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Effects of 50 Hz electric currents on mood and verbal reasoning skills

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ABSTRACT Seventy six male volunteers were studied in a crossover trial to assess the impact on the central nervous system of electric currents such as might be induced by exposure to an intense power frequency electric field. Currents totalling 500 microamperes (50 Hz) were passed through electrodes attached to the head, upper arms, and feet, simulating exposure of an average man to a vertical electric field of about 36 kV/m. Exposure was continuous for a single day (5·5 hours) and the experiment was based on a double blind, counterbalanced, within subject design. A series of psychological tests examining self reports of both stress and arousal (mood checklist) and performance tests of memory, attention, and verbal skills were administered. Although the double blind conditions were compromised to some extent by reported sensations at electrode sites, the duration of these sensations was small in relation to the overall exposure or sham exposure time and did not interact with the effects apparently associated with exposure that were found. No significant difference between the exposed and sham-exposed groups was found on the first day, but on the second day the sham exposed group felt more aroused at the end of the day and their response times had improved more on the complex problems of a syntactic reasoning test. No exposure effects were apparent in self reports of stress or in performance in a semantic reasoning test, although both showed some influence of sensations. Interpretation of the exposure effects is complicated by their apparent restriction to the second test day, which may indicate some type of state dependent transfer phenomenon.

During the past two decades there has been increasing interest in possible biological effects of electromagnetic fields associated with electrical power. This ranges from the concern of occupational physicians with the health of workers occupationally exposed to electric fields[1 2] to theoretical and experimental attempts to understand how the naturally occurring fields and currents of the body regulate biological processes.[3 4]

The electrical environment near high voltage power lines is well understood.[5 6] Directly under 400 kV lines in the United Kingdom, 50 Hz electric field strengths can rise to 11 kV/m, whereas in substations they can rise, in places, to 22 kV/m.[7] When a person is exposed to such fields, alternating charges appear on the surface of the body and small electric currents flow within it.[8] For moderately high fields, the surface charges may interact with the field to give perceptible hair vibration and small discharges (microshocks) may occur if the person touches other objects at a different potential. For men of average height who are well grounded, it has been estimated that 14 microamperes flow through the body to ground for each kV/m of electric field at 50 Hz, about a third of which enters through the head.[8] According to Deno, 40% of the induced current passes through the head and neck.[9]

The possibility that power frequency fields have undesirable effects on human health was first raised by Asanova and Rakov in a survey of substation workers.[10] They reported autonomic and central nervous system disorders in a small group of maintenance workers who were exposed to fields of up to 10 kV/m for about five hours a shift. Since those initial observations were published, there has been a substantial accumulation of information on biological interactions with low frequently electromagnetic fields.[5]

Although several occupational investigations have been conducted there is little consensus over the presence of effects.[1 11] Thus whereas some investigators

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report findings similar to those of Asanova and Rakov,[12-14] others have failed to find any effect on health indices.[2 15-17]

There are only a limited number of laboratory studies on human volunteers exposed to power frequency electric fields. Johansson *et al* exposed subjects to fields of about 20 kV/m for an unspecified time, but found no significant exposure effects in a series of simple psychological tests.[18] Hauf has summarised the results of a series of studies using fields between 1 and 20 kV/m for a maximum of three hours and reported improvements in simple reaction time.[19] This was ascribed to a non-specific stimulation effect on the skin, although it is not clear if it was regarded as evidence of field perception. Rupilius exposed subjects for three hours to a 20 kV/m electric field but failed to observe a field related effect.[20] Eisemann, who followed up that work by passing a 200 microampere current through the arms and legs, also failed to find any field related effects.[21]

More generally, occupational physicians have become interested in applying psychological techniques to evaluate exposure to a wide range of potentially neurotoxic substances. Such techniques are thought to be of particular relevance when there is no consensus on the biological correlates of exposure to the suspected agent (as is the case with electric fields) and it is intented to detect effects at subclinical levels.[22 23] Furthermore, psychological tests provide an unobtrusive measure of the functional status of the central nervous system, and because there is little published work on the psychological effects of electric field exposure there is a need to gather relevant information on mental functioning while current is passing. The present investigation examines the effect of a single exposure to a 50 Hz electric current on psychological functioning.

One of the main objectives of the present study was to separate the peripheral field induced phenomena (microshocks and hair vibration, for example) from the induced electric currents. To achieve this, no external electric fields were used and the electric current was introduced directly via electrodes attached to the body. A 500 microamperes current was used to simulate an electric field of about 36 kV/m.[8] While the field magnitude selected is somewhat higher than that normally encountered near high voltage power transmission plant,[7] the level chosen is not unrealistically high and helps to provide an additional degree of confidence for psychological functions showing no exposure effects.

