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Effects of 50 Hz electric currents on vigilance and concentration

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ABSTRACT Seventy six male volunteers were studied in a crossover trial to assess the effect on the central nervous system of 50 Hz electric currents. Currents totalling 500 microamperes were passed through electrodes attached to the head, upper arms, and feet, simulating exposure to a vertical electric field of about 36 kV/m. Exposure and sham exposure sessions were assigned using double blind techniques and current passed for about 5·5 hours during the exposure session. A series of psychological tests comprising self reports of mood and performance tests of memory, attention, and verbal skills were administered. The present paper discusses the effects of those currents on vigilance and sustained concentration and examines the hypothesis that electric fields act as stressors. The results indicate that vigilance and concentration were not influenced by exposure, nor do they support the hypothesis of a stress reaction. Although brief reports of sensations at electrode sites compromised the double blind conditions to some extent, the performance changes associated with these reports were independent of exposure per se. Within the vigilance task there were two possible exposure effects on the time taken to identify non-target numbers. Firstly, the non-targets were identified more slowly during the first hour of exposure. Secondly, for subjects not reporting sensations, non-target latencies on the second day were slower in the exposed group—there were no corresponding differences on the first day. The interpretation of this effect is complicated by its apparent restriction to the second day and may indicate some kind of state dependent transfer phenomenon.

The possibility that exposure to power frequency electromagnetic fields produces an undesirable effect on human health has received increased attention over the past decade.[1–3] Perhaps the main reasons for the paucity of early research in this area originates from the absence of any obvious evidence of a health hazard and because the fields close to generating plants are incapable of inducing significant tissue heating.[4] In recent years, however, there has been increasing interest in understanding the basis of those biological changes that appear to occur at energy levels too small to be due purely to thermal interactions.[5 6]

One hypothesis of particular interest to the present study is the suggestion that electromagnetic fields act as biological stressors.[7 8] The reported changes in corticosteroid release and white cell counts[1 9 10] form the major evidence for this contention. The general evidence, however, is not compelling and sensory factors such as microshocks and field perception possibly underlie the heterogeneous changes reported.[11] With respect to the present psychological investigation, various mild stressors are known to influence performance on the sustained attention tasks used here.[12 13] Thus in addition to an examination of sustained attention the present study should provide evidence relevant to the hypothesis that the currents induced by electric fields act as stressors.

One of the main objectives of the present study was to separate the sensory field induced phenomena from the induced body currents. This was achieved by introducing the current directly through surface body electrodes and no external electric field was used.[14] Mathematical modelling of the distribution of the induced currents[15] suggests that this technique closely simulates exposure to a vertical electric field and produces a relatively uniform distribution of current in the brain.

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Design and protocol

Only the main features of the design are summarised here because further details are available elsewhere.[14 16] Thirty eight pairs of male volunteers, with no occupational history of exposure to electric fields, attended two main session days.

Using a cross over design and double blind procedures, one subject in each pair was assigned to group A and the other to group B. Subjects in group A were exposed on the first day and sham exposed on the second day. Subjects in group B were exposed on the second day and sham exposed on the first day. On the exposure day, a 500 microamperes current (50 Hz) was passed through electrodes on the scalp and upper arm, simulating the magnitude and distribution of current in a normal adult man standing in a vertical electric field of about 36 kV/m. The current was passed, so far as practicable, continuously during the day (1030–1600).

Psychological functioning was assessed by an hour long sequence of four psychological tests that was repeated four times during the day. For the purposes of analysis, the four testing times were entered as a "time of day" factor having four levels. A mood checklist was administered before and after each exposure/sham exposure session.

PSYCHOLOGICAL TESTS

The mood checklist and two tasks probing verbal reasoning skills have been described elsewhere[14] and only the two attentional tasks (serial-reaction-time and visual-search) reported in the present paper are described here.

The apparatus for the five choice serial-reaction-time task was a large response board on which five lights, and their adjacent response discs, were arranged in the shape of a pentagon. In the centre of the board, equidistant from each response disc (17 cm), was a disc without a light.

