO. The sensitivity of the meters was 0.01 kV/m and 0.01 μT.

Results and discussion

The measurements were taken outdoors in summertime (in daylight). The mean ambient temperature ±SD was

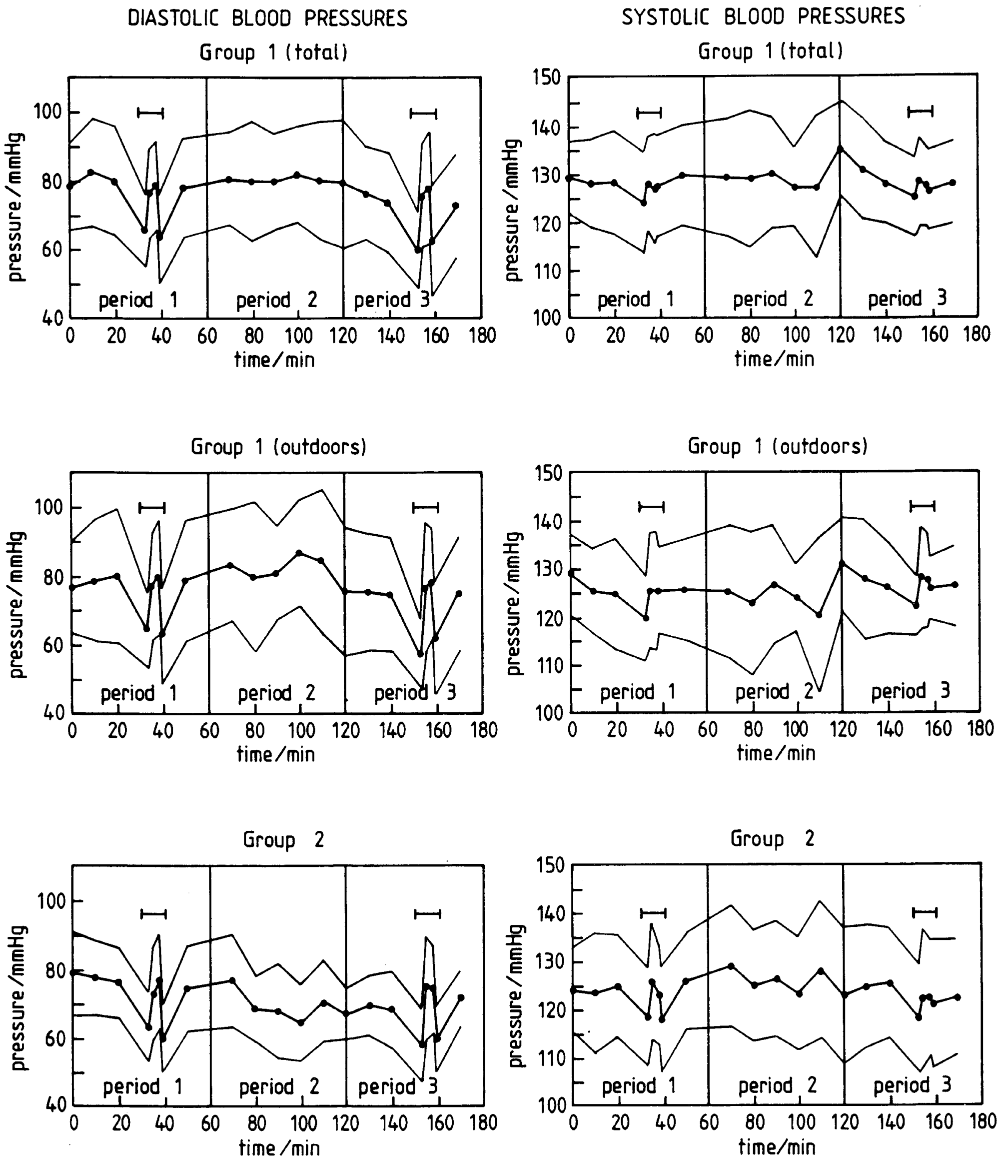

Fig. 2 Average and standard deviation graphs of blood pressure in group 1 (total $n=16$, outdoors $n=9$) and in group 2 ($n=12$). The orthostatic tests were realized in the following way: 5 min lying down, standing up, 3 min standing, lying down, 2 min lying. |——| signifies orthostatic test

19.3 ° ±3.5 °C. The measurements were started every weekday at 8:30 a.m. by setting up the electrodes and recorders.