Design and protocol

Subjects attended on four occasions. On the first occasion (familarisation) they were acquainted with the purpose and procedures for the main sessions, including a one hour practice session with the psychological tests. An initial medical examination was conducted to ensure that all those wishing to participate were healthy, chiefly to avoid introducing confounding factors into the experiment. The second and third occasions were designated main sessions and each session lasted a single day. The second main session was on the same day of the week as the first main session, normally one week later. One week after the second session, the subjects attended a final medical examination.

DESIGN

Subjects attended main sessions in exposed/sham exposed pairs, with their respective roles assigned at random (and without their or the experimenter's knowledge) on the first day and reversed for the second day. Those subjects allocated to the exposure condition on the first day and the sham exposure condition on the second day were designated group A. Those subjects meeting the two conditions in the reverse order were designated group B. Thus on each day one of the two subjects was in group A and the other was in group B. Psychological functioning was monitored during each main session day by four one hour sequences of four psychological tests.

EXPOSURE METHODOLOGY

Four commercially available EEG electrodes were attached to the scalp: two on the anterior posterior axis and two on the left right axis above the ears. Three commercially available self adhesive disposable ECG electrodes were placed on the upper part of each arm. Arm electrodes were fitted with a 2·5 cm steel disc, which made contact with the skin through a standard NaCl electrode jelly. A tin foil return electrode was placed under the instep of each foot (inside the sock).

Leads from the ten upper body electrodes and the two foot electrodes terminated at a junction box worn on a waist belt. A 10 metre multiway cable connected the current supply equipment to the junction box, thereby enabling subjects to move freely around the testing laboratory. Each upper body electrode was separately adjusted to carry 50 microamperes, providing a total current of 500 microamperes.

EXPERIMENTAL SESSIONS

Subjects arrived at 0900 and at 0920 the electrodes were fitted. Both subjects were then given a "perception test" to determine the minimum current required to produce a sensation at an electrode on the non-dominant arm. This minimum current is referred to as a "perception level." The upper body electrodes were then individually adjusted to carry 50 microamperes and the current was switched off. Subjects were provided with a perception questionnaire on which they could note the incidence and duration of any unusual sensations occurring during the remainder of the day. Just before the exposure/sham exposure session began (presession), subjects completed a mood checklist and had their pulse rate taken.

The current was turned on at 1030 and remained on until 1600 unless a subject needed to leave the testing laboratory for a brief period. The first sequence of tests started a few minutes after the current was switched on. The second, third, and final sequences of tests started at 1150, 1340, and 1500, respectively. Subjects were allowed only decaffeinated drinks during the brief breaks between testing and they ate a sandwich lunch (1250–1340). The current was switched off after the last sequence of tests (1600) and had thus flowed almost continuously for 5·5 hours. A few minutes after the current was switched off, each subject completed a second mood checklist and had their pulse rates taken (postsession). Finally, the electrodes were disconnected and the subjects were free to leave. Both the exposure and the sham exposure session followed the above procedure.

PSYCHOLOGICAL TESTS

Four performance tests were used in a battery lasting one hour. Two of the tests examined verbal reasoning skills (syntactic reasoning and semantic reasoning) and two examined sustained attention skills (visual search and serial reaction time).

The syntactic reasoning test is based on that of Baddeley[24] and represents a wide range of sentence verification tasks.[25] Subjects verified statements describing the sequence of two letters which were present—for example, A is followed by B, AB. The statements varied in linguistic complexity but conveyed similar information. They could be positive or negative with the verb in either the active or passive voice and could be either true or false with respect to the letter pair that followed. Subjects answered as many questions as possible, at a self paced rate, for 10 minutes. The test draws on working memory as well as linguistic skills.[26,27]

The semantic reasoning test examined the speed and accuracy with which information held in long term memory could be verified.[28,29] Subjects confirmed the truth or falsity of a series of statements referring to facts from everyday life (footballs are made in factories) and they attempted to answer as many questions as possible, at a self paced rate, for five minutes.

The two tests concerned with sustained attention skills will be described and discussed in a future paper. One test was a computerised version of a cognitive vigilance task used by Broadbent and Heron[30] that included a short term memory component (visual search test) and lasted 10 minutes. The other test was concerned with sustained attention and fatigue during a 20 minute period and was based on a task devised by Leonard [31] (5 choice serial reaction time test). This task has been used extensively in the examination of environmental stressors.[32]

The four psychological tests were presented and controlled by microcomputer (Research Machines Ltd 380Z, Oxford). Stimulus materials were presented on a 17″ black and white video monitor and responses made on a standard keyboard. Tests were always presented in the following order: visual search, syntactic reasoning, serial reaction time, and semantic reasoning. During testing periods, each subject sat in an individual booth that was screened off from the testing laboratory and the other subject. The testing laboratory consisted of an office and a reception area, with the two testing booths at the far end of the room.