Using his dominant hand only, a subject initiated trials by touching the centre disc and this immediately illuminated one of the lights. He extinguished that light by touching its adjacent response disc (decision time) and then touched the centre disc to initiate the next trial (movement time). Lights were illuminated randomly and with an equal probability (counterbalanced every 50 trials). The subject continued to illuminate and extinguish lights, as quickly and accurately as possible, for 20 minutes. For analysis, the 20 minute task was divided into five periods of four minutes each.

The visual-search task used was a computerised version of a cognitive vigilance task incorporating a short term memory component.[17] The subject inspected a display of sequentially presented digits (0–9) and looked for occurrences of a specified digit (the target). For each digit presented he responded by pressing, using his dominant hand only, one of two keys—that is, target or non-target—on a standard keyboard. Each response triggered presentation of the next digit. After a variable number of trials (range 10–30) a new target digit was specified on the screen. The subject had to remember this digit and identify subsequent occurrences of it until the next new target was given. In common with standard vigilance tasks, target digits were presented for identification only rarely (10%) whereas most of the trials required a "non-target" response (90%). Subjects were instructed to respond as quickly and accurately as possible. For analysis, the 10 minute task was divided into five periods of two minutes each.

Both tasks were controlled by microcomputer and the stimulus materials for the visual-search task were presented on a 17" black and white video monitor. During testing periods, each subject sat in an individual booth screened off from the testing laboratory and the other subject. A computer logging malfunction led to several incomplete data sets and the number of subjects entering into each analysis is therefore noted at the start of the analysis.

Results

Task performance was examined using an analysis of variance with covariance.[18] It has been reported elsewhere that the precautions taken to avoid the detection of current were not entirely successful.[14 16] Because the brief reports of sensations at electrode sites compromised the double blind conditions to some extent, each subject was coded according to the pattern of sensations he reported. Two "perception" groups were initially considered: those who reported no sensations (None) and those who reported sensations at some point during the study (Some). A supplementary analysis was performed when reports of sensations influenced performance—the Some group was subdivided into (*a*) those who reported sensations on both the exposed and the sham exposed day (Both) and (*b*) those who reported sensations only on the exposed day (Right). The seven subjects who reported sensations only on the sham exposed day (Wrong) could not be included in this additional analysis because they came exclusively from group B.

FIVE CHOICE SERIAL REACTION TIME

Results from 68 subjects were analysed and table 1 shows the number of subjects as a function of the grouping factors. On average, each subject attempted 214 trials (including errors and gaps) during each four minute period of the task; a total of 1070 trials during the 20 minutes of the task.

Table 1 *Number of subjects analysed in the serial-reaction-time task as a function of grouping factors*

	Perception group					
Subject group	*Total*	*None*	*Some*	*Both*	*Right*	*Wrong*
Group A	36	16	20	7	13	0
Group B	32	10	22	10	7	5
Overall	68	26	42	17	20	5

The number of trials attempted did not vary as a function of the exposure conditions, although the Some group adopted a slower workrate than the None group (206 and 226 trials/period respectively; p = 0·01). Newman-Keuls analysis of a time of day × period interaction (p < 0·001) showed that workrates (*a*) had improved by the second time of day, (*b*) remained constant during the task in the morning, and (*c*) declined with time on the task during the afternoon (fig 1).

Several interactions with perception groups were observed but further details are not provided. This is because the workrate score incorporates discrete failures (errors, gaps) and includes the movement and the decision phase of the task. Analyses for each of these parameters are presented below; the analyses of reaction times specifically excluded errors and gaps.

On average, subjects correctly extinguished each light in 573 msecs (decision time) and returned to the centre to initiate the next trial in 320 msec (movement time). The covariate analysis showed that subjects with higher presession pulse rates had slower decision times (p = 0·04) and slower movement times (p = 0·04).

Both the decision times and the movement times were (*a*) faster on the second day, (*b*) improved with the time of day, and (*c*) showed a time of day x period interaction (all p < 0·001). Newman-Keuls analysis of the interaction effects, however, showed different patterns for the two measures. Decision times remained constant during the task at all times of day except the third (postlunch), where slowing occurred during the first 12 minutes (fig 2). In contrast, movement times improved during the task at all times of day, with most improvement occurring during the first test of each day (fig 3).