Measured field strengths

The field strengths were always measured briefly at the beginning of the exposure period. The measured field strengths under the 400-kV line varied between 3.5–4.3 kV/m and 1.4–6.6 µT. The mean field strength ±SD for the electric field was 4.1 ± 0.2 kV/m and for the magnetic field, 4.8 ± 1.4 µT. Compared to our first study the measured field strengths are about the same [1].

Evaluation of the blood pressure

Ten recordings of group 1 (9 measured outdoors and 1 measured in a tent) and three recordings of group 2 were partly faulty. A recording was considered partly faulty if even one of the subject's blood pressure measurements failed, i.e. the recorder registered no results. Under the given circumstances disturbances easily affect the recorder. Therefore, the measurements from 28 subjects were analysed.

Figure 2 presents the average ±SD of the diastolic and systolic pressures of group 1 (total $n=16$, outdoors $n=9$), and of group 2 ($n=12$). The peaks in the pressure curves outside the fields (35 min and 155 min) are caused by the orthostatic tests, which were realized in the following way: 5 min lying down, standing up, 3 min standing, lying down, 2 min lying.

Comparison of blood pressure before and after exposure

The first aim was to compare the same subjects' blood pressure before and after exposure to electric and magnetic fields. The hypothesis was that blood pressure changes after exposure to a real field. In the test protocol, periods 1 and 3 were the same, so it was possible to compare period 1 with period 3. The subjects were sitting down for half an hour in period 1 (1–30 min) and in period 3 (121–150 min). These time periods are similar, and the cardiovascular autonomic function tests do not change the blood pressure, so it is relevant to compare these time periods. In addition, the results obtained during cardiovascular autonomic function tests were analysed. One problem is the subjects' vigilance, which could vary a little between periods 1 and 3, because the measurement time was 3 h. Stress may also have some effect on the results.

Table 1 The subjects' blood pressure before exposure compared to blood pressure after exposure using *t*-test for matched pairs

Analyzed time points + meantime errors (min)		*t*-test for matched pairs		
Period 1	Period 3	Group 1 (outdoors) (f=8)	Group 1 (total) (f=15)	Group 2 (f=11)
Diastolic blood pressure				
0 (2.6)	120 (1.4)	0.45	–0.45	2.75*
10 (2.7)	130 (1.4)	1.02	2.13*	2.70*
20 (2.8)	140 (1.4)	1.16	1.83	2.27*
33 (0)	153 (0)	2.83*	2.80*	1.57
35 (0.3)	155 (0.5)	0.01	0.08	–0.61
38 (–0.4)	158 (–0.5)	0.79	0.15	1.16
39 (0.3)	159 (0.3)	0.25	0.27	0.07
60 (–3.2)	180 (–4.4)	1.11	2.20*	0.88
Systolic blood pressure				
0 (2.6)	120 (1.4)	–0.51	–2.25*	0.44
10 (2.7)	130 (1.4)	–0.89	–1.32	–0.42
20 (2.8)	140 (1.4)	–0.42	0.08	–0.26
33 (0)	153 (0)	–0.81	–0.45	0.17
35 (0.3)	155 (0.5)	–0.77	–0.13	1.52
38 (–0.4)	158 (–0.5)	–0.83	–0.28	0.23
39 (0.3)	159 (0.3)	–0.09	0.39	–1.83
60 (–3.2)	180 (–4.4)	–0.16	0.55	1.67

* $P \leq 0.05$

Table 2 Comparison of diastolic blood pressure before and after exposure, F-ratios and probabilities (P) of two-factor ANOVA with replication (f=degree of freedom)

