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Acute effects of ELF electromagnetic fields: a field study of linesmen working with 400 kV power lines

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ABSTRACT The aim of the study was to investigate the possible acute effects of exposure to electric and magnetic fields. Twenty six experienced linesmen, aged 25 to 52, were studied during two working days while performing a simulated routine inspection of insulators on steel poles of a 400 kV power line. During one of the working days the inspection was performed on a power line in operation and on the other day the same procedure was performed on an identical power line, which was not in operation. The two days were found to be comparable with regard to the physical workload which, on the basis of heart rate measurements, was estimated to be high. Exposure to the electric and magnetic fields was measured using a device designed for on-worker sampling on each linesman. The mean exposure for the working day was estimated to be 2·8 kV/m (SD = 0·35) and 23·3 μT (SD = 4·2). The possible effects of exposure were studied using a battery of four automated performance tests, EEG, a mood scale, and a questionnaire to assess subjective symptoms. All workers were examined immediately before and after each workday. Furthermore, blood samples were collected for each subject on three different occasions during each workday. The battery of behavioural tests comprised a test of simple reaction time, a vigilance test, a test of short term memory (digit span), and a perceptual test (symbol digit). The four EEG recordings for each worker were judged blindly and sorted with regard to amount and stability of alpha activity. The blood samples were used for an analysis of possible changes during the workday with regard to the following hormones: thyroid stimulating hormone, luteinising hormone, follicle stimulating hormone, prolactin, cortisol, testosterone, and neopterin. Detailed analyses of the results using both parametric and non-parametric tests showed no statistically significant difference between the two conditions which could be attributed to exposure to electric and magnetic fields.

Over the past 20 years much research has been carried out to investigate health hazards in connection with exposure to electric and magnetic fields from high voltage power lines. Reviews of the available data on the biological effects of exposure to these fields do not allow any definite conclusion concerning the health risk for the general population or for occupationally exposed workers.[1–3] Results from some studies, however, do indicate that occupational exposure to electric and magnetic fields may be associated with acute effects in the nervous and circulatory systems, reduced reproduction function, and an increased risk of cancer, especially with regard to leukaemia and brain tumours.

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The first comprehensive study on occupational exposure to electric and magnetic fields was carried out in the USSR by Asanova and Rakov in 1966.[4] They reported various symptoms among switchyard workers including functional disturbances in the nervous, circulatory, and gastrointestinal systems and haematological changes. These observations were later confirmed in other investigations, first by Sazonova[5] and then by Revnova (NV Revnova *et al*, unpublished data 1968). Subjective symptoms with an abnormally high incidence included fatigue, headache, dizziness, impaired memory, nausea, loss of strength in arms and legs, respiratory difficulties, sleep disturbances, irritability, and reduced libido. Effects that were objectively recorded were reduced systolic blood pressure, sinus arrhythmia and sinus tachycardia in ECGs, and desynchronised alpha activity and focal activation in the EEG. Impaired performance on

vigilance tests and reaction time tests was also reported. These effects were most evident at the end of a workshift and tended to decrease successively after a ten hour exposure free period.

The results of several investigations published later do not support the assumption that the effects mentioned above were caused by exposure to electric and magnetic fields.[6-11] Thus Singewald *et al* carried out health examinations on ten linesmen over nine years and found no symptoms of nervous or circulatory system disorder, nor any changes in the ECG blood, lung function, kidney function, sperm production, or in vision or hearing.[12] In a study by Malboyson no differences were found between a group of 160 high voltage substation workers and linesmen and 84 low voltage linesmen with regard to routine physical examination, chest radiographs, ophthalmoscopy, ECG, and blood tests.[9] In another study performed in Canada negative results were found on examination of the nervous, blood, and circulatory systems of 56 workers occupied with maintenance work at a 750 kV substation.[10] Negative results were also found in a Swedish epidemiological study where 53 substation workers were matched and compared with a reference group.[8] No relation between occupational exposure and health condition was shown in two studies including 390[7] and 600[6] workers occupied with production and distribution of electricity, respectively.