Neither decision times nor movement times varied as a function of exposure, although sensations had a pronounced effect on the movement phase of the task. For example, Newman-Keuls analysis of a period × subject group × perception group interaction (p = 0·002; fig 4) showed that only the group exposed on the first day (group A) initiated trials more slowly when sensations were reported. A similar asymmetrical pattern between sensations and the order of exposure was observed for the time of day × subject group × perception group interaction (F(3,171) = 3·1, p = 0·006). Because the interaction with the day of

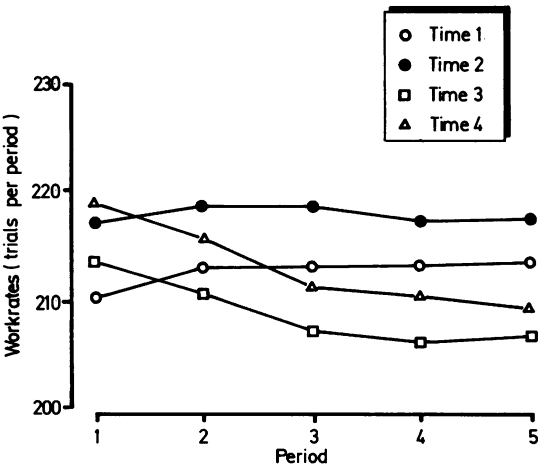

Fig 1 *Number of trials attempted (including errors and gaps) in serial-reaction-time task as a function of time of day and period: all subjects.*

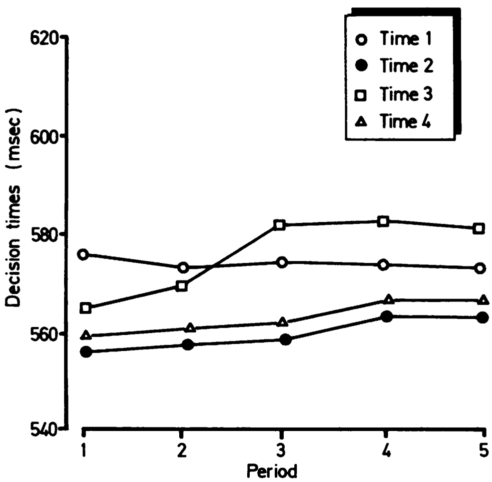

Fig 2 *Decision times in serial-reaction-time task as a function of time of day and period: all subjects.*

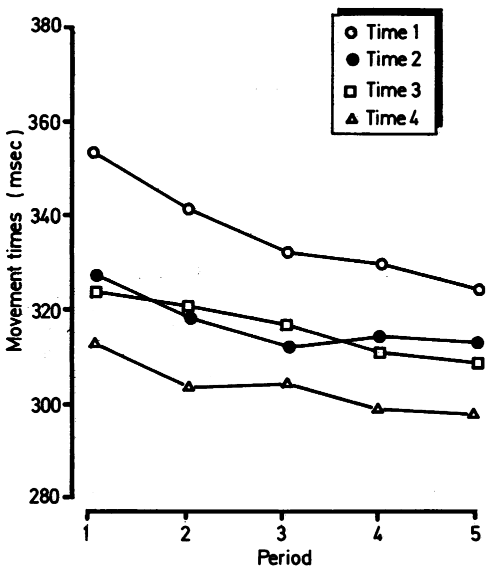

Fig 3 *Movement times in serial-reaction-time task as a function of time of day and period: all subjects.*

testing was not significant in either case, however, these findings are independent of exposure.