SUBJECTS

Seventy six male volunteers, aged between 18 and 65

Table 1 *Mean values for the 12 covariates as a function of subject group and main session day*

	Group A		*Group B*	
	Day one	*Day two*	*Day one*	*Day two*
Age (years)	36·7		35·5	
Exposure duration (minutes)	317·6		321·0	
Perception level (microamperes)*	334·8		315·1	
No of disconnections*	1·7		1·9	
Duration of sensations (minutes)*	5·1		12·0	
Presession stress	2·1	1·5	1·8	1·4
Presession arousal	7·5	6·8	7·8	7·9
Presession pulse rate (bpm)	63·3	62·9	62·7	63·4
Duration of sleep (hours)†	7·0	7·1	6·9	7·1
Duration of extra sleep (hours)‡	−0·1	−0·1	−0·4	−0·3
Caffeine intake since rising (cups)	0·8	0·8	0·7	0·7
Alcohol consumption (cl)†	2·0	2·8	1·6	1·1

*Values for the exposure day only.
†Values for the night preceding the exposure/sham exposure day.
‡Difference between the duration of sleep the previous night and normal sleep time.

(mean = 36), took part in the study. All volunteers received their normal pay. No subjects had a previous history of occupational exposure to electric fields.

A computer logging malfunction lead to several incomplete data sets and the number of subjects entering into each analysis is therefore noted at the start of that analysis.

Results

Twelve variables were designated as covariates. Table 1 shows their mean values as a function of the day of testing and subject group (group A and group B) and demonstrates that good group matching was achieved by the double blind and random allocation of conditions.

PERCEPTION

The extent to which the double blind nature of the experiment was compromised by the detection of current was assessed using data from the perception questionnaire using non-parametric statistics.[33] Although the average perception level was about 320 microamperes (see table 1) and each electrode current was only 50 microamperes, nearly two thirds of the subjects reported itching or prickling sensations at electrode sites. These reports, however, were not confined to periods of exposure. Considering both subject groups, 28 never reported sensations, 23 reported sensations only on the exposure day, 18 sensations on both days, and seven sensations only on the sham exposure day.

A McNemar test showed that subjects were more likely to report sensations on the exposure rather than sham exposure day ($p = 0{\cdot}012$), although this varied as a function of subject group (group A, $p < 0{\cdot}001$; group B, $p = 0{\cdot}65$). A Wilcoxon test showed that the total duration of these sensations was estimated to last longer during exposure (8·4 minutes) than during sham exposure (2·6 minutes); $Z = -4{\cdot}07$, $p < 0{\cdot}001$. This pattern of longer lasting sensations on the exposure day was common to both group A ($Z = -2{\cdot}68$, $p = 0{\cdot}007$) and group B ($Z = -2{\cdot}91$, $p = 0{\cdot}004$). The correlation between the duration of sensations on the exposure day and individual perception levels on that day was not significant ($r = -0{\cdot}043$, $p > 0{\cdot}25$).

The absence of correlation between perception levels and duration of sensations is puzzling because a negative correlation would be expected. Furthermore, because large numbers of subjects reported sensations during sham exposure it is obvious that sensations were not in all cases due to the passage of current. What is clear, however, is that the double blind nature of the study is compromised to some extent by the pattern of sensations reported by subjects.

Rather than omitting all subjects who reported sensations, subjects were classified according to the pattern of sensations they reported. The initial classification considered two "perception" groups: those who reported no sensations (None) and those who reported sensations at some point during the two main sessions (Some). In those analyses where perception influenced performance scores three perception groups were considered: no sensations (None), sensations on both days (Both), and sensations only on the exposure day (Right). Subjects reporting sensations only on the sham exposure day (Wrong) could not be considered in this supplementary analysis because they came exclusively from group B. This strategy was thought to be useful because (*a*) sensations were only briefly experienced during the 319 minute exposure, (*b*) reports of sensations were not necessarily related to current, and (*c*) it was of considerable interest to determine whether any exposure effects were dependent on, or independent of, reports of sensations.

SELF REPORTS OF MOOD

The mood checklist used here is designed to assess self reports of two bipolar factors which have been labelled "stress" and "arousal." The stress factor is thought to represent an internal response to the perceived favourability of the environment whereas the arousal factor corresponds to a sleep wakefulness dimension.[34] Stress scores have a range of 0–18 and arousal scores a range of 0–12. Scores were analysed by an analysis of variance with covariance, with presession and postsession scores entered as a time of day factor having two levels. Table 2 shows the number of subjects as a function of the grouping variables.