Acute effects on subjects exposed to electromagnetic fields have also been investigated in a few experimental studies. In a Swedish study no effects on reaction time or psychomotor function could be observed in subjects exposed to 20 kV/m (50 Hz).[12] An increased reaction time during exposure, however, has been reported from Germany for subjects exposed to electric fields from 1 to 20 kV/m for 45 minutes to five hours.[14] No field related effects were observed with regard to the nervous, blood, and circulatory systems in other German investigations using either an exposure of 20 kV/m or an exposure to magnetic fields up to 5000 μT.[13-16]

In more recent experimental studies of acute effects on central nervous functions some positive results have emerged from the United States[17-19] and from the United Kingdom[20] (and JA Bonnell *et al*, unpublished data). In the American studies in which 12 subjects were exposed for six hours to 9 kV/m and 19 μT, field related changes in evoked potentials after both acoustic and optic stimulation and a field related decrease in heart rate at rest were found. The latter effect was verified in a recently performed replication of the study. In the United Kingdom studies 76 subjects were exposed to an electric field corresponding to 36 kV/m. Exposure was found to bring about changes in mood and a performance decrement in a reasoning test.

Neither the results from the field investigations of exposed workers nor the results from the human experimental studies referred to above allow a reliable assessment of the risk for acute effects on the nervous system in the case of occupational exposure to electric and magnetic fields. In these circumstances it was decided that a study should be conducted on a group of linesmen performing routine maintenance work leading to such exposure.

The present investigation was performend using an experimental design similar to the one we have successfully applied in our studies of the acute effects of occupational exposure to low concentrations of organic solvents.[21 22]

Method

EXPERIMENTAL GROUP

The investigation was performed from August to October 1986 at a conference centre of the Swedish State Power Board. Twenty six experienced linesmen were studied, 20 employed at the Swedish State Power Board and six at the Sydkraft Power AB. Age ranged from 25 to 52 (M = 38 years, SD = 7 years) and the duration of employment varied from four to 28 years (M = 12 years, SD = 6 years).

EXPERIMENTAL DESIGN

The study was performed under standardised conditions. The linesmen were studied two at a time during two workdays. During one workday the linesmen performed simulated routine inspection of insulators on steel poles of a 400 kV power line in operation. On the second day the same procedure was performed on an identical line which was not, however, in operation. The schedule followed is shown in table 1.

Table 1 *Time of day for each activity during the two examination days*

Time of day	*Activity/measurement*
0645–0700	Blood samples
0700–0730	Breakfast
0735–0745	Safety regulation information
0750–0920	Individual psychometric testing (45 min) and EEG recording (45 min)
0925–0945	Coffee break
0945–1000	Journey to worksite by car
1000–1200	Simulated inspection of insulators
1200–1210	Blood samples
1210–1230	Lunch in a house trailer placed under line in order to expose linesmen during lunch break
1230–1430	Simulated inspection of insulators
1430–1445	Journey from worksite
1445–1500	Coffee break
1500–1630	Individual psychometric testing (45 min) and EEG recording (45 min)
1630–1710	Blood samples
1710	Dinner

SIMULATED INSPECTION OF INSULATORS

In accordance with normal inspection of insulators two linesmen worked together as prescribed in the security regulations.[23] During 2 × 2 hours the linesmen performed inspection of insulators. The number of inspections during each work period was not decided in advance but the linesmen were asked to perform the inspection at their normal work pace.

The inspections were alternated between the linesmen. When the inspection was completed the two linesmen walked a distance of 360 m, corresponding to the average distance between two poles.

They were exposed for 4·5 hours; during inspection of the insulators, during the simulated walk between the poles, and during the lunch break. The linesmen had lunch in a house trailer placed under the lowest point of the line.

The sequence of the exposure conditions was balanced. Thus half the linesmen performed the inspection on a power line in service on the first day (exposure condition; pole height 19·6 m) while the other half performed their first inspection on an identical line, which was not, however, in operation (control condition; pole height 21·6 m).