Two types of discrete failure were examined: errors and gaps. Errors were recorded when a subject touched a response disc of a non-illuminated light and an average of 11 errors were made during each period (5%). Covariate analysis showed that subjects who slept longer the previous night made fewer errors ($F(1,63) = 4{\cdot}15$, $p = 0{\cdot}04$). Although no effects relating to exposure or sensations were observed, errors were (*a*) more frequent on the second day, (*b*) increased during each day, and (*c*) increased with time on the task (all $p < 0{\cdot}001$). The sensitivity of error rates to prolonged work is in agreement with earlier research.[12]

Lapses in concentration were assessed by counting the incidence of extra long reaction times. These extra long reactions, called "blocks"[9] or "gaps,"[12] identify periods of relative inaction during task performance. A decision gap identifies relative inaction during light detection, response selection, and motor execution. A movement gap identifies relative inaction during the more automatic movement phase—that is, return to centre. In the present study a gap was counted when a correct reaction time exceeded a subject's mean reaction time by more than two standard deviations; correct reactions longer than 1·5 seconds were always regarded as gaps. New decision gap and movement gap settings were calculated each time the task was performed.

Neither type of gap varied as a function of exposure or sensations, although several task specific effects were observed. In common with earlier work,[12] periods of relative inaction during decision making increased after eight minutes of continuous responding (time of day × period: $p = 0{\cdot}01$). This increase was particularly evident in the afternoon, the steepest increase occurring in the postlunch test (fig 5). The incidence of movement gaps declined rapidly during the first eight minutes (9·3 to 5·2 gaps/period) and then remained constant; the first test of the day showed the steepest decline (day × time of day × period; $p = 0{\cdot}003$). This pattern suggests the rapid establishment of a motor skill—that is, return to centre—which is unaffected by later "lapses in concentration" during decision making.

VISUAL-SEARCH

Two subjects had excessively high omission rates (>90%) and their results were not included in the analysis. Table 2 shows the distribution of the remaining 72 subjects as a function of the grouping factors. On average, each subject responded to 144 digits (including all errors) during each period: a total of 720 digits during the 10 minute task. As shown in fig 6, workrates improved throughout the task in the morning. At other times this improvement was restricted to the first few minutes (time of day × period: $p < 0{\cdot}001$). In the analyses presented below omission and commission errors are excluded from calculations of target and non-target latencies.

On average, each subject correctly identified targets in 612 msecs and non-targets in 388 msecs. In general, non-target latencies improved during the first test of the day and then remained stable (day × time of day × period: $p < 0{\cdot}001$). Target latencies show a time of day × period interaction ($p = 0{\cdot}004$) similar to that found for overall workrates (cf fig 6).

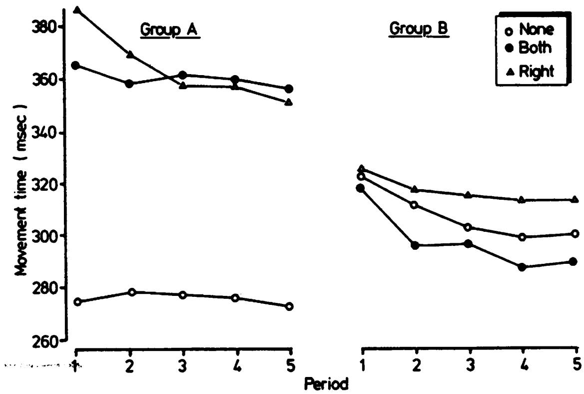

Fig 4 *Effect of reports of sensations on movement times in serial-reaction-time task: excluding Wrong perception group.*

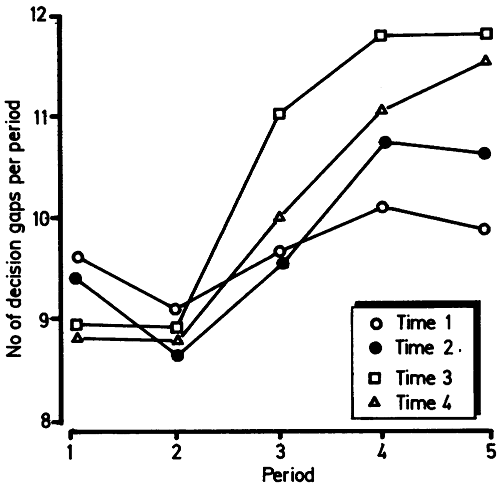

Fig 5 *Number of lapses in concentration in serial-reaction-time task as a function of time of day and period: all subjects.*