STRESS SCORES

Analysis of stress scores did not show any effects of

Table 2 *Number of subjects analysed in the mood checklist as a function of grouping factors*

Subject group	*Perception group*					
	Total	*None*	*Some*	*Both*	*Right*	*Wrong*
Group A	38	17	21	8	13	0
Group B	37	11	26	10	9	7
Overall	75	28	47	18	22	7

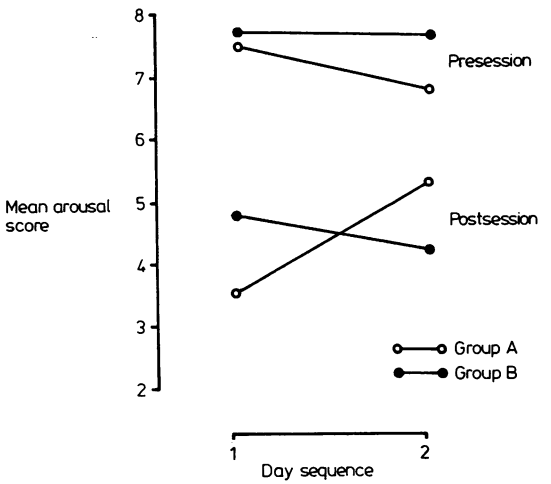

Fig 1 *Effect of exposure to 50 Hz currents on arousal scores.*

exposure and subjects rated themselves equally stressed at all points during the main sessions. Although the stress scores were low (mean 1·8), covariate analysis showed significant effects of presession arousal and the during of sensations on the exposure day. Presession arousal was negatively correlated with overall stress levels (F(1,69) = 5·59, p = 0·02). The duration of sensations was positively correlated with overall levels of stress (F(1,69) = 12·4, p = 0·001), indicating that subjects feeling more stressed were those reporting longer lasting sensations. Omitting the duration of sensations covariate did not uncover any other effects, confirming that the None and Some groups had equivalent stress scores. This pattern of results was confirmed in an analysis of the None, Both, and Right perception groups.

AROUSAL SCORES

Analysis of arousal scores showed a significant effect of exposure that was independent of perception: a day × time of day × subject group interaction; F(1,71) = 6·41, p = 0·014. A reanalysis using the None, Both, and Right perception groups showed that the interaction remained significant (F(1,62) = 9·76, p = 0·003) and independent of perception (F(2,62) = 0·58, p = 0·57). The main effect of time of day was highly significant, showing lower levels of arousal at the end of the day (F(1,69) = 98·4, p < 0·001). In addition, two covariates were correlated with within subject arousal scores. Presession pulse rate was positively correlated (F(1,69) = 9·17, p = 0·004) and recent alcohol consumption was negatively correlated (F(1,69) = 13·71, p < 0·001). Thus on the day a subject felt generally less aroused, he tended to have drunk more alcohol the night preceding the experimental session or had a lower pulse rate at the start of the day, or both.

Newman-Keuls analysis of the exposure effect shown in fig 1 indicated equivalent arousal scores at the start of the day (presession) for both subject groups and that the effect was localised to postsession scores. Inspection of the postsession scores shows arousal to be lower after exposure than after sham exposure (a simple cross over effect). The between subject differences, however, were not significant and the effect appears only in group A, whose postsession scores on the exposure day was lower than on the sham exposure day (p < 0·01). Postsession scores for group B did not differ on the two days.

VERBAL REASONING SKILLS

Syntactic reasoning

Subjects attempted an average of 103 syntactic reasoning questions during the 10 minute task. Statements were verified with an overall accuracy of 98·5% and with an average correct response time of 3·39 seconds. A Kolmogorov-Smirnov goodness of fit test[33] showed that the distribution of response times did not depart significantly from normality (p > 0·25). Because the overall accuracy rate was high, however, these scores were analysed using the arcsine transformation.[35] Table 3 shows the number of subjects entering into the analysis.

The duration of sleep the previous night was correlated with correct response time (F(1,67) = 5·97, p = 0·017), indicating that the longer the subject had slept the faster he verified statements. The day × time of day interaction was significant both for response time (F(3,204) = 10·6, p < 0·001) and for accuracy (F3,204) = 6·22, p < 0·001). Newman-Keuls analysis showed that response times improved on both days and that accuracy stabilised by the second test on the

Table 3 *Number of subjects analysed in the syntactic reasoning test as a function of grouping factors*

Subject group	*Perception group*					
	Total	*None*	*Some*	*Both*	*Right*	*Wrong*
Group A	38	17	21	8	13	0
Group B	34	10	24	10	8	6
Overall	72	27	45	18	21	6