Analyzed time points		Two-factor ANOVA with replication					
Period 1	Period 2 or 3	Subject		Period		Interaction	
		F	P	F	P	F	P
Group 1 (outdoors)		f=(8, 18)		f=(1, 18)		f=(8, 18)	
10, 20	70, 80	9.86	<0.01	0.32	0.58	0.77	0.63
10, 20	90, 100	25.52	<0.01	4.75	0.04*	3.36	0.02*
10, 20	130, 140	31.87	<0.01	5.30	0.03*	3.12	0.02*
Group 1 (total)		f=(15, 32)		f=(1, 32)		f=(15, 32)	
10, 20	70, 80	8.70	<0.01	0.13	0.72	1.00	0.48
10, 20	90, 100	13.04	<0.01	0.02	0.88	2.36	0.02*
10, 20	130, 140	15.32	<0.01	11.96	<0.01	2.09	0.04*
Group 2		f=(11, 24)		f=(1, 24)		f=(11, 24)	
10, 20	70, 80	4.42	<0.01	3.20	0.09	1.59	0.16
10, 20	90, 100	10.34	<0.01	42.26	<0.01	4.27	<0.01
10, 20	130, 140	10.08	<0.01	27.35	<0.01	3.21	0.01*

* $P \leq 0.05$

Group 1 consisted of two sub-groups: subjects who were measured outdoors and subjects who were measured in tents when it was raining. When the subjects were in the tent, the electric fields changed, and so the exposure fields changed, too. Therefore, in statistical analysis, we used both the entire group and also the sub-group of subjects who were measured outdoors.

In the analysis we compared the subjects' systolic and diastolic blood pressure before exposure to the values afterwards (group 1 (outdoors)/group 1 (total)). We calculated the differences in blood pressure of all subjects at all measurement points, e.g. the differences between blood pressure at 0 min and blood pressure at 120 min. The differences at eight measurement points (1–60 min and 120–180 min) were compared by using *t*-tests for matched pairs. Then we compared the subjects' blood pressure before the 'sham' exposure to the values after 'sham' exposure (group 2). The differences of group 2 and results of *t*-tests for matched pairs were also analysed (Table 1).

A similar comparison was made with a two-way analysis of variance (ANOVA) with replication (Tables 2 and 3). The analysis was made for each group in the following way: period 1 (10 min, 20 min) compared with period 2 (70 min, 80 min); period 1 (10 min, 20 min) compared with period 2 (90 min, 100 min); period 1 (10 min, 20 min) compared with period 3 (130 min, 140 min). The cardiovascular function test points were not included in the analysis, because the tests may cause errors.

According to the *t*-tests for matched pairs, in group 1 (outdoors) the result of diastolic blood pressure was significant ($P \leq 0.05$) (difference before and after exposure) at one point; in group 1 (total) the result was significant ($P \leq 0.05$) at three points; and in group 2, the result was significant ($P \leq 0.05$) at three points. In Table 2 (results of ANOVA) P is always less than 0.01 related to the factor subject. When period 1 (10 min, 20 min) is compared with period 2 (90 min, 100 min) or with period 3 (130 min, 140 min), interaction can be detected ($P \leq 0.05$ or 0.01). It is difficult to draw conclusions from these results, but the differences in diastolic blood pressure seem to derive from the interaction of the two factors, subjects and periods.

According to the *t*-tests for matched pairs in group 1 (outdoors), the result of systolic blood pressure was not significant ($P \leq 0.05$) (no difference before and after exposure) at any point; in group 1 (total) the result was significant ($P \leq 0.05$) at one point; and in group 2, the result was not significant ($P \leq 0.05$) at any point. Table 3 (results of ANOVA) shows that $P \leq 0.01$ related to the factor subject, and there is interaction between subjects and periods in group 1 (outdoors and total).