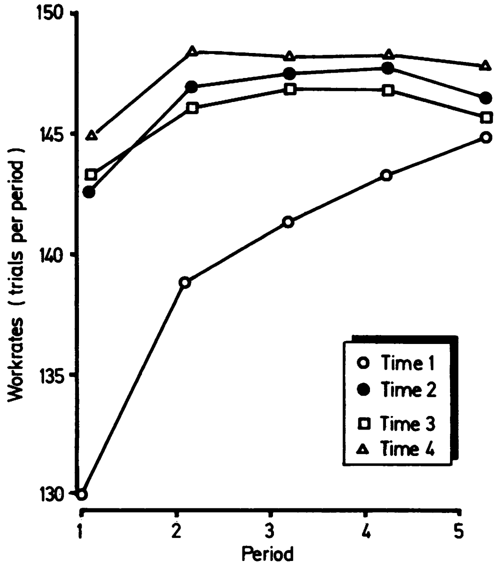

Fig 6 *Number of trials attempted (including errors) in the visual-search task as a function of time of day and period: all subjects.*

The covariate analyses showed that (*a*) older subjects identified targets (p = 0·005) and non-targets (p = 0·004) more slowly, (*b*) targets were detected faster when presession arousal was high (p = 0·03), and (*c*) non-targets were detected faster when presession stress was low (p = 0·04). Because both target and non-target latencies were influenced by reports of sensations, only the None-Both-Right analyses are reported.

Two significant effects of exposure were observed. The first was a day × subject group × perception group interaction for non-target latencies (F (2,58) = 4·2, p = 0·02) but not for target latencies (p = 0·43). Although the interaction could have shown worse performance for those who thought they were being exposed, the opposite was the case—that is, the effect was localised to those who did not report sensations. For subjects not reporting sensations, the exposed and the sham exposed groups had equivalent non-target latencies on the first day (fig 7). On the second day, however, the exposed group (group B) responded more slowly than the sham exposed group (group A). Newman-Keuls analysis isolated the exposure effect to group A's superior improvement from the first to the second day (p < 0·05). Because the effect is restricted to those not reporting sensations, it is possible that those who believed they were being exposed made some special effort. The magnitude of this effect did not vary with time into the exposure period (p = 0·58).

The second exposure related effect was also restricted to non-target latencies: a day × time of day × subject group interaction (F (3,177) = 3·08, p = 0·03). This effect was not influenced by reports of sensations (p = 0·58) and suggests a simple cross over in which non-target latencies were slower during the first hour of exposure (fig 8). Newman-Keuls analysis, however, failed to identify the source of the effect.

Finally, as shown in fig 9, sensations appeared to have an asymmetric influence on target latencies (period × subject group × perception group interaction: F (8,236) = 2·32, p = 0·02). This effect was independent of the day of testing (p = 0·64) and does not represent an effect of exposure per se.

With regard to error rates, one commission error only was made, on average, during the task and this

Table 2 *Number of subjects analysed in the visual-search task as a function of grouping factors*

	Perception group					
Subject group	*Total*	*None*	*Some*	*Both*	*Right*	*Wrong*
Group A	37	16	21	8	13	0
Group B	35	11	24	9	8	7
Overall	72	27	45	17	21	7

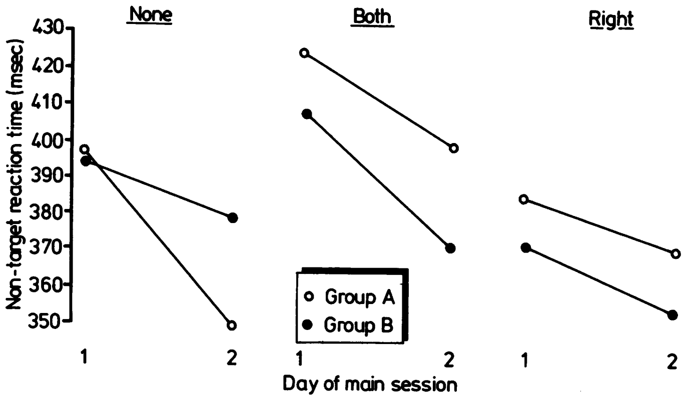

Fig 7 *Effect of exposure and sensations on non-target latencies in visual-search task as a function of day and subject group; excluding Wrong perception group.*

rate did not vary as a function of exposure, sensations, or any of the other conditions examined. The omission error rate forms the main measure of vigilance skill, and because the overall rate was low (13%), the results were analysed using the arc-sine transformation.