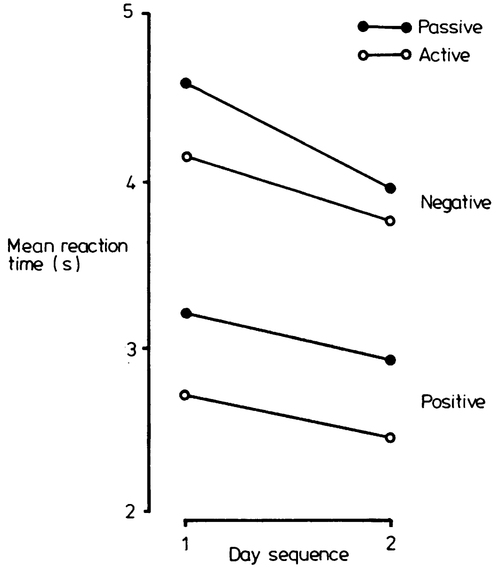

Fig 2 *Mean reaction times in syntactic reasoning test as a function of day of testing and difficulty of reasoning problem.*

first day. This indicates that verification speeds continued to improve after learning (in terms of accuracy) was completed.

On average, active statements were answered 386 msecs faster than passive ones ($F(1,68) = 89{\cdot}6$, $p < 0{\cdot}001$) but with equal accuracy ($p = 0{\cdot}71$). Positive statements were answered 1241 msecs faster than negative ones ($F(1,68) = 260{\cdot}9$, $p < 0{\cdot}001$) and more accurately ($F(1,68) = 19{\cdot}5$, $p < 0{\cdot}001$). A highly significant day × voice × negation interaction for response times ($F(1,68) = 9{\cdot}63$, $p = 0{\cdot}003$) indicated that statements proved more difficult to verify in the order: active positive, passive positive, active negative, and passive negative. As shown in fig 2, the interaction with the day of testing showed that the most difficult statements (passive negative) were those showing the most improvement between the first and second days.

The "truth" of the reasoning statement only influenced verification times for positive statements (truth × negation interaction: $F(1,68) = 87{\cdot}1$, $p < 0{\cdot}001$), with "true" statements showing a 450 msec advantage for positive forms over negative forms ($p < 0{\cdot}01$). The 100 msec advantage for negative forms in "false" statements was not significant (fig 3). The truth × negation interaction was also significant for accuracy scores ($F(1,68) = 30{\cdot}7$, $p < 0{\cdot}001$), but showed equivalent accuracy for all statements except true negative ones, which were answered less accurately (fig 4).

A significant effect of exposure that varied with the voice of the statement (day × voice × subject group; $F(1,68) = 5{\cdot}09$, $p = 0{\cdot}027$) was apparent in verification speeds. This exposure effect was independent of whether perception was reported ($p = 0{\cdot}40$), was not reflected in accuracy scores ($p = 0{\cdot}74$), and did not vary with time into the exposure period ($p = 0{\cdot}18$). The truth × voice × subject group × perception group interaction ($F(1,68) = 4{\cdot}28$, $p = 0{\cdot}042$), however, showed that verification speeds did show some variation as a function of perception. The scores were therefore reanalysed using the None Both Right groups.

The effect of exposure on verification speeds remained significant ($F(1,60) = 8{\cdot}27$, $p = 0{\cdot}006$), independent of perception ($F(2,60) = 1{\cdot}42$, $p = 0{\cdot}25$), and was not reflected in accuracy scores ($p = 0{\cdot}80$). Two further interactions involving the negation factor, however, attained significance for verification speeds. The most important was an exposure effect that varied for positive and negative forms (day × negation × subject-group: $F(1,60) = 5{\cdot}67$, $p = 0{\cdot}017$). The effect also was independent of the three types of perception ($p = 0{\cdot}57$), time into the exposure

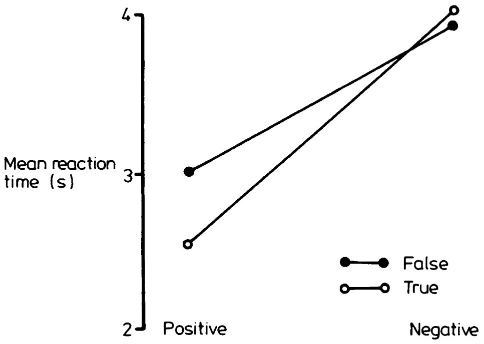

Fig 3 *Mean reaction times in syntactic reasoning test as a function of truth of statement and presence of negatives.*