Table 3 Comparison of systolic blood pressure before and after exposure, *F*-ratios and probabilities (*P*) of two-factor ANOVA with replication (*f*=degree of freedom)

Analyzed time points		Two-factor ANOVA with replication					
Period 1	Period 2 or 3	Subject		Period		Interaction	
		F	*P*	*F*	*P*	*F*	*P*
Group 1 (outdoors)		*f*=(8, 18)		*f*=(1, 18)		*f*=(8, 18)	
10, 20	70, 80	9.47	<0.01	0.28	0.60	5.62	<0.01
10, 20	90, 100	10.17	<0.01	0.04	0.85	2.37	0.06
10, 20	130, 140	33.84	<0.01	2.99	0.10	5.87	<0.01
Group 1 (total)		*f*=(15, 32)		*f*=(1, 32)		*f*=(15, 32)	
10, 20	70, 80	10.43	<0.01	0.43	0.52	4.11	<0.01
10, 20	90, 100	11.02	<0.01	0.24	0.63	2.23	0.03*
10, 20	130, 140	16.44	<0.01	1.81	0.19	3.91	<0.01
Group 2		*f*=(11, 24)		*f*=(1, 24)		*f*=(11, 24)	
10, 20	70, 80	7.62	<0.01	1.91	0.18	1.09	0.41
10, 20	90, 100	11.69	<0.01	0.15	0.70	1.76	0.12
10, 20	130, 140	9.91	<0.01	0.28	0.60	0.71	0.72

* $P \leq 0.05$

Comparison of group 1 (test group) and group 2 (reference group)

The second aim was to compare the blood pressure of the subjects exposed to real fields with that of the subjects exposed to ‘sham’ fields. The hypothesis was that the blood pressure of group 1 during exposure differs from that of group 2. We compared group 1 (outdoors/total) to group 2. In this analysis we used period 1 (0–60 min) and 2 (60–120 min). The first period was used to test that there were no differences between the groups when the subjects were not exposed. The second period tested the differences when the subjects were exposed. In group 1 the subjects had to walk a short distance (200 m) when they entered real fields (under the transmission line). In the analysis this has been taken into consideration. Periods 1 and 2 of the groups were evaluated using the *t*-test (Table 4).

The results were also analysed with a two-way analysis of variance (ANOVA) with replication. The analysis was carried out between group 1 (outdoor/total) and group 2 in period 1 (10 min, 20 min), period 2 (70 min, 80 min), period 2 (90 min, 100 min) and period 2 (70 min, 80 min, 90 min, 100 min, 110 min). The results are presented in Tables 5 and 6.

Table 4 Comparison of group 1 (total and outdoors) to group 2 using *t*-test

Time (min)	Group 1 (total) DBP/mm Hg		Group 1 (outdoors) DBP/mm Hg		Group 2 DBP/mm Hg		*t*-test G 1 (total)/G 2 (*f*=26)	*t*-test G 1 (outdoors)/G 2 (*f*=19)
	Average	SD	Average	SD	Average	SD	*t*	*t*
Diastolic blood pressure (DBP)								
0	78.1	12.7	76.7	13.6	78.8	12.0	–0.13	–0.37
10	82.3	15.7	78.7	17.7	77.5	10.9	0.90	0.19
20	79.8	15.9	80.0	19.6	76.0	10.2	0.71	0.61
33	65.1	10.4	64.1	10.9	62.8	10.0	0.59	0.28
35	76.1	12.9	76.9	15.7	72.7	13.2	0.69	0.67
38	78.6	13.0	79.8	16.7	76.7	13.8	0.37	0.47
39	62.9	12.9	62.4	13.7	59.5	9.5	0.78	0.58
60	77.9	14.5	78.7	17.5	74.3	12.4	0.71	0.68
70	80.6	13.5	83.1	16.2	76.8	13.5	0.75	0.98
80	79.8	17.5	79.6	21.9	68.4	9.4	2.02	1.59
90	79.7	14.0	80.8	13.6	67.8	13.9	2.23*	2.14*
100	81.8	13.9	86.7	15.3	64.3	11.1	3.58**	3.90**
110	79.9	17.2	84.1	20.9	70.7	11.8	1.60	1.88
120	79.3	19.0	75.3	18.5	66.8	7.4	2.14*	1.45
Systolic blood pressure (SBP)								
0	129.3	7.3	128.8	8.5	123.9	8.7	1.78	1.28
10	127.9	9.1	125.2	8.7	123.3	12.4	1.15	0.41
20	128.2	10.6	124.7	11.4	124.8	10.6	0.85	–0.02
33	124.1	10.4	119.6	8.8	118.3	10.1	1.46	0.29
35	127.9	9.7	125.3	11.9	125.7	12.0	0.55	–0.06
38	126.8	11.5	125.2	12.3	122.8	10.2	0.96	0.50
39	127.4	10.5	125.3	8.9	117.8	11.0	2.34*	1.68
60	129.7	10.3	125.4	10.3	125.8	9.9	1.00	–0.09
70	129.1	12.1	125.1	13.9	129.0	12.5	0.03	–0.67
80	128.9	14.2	122.7	14.9	124.8	11.4	0.83	–0.36
90	130.2	11.5	126.7	12.3	126.3	11.9	0.88	0.08
100	127.2	8.0	123.9	6.9	123.1	11.6	1.11	0.18
110	127.1	14.6	120.2	16.0	128.1	14.1	–0.17	–1.20
120	135.3	9.8	131.0	9.6	122.6	14.1	2.83**	1.54