No effects of exposure or sensations were observed on omission scores, although covariate analysis showed that (*a*) older subjects made fewer omissions ($F(1,66) = 5{\cdot}34$, $p = 0{\cdot}02$) and (*b*) fewer omissions were made when presession arousal was high ($F(1,66) = 4{\cdot}37$, $p = 0{\cdot}04$). Furthermore, the omission rate increased as the task continued, was higher at the end of the day, and was generally higher on the second day (all $p < 0{\cdot}001$). The increase as the task continued (vigilance decrement) agrees with previous research.[20] Newman-Keuls analysis of a time of day × period interaction ($p = 0{\cdot}04$) showed the vigilance decrement to be less steep during the middle of the day (fig 10).

Discussion

The question as to whether the currents induced by a power frequency electric field have a stressor action was specifically addressed in the present study. Support for this hypothesis was not obtained.

In the serial-reaction-time task sustained performance elicited an increasing number of lapses in concentration and loss of compensatory control. These features of performance were not influenced by exposure. It cannot be argued, therefore, that the failure to uncover exposure effects was a reflection of task insensitivity. We may conclude, therefore, that (*a*) exposure does not impair sustained concentration or compensatory control and (*b*) a 50 Hz electric current does not appear to act as a stressor. This last conclusion is also supported by the failure to find an effect of exposure on self reported stress.[14]

In the unpaced vigilance task used here transitory failures in attending to target digits led to errors of response selection (omissions) and the robust vigilance decrement indicated that these transitory failures became more frequent as the task continued. Exposure to electric currents and reports of sensations at electrode sites did not influence the size of the vigilance decrement or the degree of caution exercised. Task performance, however, did vary as a function of the time of day and task duration and there

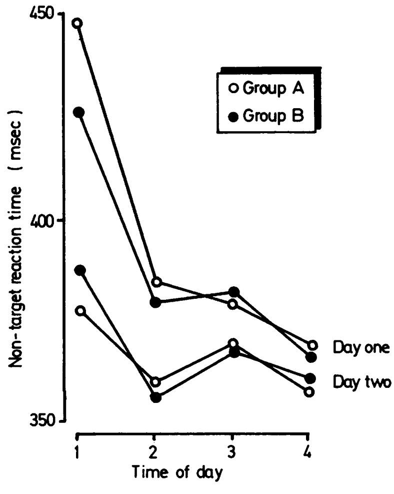

Fig 8 *Effect of exposure to 50-Hz currents on non-target latencies in visual-search task: excluding Wrong perception group.*

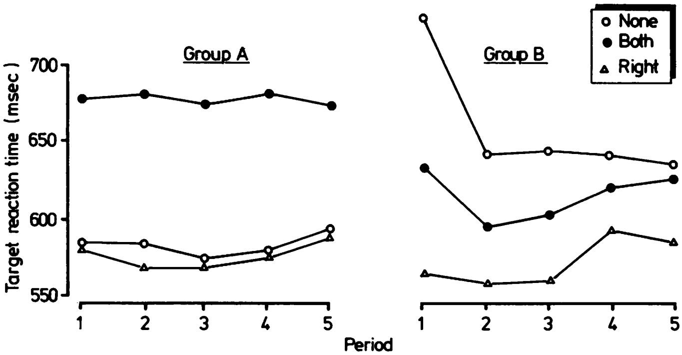

Fig 9 *Effect of sensations on target latencies in visual-search task: excluding Wrong perception group.*

was evidence that older subjects worked more carefully at the task. Furthermore, target identifications were faster and more accurate when arousal was high, and non-target identifications were slower when stress was high. Thus it cannot be argued that the failure to find exposure effects on these parameters was due to the insensitivity of the vigilance task.