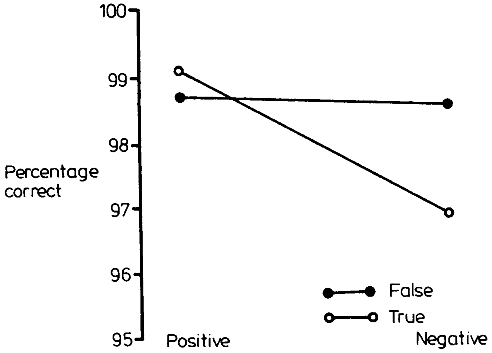

Fig 4 *Mean accuracy in syntactic reasoning test as a function of truth of statement and presence of negatives.*

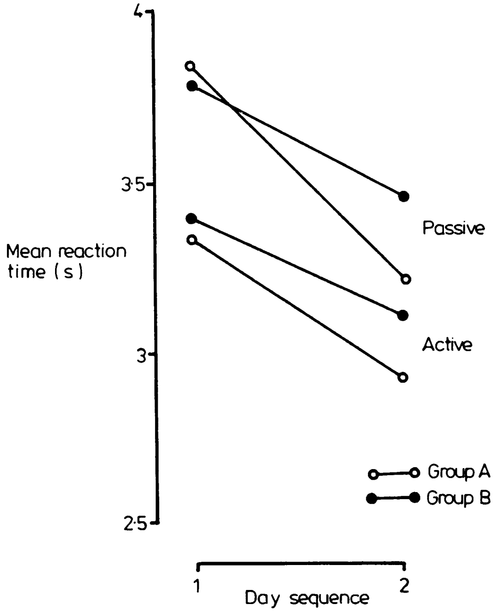

Fig 5 *Effect of exposure to 50 Hz currents on reaction times in the syntactic reasoning test as a function of voice of reasoning problem: all subjects.*

period (p = 0·55), and was not reflected in accuracy scores (p = 0·60). The four way interaction involving perception entered into a higher order interaction with the negation factor (F(2,60) = 3·37, p = 0·03) and in general terms the group reporting sensations on both days verified negative statements slower than the other two groups. The patterns for the None and Right perception groups were identical. Since this effect did not depend on the day of testing (p = 0·93) it is independent of exposure.

Figure 5 shows the exposure effect as a function of the voice of the statement and fig 6 the exposure effect as a function of the presence of negatives. Newman-Keuls analysis showed a similar pattern of results for both interactions and that the exposure effect was localised to group A. This group showed greater improvement in response times both for passive and negative statements. Whereas verification times were numerically slower for group B on the second day (when they were exposed) there is no reversal on the first day, thus indicating an asymmetrical effect.

By contrast with the verification speeds, accuracy scores showed several effects related to perception. The most important was a day × negation × subject group × perception group interaction for both the None Some analysis (F(1,68) = 6·45, p = 0·013) and the None Both Right analysis (F(2,60) = 5·94, p = 0·004). Figure 7 shows that this effect is restricted to those subjects reporting perception, who show less accurate performance on the negative statements.

SEMANTIC REASONING

Subjects attempted about 75 questions during the five minute task, answering correctly in about 1·63 seconds and making an average of two errors. Table 4 shows the number of subjects entering into the analysis. The covariate analysis shows that older subjects answered the questions more accurately (F1,65) = 5·63, p = 0·02). Furthermore, subjects with lower pulse rates answered questions faster (F(1,64) = 5·15, p = 0·03) and on the day a subject felt more aroused he also answered questions faster: F(1,64) = 6·26, p = 0·02.

Correct response times improved from the first to last session on both days, with greater improvement on the first day (F(3,198) = 12·95, p < 0·001) and faster speeds on the second day (F(1,63) = 18·75, p < 0·001). A perception interaction which was independent of exposure (time of day × period × perception group: F(12,792) = 1·91, p = 0·03) was also significant.

Errors show a time of day × subject group (F(3,198) = 3·5, p = 0·017) interaction and a complex four way interaction involving perception (time

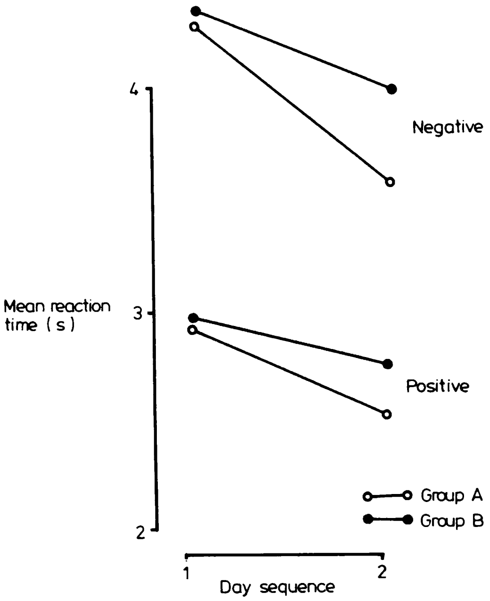

Fig 6 *Effect of exposure to 50 Hz currents on reaction times in the syntactic reasoning test as a function of presence of negatives in reasoning problem: excluding Wrong perception group.*