WEATHER CONDITIONS

The working condition for the linesmen depends on weather conditions; thus, for example, the number of discharges is affected by humidity and the effort required to hold the rod is affected by the wind. To obtain a basis for comparing the weather between the exposed and control conditions, temperature, wind velocity (thermoanemometer Wallac GGA23S), and air humidity (temperature and moist measuring instrument Kane-May 8001) were measured several times each day. The mean temperature remained relatively stable during the research period (table 2). The wind conditions were more varied. On average there was a 4·3 m/sec wind in the exposed condition and a 1·3 m/sec wind in the control condition. This variation was partly because the line in operation was in a more open area than the control line. Furthermore, the wind velocity was measured on the ground and not at pole height which would have been more correct. When all the linesmen were asked whether the wind had troubled them during work, it became clear that the wind was significantly more vigorous in the exposed condition than in the control condition ($F_{1,23} = 33{\cdot}08$; $p < 0{\cdot}001$). The air humidity varied between 44% and 100% RH during the investigation period. The variation between the two consecutive days, however, was minimal.

Table 2 *Mean values and range of temperature, wind, and air humidity*

Measure	*Exposure*	*M*	*Range*
Temperature (°)	Exposed	10·3	5–17
	Control	10·7	3–17
Wind (m/sec)	Exposed	4·3	0–13
	Control	1·3	0–5
Air humidity (RH)	Exposed	73	44–95
	Control	80	57–100

MEASUREMENT OF ELECTRIC AND MAGNETIC FIELDS

Exposure to the electric and magnetic fields was measured using a personal device designed for on-worker sampling, BE-log dosimeter. The load of the line was checked at each exposure condition. The linesmen wore the dosimeter also during the control condition and thus both the extra weight and the practical difficulties with the dosimeter during inspection of the insulators were identical in both conditions.

The BE-log dosimeter has been developed within the framework of a prospective epidemiological investigation of workers occupied in the production and distribution of electricity[24] in progress at present.

Specification of the BE-log dosimeter:

Frequency, 50 Hz
Magnetic field, x, y, z direction 0·2–200 μT
Electric field, 0–30 kV/m unperturbed field
Linearity 12%
A check of the field strength Bx, By, Bz, and E is stored every 15 sec
Resolution, a change of 1 LSD equals 2·8% of reading
Weight of equipment, 2·8 kg

Measurements made by the BE-log dosimeter show values about 10% higher than measurements made by handheld instruments.

PHYSICAL WORKLOAD

Heart rate was measured continuously in order to assess the workload of a strenuous but common task among linesmen. It was registered every minute by a pulse electrode belt and a micro based data collecting system. The data were stored in a computer memory and the results were evaluated at the end of the workday. The box containing the computer memory was fastened in a suitable position to ensure that the instruments would not hinder the subject from carrying out his work, including when climbing and when inspecting the insulators.

SUBJECTIVE ASSESSMENT

In connection with the afternoon test sessions the linesmen were asked to answer three questionnaires. The first questionnaire consisted of 14 descriptive mood adjectives coupled to four fixed response categories (not at all, not especially, much, very much). Half the adjectives constituted a subscale of

wakefulness (sleepy, concentrated, tired, energetic, awake, feeble, and peppy) and the other half a subscale of stress (relaxed, tense, irritated, stressed, cool, clutched up, and calm).

In the second questionnaire the linesmen rated the extent to which they experienced several subjective symptoms. The same response categories as for the mood descriptive adjectives were used.

In the third questionnaire they marked the position from which they inspected the insulators on a stylised pole. This questionnaire also contained questions about the occurrence of discharges and near accidents and the use of special protective equipment and medicine.

PSYCHOMETRIC INVESTIGATION

The psychometric assessment was accomplished using a computerised battery of four tests included in the SPES (Swedish performance evaluation system) (Gamberale F, unpublished data). The four tests were: simple reaction time (SPES1), colour word vigilance (SPES3), symbol digit (SPES5), and digit span (SPES6).

The tests were administered using a microcomputer (ABC806, Luxor AB, Motala, Sweden) with a dual disc drive, a reaction time panel with an adaptor, an external millisecond clock, a modified numerical keyboard, and a printer.

As a complement to the short instruction on the screen, each subject received oral instructions before each test.

The tests were administered in the order described below:

Simple reaction time (SPES1) The simple reaction time task was to press a button as quickly as possible when the light came on. A total of 176 stimuli were administered during 11 minutes at intervals of 3·75 ± 1·25 sec. The first minute served as practice, after which performance capacity was assessed for 10 minutes.