* $P \leq 0.05$; ** $P \leq 0.01$

Table 5 Diastolic blood pressure, comparison between groups 1 and 2, *F*-ratios and probabilities (*P*) of two-factor ANOVA with replication (f = degree of freedom)

Analyzed time points Period 1, 2	Two-factor ANOVA with replication					
	Subject		Period		Interaction	
	F	*P*	*F*	*P*	*F*	*P*
Group 1 (outdoors)/group 2						
	f=(11, 21)		f=(1, 21)		f=(8, 21)	
10, 20	14.30	<0.01	1.61	0.22	7.82	<0.01
70, 80	2.82	0.02*	5.25	0.03*	2.12	0.08
90, 100	13.81	<0.01	72.86	<0.01	5.94	<0.01
	f=(11, 84)		f=(1, 84)		f=(8, 84)	
70, 80, 90, 100, 110	11.79	<0.01	44.81	<0.01	5.80	<0.01
Group 1 (total)/group 2						
	f=(15, 28)		f=(1, 28)		f=(11, 28)	
10, 20	10.25	<0.01	3.93	0.06	5.28	<0.01
70, 80	2.61	0.01*	9.47	<0.01	2.61	0.02*
90, 100	8.03	<0.01	80.18	<0.01	4.70	<0.01
	f=(15, 112)		f=(1, 112)		f=(11, 112)	
70, 80, 90, 100, 110	8.11	<0.01	33.41	<0.01	12.89	<0.01

* $P \leq 0.05$

Table 6 Systolic blood pressure, comparison between groups 1 and 2, *F*-ratios and probabilities (*P*) of two-factor ANOVA with replication (f = degree of freedom)

Analyzed time points Period 1, 2	Two-factor ANOVA with replication					
	Subject		Period		Interaction	
	F	*P*	*F*	*P*	*F*	*P*
Group 1 (outdoors)/group 2						
	f=(11, 21)		f=(1, 21)		f=(8, 21)	
10, 20	7.38	<0.01	1.37	0.25	3.99	0.01*
70, 80	3.44	0.01*	0.00	0.95	7.56	<0.01
90, 100	5.12	<0.01	1.41	0.25	9.93	<0.01
	f=(11, 84)		f=(1, 84)		f=(8, 84)	
70, 80, 90, 100, 110	5.19	<0.01	0.02	0.88	12.06	<0.01
Group 1 (total)/group 2						
	f=(15, 28)		f=(1, 28)		f=(11, 28)	
10, 20	7.14	<0.01	2.73	0.11	4.70	<0.01
70, 80	4.56	<0.01	0.00	1.00	6.93	<0.01
90, 100	5.05	<0.01	3.21	0.08	11.34	<0.01
	f=(15, 112)		f=(1, 112)		f=(11, 112)	
70, 80, 90, 100, 110	8.95	<0.01	5.97	0.02*	9.41	<0.01