There were two findings in the vigilance task that pointed to a possible effect of electric currents on non-target latencies. The first corresponds to the traditional cross over pattern for this type of design,[21 22] but the slower latencies found were restricted to the first hour of the exposure day (fig 8). If construed as a genuine effect of exposure (independent of reports of sensations) it might indicate that habituation or adaptation occurred with continued exposure. The second finding, restricted to those subjects who do not report sensations, was an order of exposure asymmetry (fig 7) that did not vary with time into the exposure period. This is similar to the asymmetry reported in the syntactic reasoning task[14] and so many of the comments made previously apply here—for example, inherent group differences or transfer effects.

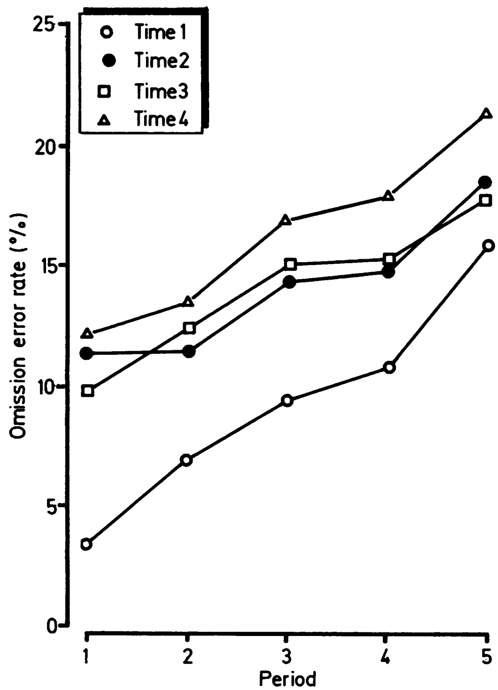

Fig 10 *Omission error rates in visual-search task as a function of time of day and period: all subjects.*

In contrast to the relative paucity of positive findings for the exposure condition reports of sensations had pronounced effects in both tasks. Although the generally slower performance by those reporting sensations was not entirely unexpected, the asymmetric relation with the order of exposure was puzzling and warrants some discussion. The clearest example of this asymmetry was observed in the serial reaction time task (see fig 4) and its presence on both days probably reflects a carry over effect from the first day. This explanation receives some support from the fact that the asymmetry was restricted to trial initiation, because there is evidence that this became a routine and automatic response very early during the task. Of more interest, however, the carry over effect was restricted to those who were exposed on the first day. There is a suggestion, therefore, that sensations during exposure might be having a different effect from sensations during sham exposure.

In summary, the two sustained attention tasks reported in the present paper were sensitive to lapses in concentration, loss of compensatory control, and declining vigilance skill. These aspects of peformance did not vary as a function of the exposure conditions. Thus an important conclusion of the present study is that up to 5·5 hours exposure to a simulated 36 kV/m electric field has no influence on vigilance and sustained concentration. Furthermore, the hypothesis that the electric currents induced by power frequency fields have a stressor action was not supported.

Although the study findings were essentially negative, of special interest was the observation of an exposure effect restricted to the second day because this pattern has been noted before.[14] Thus state dependent transfer mechanisms warrant more specific attention. Moreover, it seems clear that quite brief reports of sensations at electrode sites, even during sham exposure, can disrupt performance on sustained attention tasks and this highlights the importance of eliminating all reports of sensations during electric field exposure.

The practical significance of these results for the electricity supply industry is difficult to assess. The currents applied were greater than would normally be experienced, even briefly, by people working near high voltage substations and transmission lines and the single exposure used gives little guidance for predicting what the consequences of repeated exposures might be. Further work is required to replicate (or otherwise) the effects of current suggested by the present experiments.

The cooperation of staff from the CEGB and NorWEB, both those who participated in the experiments and those helping in the recruitment of volunteers, is gratefully acknowledged. I am particularly indebted to W R Lee, D E Broadbent, J C Male, W T Norris, and J A Bonnell for their valuable contributions to the work reported here. This work was supported by the Central Electricity Generating Board.

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