Colour word vigilance (SPES3) is a complex reaction time test. The Swedish word for "red," "yellow," "white," or "blue" was presented on the screen. These words were chosen because in Swedish they are all three letter words. The word could be written with text in any one of the colours. The task was to press a button as fast as possible when there was congruency between the meaning of the word and the colour of the text. When there was a discrepancy, however, the stimuli should be ignored. The 16 possible combinations of words and colours were randomly distributed within each sequence of 16 stimuli. A total of 208 stimuli was administered with a fixed interval of two seconds. The 16 stimuli presented at the beginning of the test served as practice. Thus performance was estimated from a total of 192 stimuli, with 48 stimuli showing congruency between meaning of the word and colour of the text.

Symbol digit (SPES5) is a test of perceptual speed. It is a modification of digit symbol, a well known test included in the Wechsler Adult Intelligence Scale. In the computerised version a row of symbols are paired to the digits 1–9. In a row below the same symbols are presented, but in a different order and without digits. The task was to mark the correct digit below each symbol as fast as possible. The first item served as practice and performance was based on the following nine items.

Digit span (SPES6) is a short term memory test. A series of digits was presented on a screen. Each digit was shown for one second. The first series included three digits. When the series was completed, the task was to repeat the series on the keyboard. The series were increased by one digit after a correct response and decreased by one digit after an incorrect response. After six incorrect responses the test was interrupted.

NEUROPHYSIOLOGICAL EXAMINATION

Electroencephalography (EEG) was performed on four occasions for each subject: in the morning before beginning work and in the afternoon after finishing work on both examination days. Thus one of these four EEG examinations was conducted after exposure. The EEG examinations were made according to clinical standards, including 21 electrodes following the 10/20 system. The subjects were in a horizontal position with the eyes closed, except for some eye openings of five seconds during recording time. Total recording time was 15 minutes and the EEG signals were recorded on paper (8 channel SLE EEG machine) and on magnetic tape (8 channel Johne and Reilhofer digital tape recorder).

The EEG recording was assessed according to normal clinical routine as regards pathological deviation from the normal EEG pattern. In addition, the four recordings from each subject were ranked in the following way: one 10 second epoch with maximally constant activity was chosen from two anteroposterior derivations (medial and lateral, respectively) in each recording. These epochs were ranked regarding the stability and amplitude of the alpha activity. The four epochs were thus given a rank order number from one to four. The ranking was done blindly—that is, at the time of ranking the postexposure recording could not be identified.

HORMONE EXAMINATION

Blood samples were collected (3 × 5 ml/sample) three times a day at 0645, 1200, and 1700 (see table 1). These blood samples were used for analyses of the concentration of the following hormones: thyroid stimulating hormone, luteinising hormone, follicle stimulating

hormone, prolactin, cortisol, testosterone, and neopterin.

Results

EXPOSURE

The mean exposure of the linesmen to electric fields during the workday was 2·8 kV/m, with a range of 2·1–3·6 kV/m (fig 1). The mean exposure to magnetic fields was 23·3 μT and the variation between the linesmen was 14·7–24·8 μT (fig 2). Figures 3 and 4 show the variation in exposure to electric and magnetic fields during one workday.

PHYSICAL WORKLOAD

Owing to interference from the strong electric fields much of the heart rate data was lost. Thus a complete description of the workload for the entire group of linesmen cannot be presented. A typical example of the changes in heart rate during a workday, however, included three climbs before lunch, lunch break, and finally three climbs after lunch. The physical workload was high when climbing or during the inspection of the insulator, as indicated by a heart rate varying between 140 and 160 beats/min. During the walks between the poles heart rate varied between 86 and 120 beats/min.

SUBJECTIVE SYMPTOMS

The ratings of wakefulness and stress did not show any significant differences between exposure and control conditions (figs 5 and 6). Nor did the ratings show any significant differences when the first and second day of work were compared. Independent of exposure condition, wakefulness was generally rated as being high whereas stress was rated as being low.

Figure 7 shows the results of the ratings of subjective symptoms occurring during the workdays; these symptoms were not related to the exposure conditions. For these symptoms also there were no significant differences between the first and the second workday. The most troublesome symptom was the strain in the thighs, a common problem caused by frequent climbing.