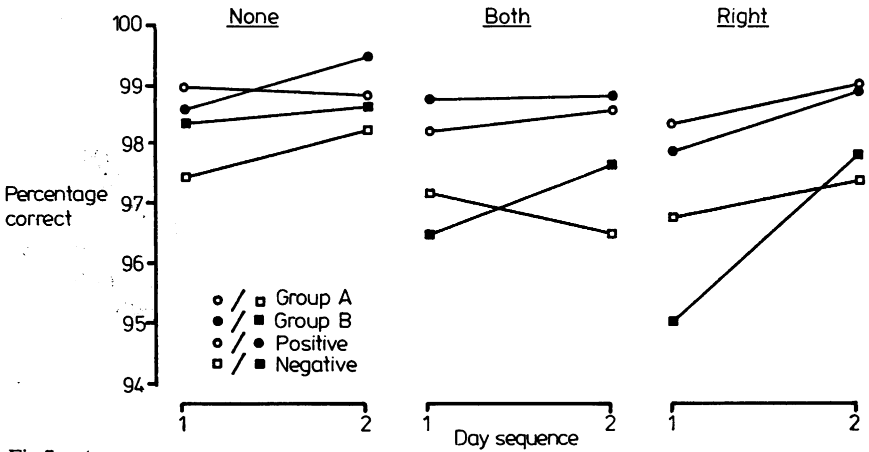

Fig 7 *Accuracy scores in syntactic reasoning test as a function of day, subject-group, perception group, and presence of negatives.*

of day × period × subject group × perception group: F(12,972) = 1·82, p = 0·04).

When analysed using the None Both Right classification, the perception effect for errors reduced to the time of day × subject group interaction (p = 0·01) and, for correct response times, a day × time of day × perception group interaction (F(3,174) = 3·53, p = 0·002). Newman-Keuls analysis showed an increase in errors over the day for group A and a constant error rate for group B. Because this effect does not depend on the day of testing, it is not confounded with exposure. For correct response times, the perception interaction shows the three perception groups improve at different rates on both days (Fig 8), with no improvement by the Both group on the second day. Once again, this effect is independent of exposure.

Discussion

The purpose of the present study was to investigate the possible effects on human performance of a short term exposure to the electric currents which would be induced by a power frequency electric field. A 500 microamperes 50 Hz current was used to simulate exposure to an overhead electric field of about 36 kV/m. The current was passed almost continuously for about 5·5 hours during a single day, with four one hour blocks of psychological testing during this period. Although the double blind nature of the study was compromised to some extent by reports of sensations at electrode sites, the duration of these sensations was small in relation to the overall exposure of sham exposure time and more importantly did not interact with the effects of current which were found.

Two exposure effects were observed and neither was compromised by the particular pattern of sensations reported. The exposure effects were apparent in self reports of arousal and in correct response times to the linguistically complex statements of a syntactic reasoning test. In contrast, neither self reports of stress nor performance in a semantic reasoning test varied as a function of the exposure conditions, but both showed some dependence on the duration or particular pattern of sensations reported by subjects.

The pattern of postsession arousal scores was consistent with the simple hypothesis that subjects felt less aroused after exposure. Post hoc testing, however, showed an effect restricted to those subjects exposed on the first day and sham exposed on the second day (group A). Thus in addition to this simple hypothesis, four other classes of hypotheses need to be considered to explain the observed pattern.

Firstly, from the magnitude of the changes between presession and postsession scores on the sham exposure day (see fig 1), it could be argued that group

Table 4 *Number of subjects analysed in the semantic reasoning test as a function of grouping factors*

Subject group	*Perception group*					
	Total	*None*	*Some*	*Both*	*Right*	*Wrong*
Group A	36	15	21	8	13	0
Group B	34	9	25	10	9	6
Overall	70	24	46	18	22	6

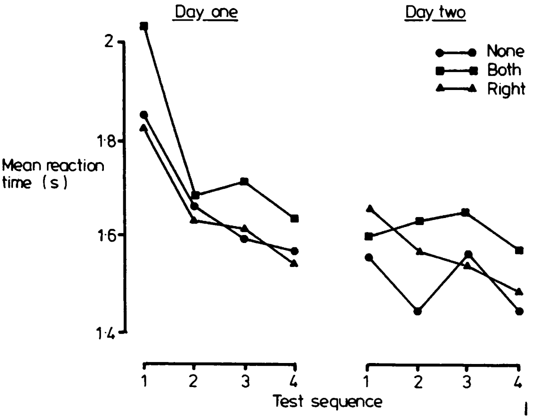

Fig 8 *Mean reaction times in semantic reasoning test as a function of day, time of day, and perception group.*

A were more able to sustain their levels of arousal over the day—that is, a real difference between the two randomly allocated subject groups. Under this hypothesis, group B do not show an influence of current because the large fall in arousal experienced over the sham exposure day is obscuring any additional fall on the exposure day—that is, a floor effect.