* $P \leq 0.05$

The variances (in diastolic blood pressure) for the groups [group 1 (total)/group 2] are not the same at the points 80 min [$F(15, 11) = 3.39$], 120 min [$F(15, 11) = 6.45$] and for the groups [group 1 (outdoors)/group 2] at the points 20 min [$F(8, 11) = 3.81$], 80 min [$F(8, 11) = 5.60$], 110 min [$F(8, 11) = 3.24$], 120 min [$F(8, 11) = 6.42$] according to variance ratio test. Therefore, the error of the hypothesis is 10% at points 80 min [group 1 (total)/group 2] or at points 20 min, 80 min, 110 min [group 1 (outdoors)/group 2].

According to the *t*-test, in the results of systolic blood pressure (difference during exposure) there is only one significant ($P \leq 0.01$) point, at 120 min. This is probably due to the influence of walking in group 1. The variance analysis (Table 6) shows that there is again interaction between the factors subjects and periods.

In Table 4 the results of diastolic blood pressure are significant ($P \leq 0.01$) at one point (outdoors and total). The results are significant ($P \leq 0.05$) at two points (outdoors) and 3 points (total), when using the *t*-test. However, the variance analysis proves that at time points 90 min and 100 min there is interaction ($P \leq 0.01$) between the factors subjects and periods. The results are the same when five replications are used. It is not easy to draw conclusions from these results, but it seems that the interaction has a considerable influence on the statistical results.

It seems that the fields (<4.3 kV/m and <6.6 μT) do not influence the blood pressure, which is a result similar to the one we found for heart rate [7].

Acknowledgements The expertise and assistance of the staff of Department of Clinical Physiology, Tampere University Hospital, Medical Research Centre Biotest and Department of Mathematics, Tampere University of Technology, are gratefully acknowledged. Special thanks go to Prof. Arto Uusitalo (University of Tampere), Prof. Harry Frey (University of Tampere) and Assoc. Prof. Björn Falck (University Hospital, Uppsala) for their advice.

References

1. Korpinen L, Partanen J, Uusitalo A (1993) The influence of 50-Hz electric and magnetic fields on the human heart. Bioelectromagnetics 14:329–340
2. Korpinen L, Partanen J (1994 a) The influence of 50-Hz electric and magnetic fields on the extrasystoles of human heart. Rev Environ Health 2:105–112
3. Tenforde TS, Budinger TF (1986) Biological effects and physical safety aspects of NMR imaging and in vivo spectroscopy. In: Thomas SR (ed) NMR in medicine: instrumentation and clinical applications. Monograph Series American Association of Physicists in Medicine, New York
4. Cerreteli P, Malaguti C (1976) Research carried on in Italy by ENEL on the effects of high voltage electric fields. Rev Gen Electr (Special issue) 65–74
5. Graham C, Cook MR, Cohen HD (1990) Final report: immunological and biochemical effects of 60-Hz electric and magnetic fields in humans. (Report #DE90006671) NTIS, Springfield
6. Graham C, Cohen HD, Cook MR, Gerkovich MM, Riffle DW (1993) Human cardiac response to 60-Hz fields: exposure parameters and individual differences. In: Blank M (ed) Electricity and magnetism in biology and medicine. San Francisco Press, San Francisco, pp 762–769
7. Korpinen L, Partanen J (1994 b) The influence of 50-Hz electric and magnetic fields on the pulse rate of human heart. Bioelectromagnetics 15:503–512
8. Piha J (1988) Cardiovascular autonomic function tests. Responses in healthy subjects and determination of the age-related reference values. (Publication ML:85) Social insurance institution, Turku, Finland
9. Uusitalo A, Sovijärvi A, Länsimies E, Vuori I (1988) Clinical Physiology (in Finnish). Orion, Hämeenlinna, Finland, pp 136–141, 521–522
10. IEEE (1979) IEEE recommended practices for measurement of electric and magnetic field from AC power lines (Std 644–1979)