The subjects reported few discharges and when these did occur they were not considered particularly annoying. Only one near accident was reported during the investigation: a rubber plug came loose and the linesman dropped his rod.

PSYCHOMETRIC TESTING

Table 3 shows the mean values and the standard deviations of the performance variables of the tests. The statistical analysis of the results was performed with a three way ANOVA with exposure condition, time of day, and subjects as the three sources of variation. For three of the tests the variance model was modified so that it also included an analysis of the performance changes during the test period, followed by a test for trends. These performance changes are shown in figs 8–10.

Simple reaction time—Neither the mean reaction time nor the mean variation (SD) of performance on

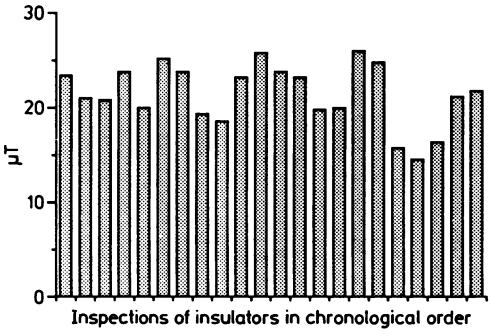

Fig 2 *Mean exposure to magnetic fields during workday for each of 22 linesmen performing inspection of insulators.*

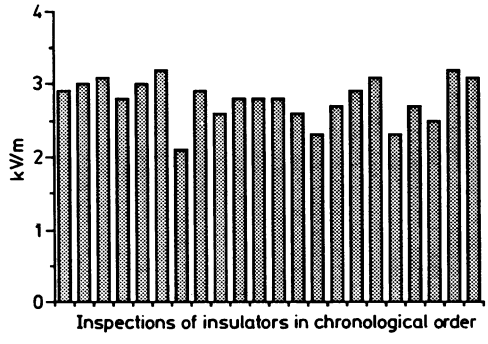

Fig 1 *Mean exposure to electric fields during workday for each of 22 linesmen performing inspection of insulators.*

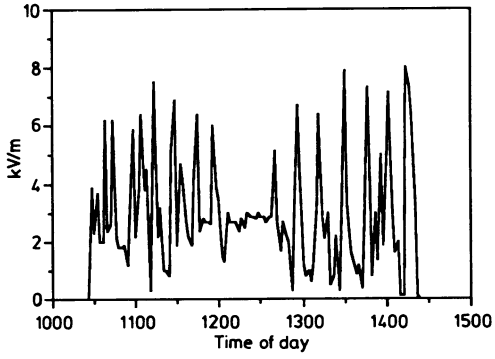

Fig 3 *Exposure to electric fields during workday for one linesman performing inspection of insulators.*

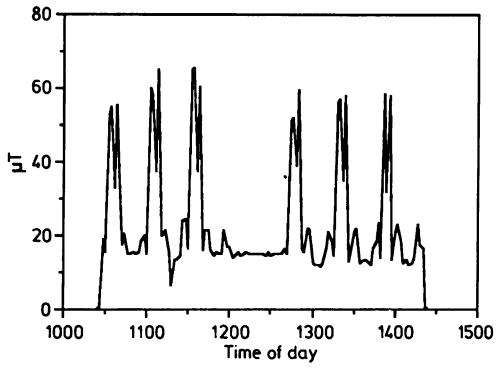

Fig 4 *Exposure to magnetic fields during workday for one linesman performing inspection of insulators.*

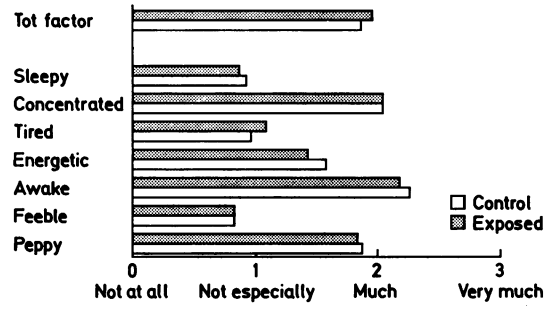

Fig 5 *Mean values of linesmen's ratings of wakefulness after exposure condition and control condition respectively.*

the simple reaction time test showed any significant difference between the exposed and the control condition (table 3). In both conditions, however, the mean reaction time was significantly shorter in the afternoon than in the morning ($F_{1,23} = 16{\cdot}20$; $p < 0{\cdot}001$). The analysis of the reaction time changes during the test period also showed a significant difference between the exposed and control conditions ($F_{1,23} = 6{\cdot}72$; $p < 0{\cdot}05$). In the control condition the reaction time increased more during the test than in the exposure condition (fig 8). This difference resulted in a significant interaction between exposure and time blocks ($F_{4,92} = 3{\cdot}54$; $p < 0{\cdot}01$).

Colour word vigilance—Performance on the colour word vigilance test was not related to exposure condition. Also, in this test performance was better in the afternoon than in the morning both with regard to the mean reaction time ($F_{1,23} = 36{\cdot}08$; $p < 0{\cdot}001$) and to the number of misses ($F_{1,23} = 12{\cdot}58$; $p < 0{\cdot}01$). There was also a significant increase in reaction time over the test period ($F_{5,115} = 3{\cdot}23$; $p < 0{\cdot}01$). Since the analysis did not show any significant interactions, however, this increase over the test period (fig 9) was not related to the exposure condition or to the test session.

Symbol digit showed no significant difference in performance between the two exposure conditions. Performance on the test was significantly better in the afternoon than in the morning ($F_{1,23} = 32{\cdot}84$; $p < 0{\cdot}001$).

Digit span also showed no significant difference in performance between the two exposure conditions and the linesmen performed significantly better in the afternoon than in the morning ($F_{1,23} = 4{\cdot}94$; $p < 0{\cdot}05$).

NEUROPHYSIOLOGICAL EXAMINATION

According to the visual evaluation, all EEG record-

Table 3 *Mean values (M) and standard deviations (SD) for the linesmen's performance on the four psychomotoric tests in the different test sessions*

		Exposure condition			*Control condition*		
		am	*pm*	*am + pm*	*am*	*pm*	*am + pm*
Simple reaction time:							
Reaction time (ms)	M	250	242	246	255	245	250
	SD	31	29	30	32	27	30
Variation	M	53	51	52	54	53	53
	SD	17	18	17	15	16	16
Colour word vigilance:							
Reaction time (ms)	M	533	513	523	526	506	516
	SD	40	44	42	52	40	47
No misses	M	4·4	2·0	3·2	4·1	1·7	2·9
	SD	4·5	2·5	3·5	6·7	1·6	4·1
Symbol digit:							
Reaction time (sec)	M	28·7	25·3	27·0	27·7	25·0	26·3
	SD	6·9	4·4	6·0	5·2	4·4	4·8
Digit span:							
No correct digits	M	7·5	7·7	7·6	7·4	7·8	7·6
	SD	1·4	1·5	1·4	1·0	1·2	1·1

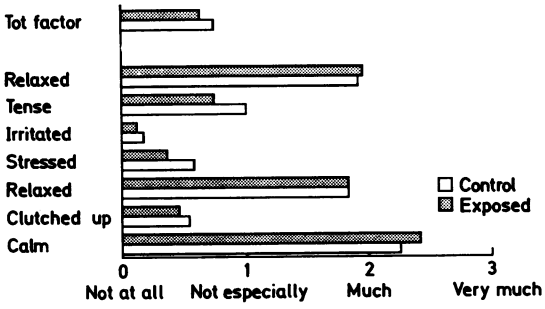

Fig 6 *Mean values of linesmen's rating of stress after exposure condition and control condition respectively.*

ings were within normal limits. The rankings were analysed by a non-parametric method (Friedman's analysis of variance by ranks). There were no statistically significant differences in rank order between the different registrations. Thus no significant effect of exposure could be shown using this technique.

HORMONE ANALYSES

Table 4 shows the mean values and standard deviations of the serum concentration of the different hormones for the three sampling occasions on each of the two workdays.

The statistical analyses (ANOVA) of the hormone values showed only one significant difference between the exposed and the control conditions. The testosterone values were higher in the exposed condition compared with the control condition ($F_{1,25} = 5{\cdot}35$; $p < 0{\cdot}05$). Since there was no significant interaction between exposure condition and sampling occasion, the difference found in the concentration of testosterone could not be related to the electric and magnetic fields.

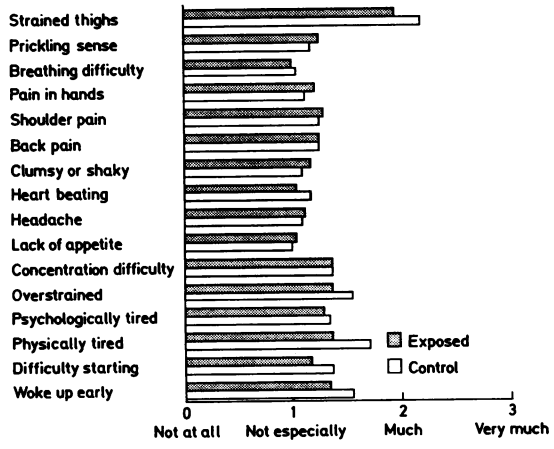

Fig 7 *Mean values of linesmen's ratings of discomfort in various variables.*

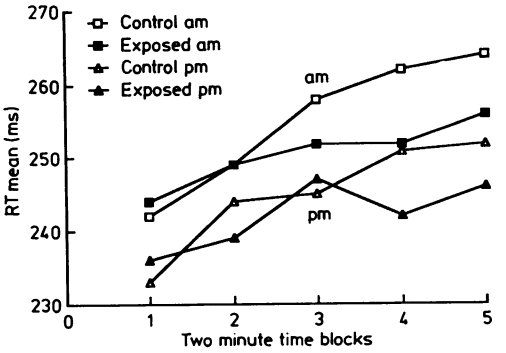

Fig 8 *Changes in mean reaction time (RT) over time (2 minute time blocks) in simple reaction time test at different test sessions.*

The ANOVA showed significant differences between the three sampling occasions for testosterone ($F_{2,50} = 30{\cdot}87$; $p < 0{\cdot}001$), thyroid stimulating hormone ($F_{2,50} = 14{\cdot}0$; $p < 0{\cdot}001$), prolactin ($F_{2,50} = 18{\cdot}49$; $p < 0{\cdot}001$), cortisol ($F_{2,50} = 63{\cdot}03$; $p < 0{\cdot}001$), and neopterin ($F_{2,50} = 6{\cdot}32$; $p < 0{\cdot}01$). The trend analyses confirmed a linear decrease over the workday in the serum concentration of testosterone, thyroid stimulating hormone, and cortisol. For prolactin and neopterin the change in the trend over the workday was quadratic. The serum concentration of prolactin was at its lowest level at 1200. At the same time of day the neopterin concentration was at its highest level.

Discussion

The aim of the present study was to investigate to what extent occupational exposure to electric and magnetic

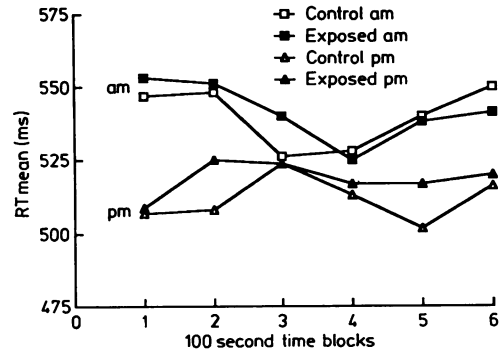

Fig 9 *Changes in mean reaction time (RT) over time (100 s time blocks) in colour word vigilance test at different test sessions.*

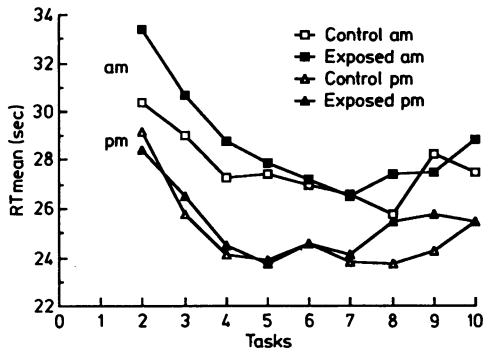

Fig 10 *Changes in mean reaction time (RT) over time in symbol digit test at different test sessions.*

fields may constitute a risk for acute effects on the nervous system. Previous indications of possible effects on the nervous system of this type of exposure derive from health examinations of groups of workers.[1-3] In these studies, however, there was no satisfactory control of the exposure conditions with regard to the electric and magnetic fields or with regard to other environmental and work organisational factors. Acute effects on the nervous system have also been observed in experimental laboratory studies. In these studies subjects have either been exposed in chamber with relatively uniform electric and magnetic fields, as in the American studies mentioned earlier,[17-19] or the subjects were exposed to current transferred to the body by electrodes, as in a study recently performed in the United Kingdom.[20] The extent to which these experimental conditions may be representative of occupational exposure is not known.

In the present investigation the exposure conditions were undoubtedly representative for a linesman occupied with maintenance work on 400 kV power lines. Thus all the operations during the inspection of insulators were performed in the same way as during normal inspections.

The quasiexperimental design adopted for the present study was similar to that which has been successfully applied by our institute in field studies of acute effects of low doses of organic solvents.[21,22] With this procedure, each linesman was examined before and after a day of work in electromagnetic fields. Each linesman was also examined before and after a workday during which no exposure to electromagnetic fields occurred. Thus in this experimental design each linesman acted as his own control.

None of the effect variables was negatively affected by exposure to the electric and magnetic fields. There was no difference between exposure and control condition in the linesmen's assessment of mood or subjective symptoms, and neither EEG nor the serum concentrations of the analysed hormones showed any relation to the exposure conditions.

Only one of the performance variables of the computerised test battery indicated a significant difference between the exposure conditions. The increase in simple reaction time over the test period, which is characteristic of the test used,[25,26] was less pronounced in the exposure condition compared with the control condition. Since this increase in reaction time appeared not only after work but also before work, it cannot be directly attributed to the field exposure. It cannot be excluded that this effect on performance was because the linesmen were aware of the conditions under which they were working. The fact that no such effects were shown by the other psychometric tests, however, argues against this interpretation. Performance on all the psychometric tests, as well as the concentration in serum for five of the

Table 4 *Mean values (M) and standard deviations (SD) of serum concentration of the different hormones on three sampling occasions (0645, 1200, and 1700) in exposure and control conditions*

		Exposure condition Time of day			*Control condition Time of day*		
Hormones		*0645*	*1200*	*1700*	*0645*	*1200*	*1700*
Testosterone	M	27·3	25·4	20·0	25·8	23·4	17·1
	SD	8·7	9·1	7·8	9·5	6·6	5·3
Thyroid stimulating hormone	M	2·0	1·9	1·4	2·3	2·1	1·4
	SD	1·3	1·4	1·2	1·5	1·4	1·2
Prolactin	M	12·3	6·4	7·2	11·8	6·0	7·6
	SD	7·1	3·1	4·0	5·8	2·8	4·9
Cortisol	M	554	364	348	543	377	271
	SD	126	150	134	113	108	87
Neopterin	M	4·3	5·1	4·3	3·9	4·6	4·5
	SD	1·3	1·9	1·5	1·2	1·5	1·8
Follicle stimulating hormone	M	4·2	5·6	4·3	4·6	5·6	4·2
	SD	2·5	5·9	2·3	3·1	5·9	2·4
Luteinising hormone	M	11·8	18·4	10·8	8·4	13·1	10·5
	SD	22·3	31·4	22·4	12·2	26·2	22·5

analysed hormones, showed significant variation during the day. The test performance was consistently better in the afternoon than in the morning. For simpler reaction time, colour word vigilance, and digit span the improvement in performance in the afternoon was probably due entirely to a natural variation associated to the circadian rhythm. The performance improvement observed in symbol digit, however, was probably a combination of the effects of the circadian rhythm and of practice.

The serum concentrations of testosterone, thyroid stimulating hormone, and cortisol decreased during the workday whereas the changes for prolactin and neopterin followed a quadratic trend. These changes probably resulted from an interaction between the effect of the physical load imposed by the work and the normal circadian variation in the concentration of these hormones.

In summary, this study could not show any negative, acute effect on the nervous system caused by exposure to electric and magnetic fields. The occupational exposure to electric and magnetic fields during work with production and distribution of electricity seldom exceeds the levels studied in this investigation. It should be observed, however, that this study dealt only with the possible effect of one day of exposure in a group of healthy linesmen who had never complained about such exposure.

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