The second class of explanation assumes that on the second day all subjects are better able to sustain their levels of arousal, perhaps because they found the testing procedure more familiar and therefore less tiring. Thus group A were feeling more aroused at the end of the second day because they benefited from (*a*) being in the sham exposure condition and (*b*) increased familarity with the testing procedure. Similarily, for group B the benefit derived from increased familiarity with the testing procedure is offset by the tendency for arousal to fall as a result of exposure.

The other two explanations are based on the notion of state dependent transfer, the exposed condition being assumed to represent a distinct "pharmacological" or "psychological" state. In general terms, transfer effects refer to the influence one experience has on subsequent experiences.[36] Because the two subject groups differ only in the order in which the exposure/sham exposure conditions were presented, the explanation must lie in the direction of the transfer—that is, it is asymmetrical with respect to the day on which exposure occurred. Either subjects trained in the presence of current (group A) were more able to sustain arousal when subsequently retested in the sham exposure condition, or subjects trained in the sham exposure condition (group B) were less able to sustain arousal when retested in the exposure condition.

Perhaps the most important studies relevant to the effects of current observed in the syntactic reasoning test are those reported by Hitch and Baddeley[26] and Baddeley and Hitch.[27] They used the syntactic reasoning task to examine the role of working memory in sentence verification, where working memory is conceptualised as consisting of short term storage space and processing functions. Their studies have shown that a prior memory load slows the verification of both simple and complex statements equally but a concurrent memory load slows the verification of passive and negative statements more than of active and positive statements. That is, the simultaneous processing of the reasoning statement and the memory load leads to a larger effect on the more complex reasoning problems. Despite the fact that a six item memory load is close to the limits of the short term store,[37] the prior memory load produced no differential effect on the more complex statements. These results would suggest that processing functions rather than memory functions were influenced by the current.

The important effects of exposure in the syntactic reasoning task may therefore be summarised as follows. The effects of current found indicate a processing difficulty that is restricted to verification speeds rather than accuracy. Because the two subject groups verify statements with equivalent speeds on the first day, the exposure effect is asymmetrical with respect to the day of exposure. Furthermore, because the magnitude of the effect of current does not vary with time into the exposure period, the effect of exposure on the second day would seem to be immediate.

The failure to find an effect of exposure on the first day could be ascribed to intrinsic differences between the two randomly allocated subjects groups. If it is assumed that group A are intrinsically better at the task than group B the pattern could suggest an exposure effect on both days: equivalent performance on the first day being attributed to the group A superiority being counteracted by the exposure condition.

If intrinsic differences between the two subject groups are not the source of the second day effect, then it is asymmetric and is most probably due to the order of presenting the exposure conditions. As with the explanation of the arousal finding, this would involve the notion of state dependent transfer. Two hypotheses are consistent with the pattern found. Firstly, it could be that the skill acquired during exposure transfers to the sham exposure condition more readily than the skill acquired during sham exposure transfers to that of exposure. Secondly, it could be an effect on a person's ability to apply the skill previously acquired. It is important to note that skill acquisition must be assumed to be equivalent in both subject groups because of their equivalent performance throughout the first day. Both of these explanations represent a form of asymmetric transfer and they are not necessarily mutually exclusive. The failure to find that the time into the exposure period modified the magnitude of the effect provides some support for the notion of state dependent transfer. In this connection it is interesting to note that a recent study of human performance in 60 Hz electromagnetic fields, using a counter balanced within subject design in which subjects were exposed twice, has shown a reversal of field effects from the first to second exposure day.[38]

By contrast with the effect of current on arousal scores, stress scores remained low and constant and are independent of exposure. Although there is no evidence that stress levels were higher after reports of sensations or higher in the groups reporting sensations, overall stress scores are strongly correlated with the duration of sensations reported on exposure days. Thus when a subject reports sensations, these sensations are reported to last longer when he feels more stressed. This finding lends some support to the argument that the physiological and biochemical stress responses reported in earlier studies of electric field exposure[39-41] may relate to field perception rather than to the induced body currents.[42 43]

One recent study which measured the actual exposure of CEGB staff to power frequency electric fields found that considerably less exposure occurred than had been expected from estimates of field strengths and the time spent within these fields.[2] A more recent study, which classified exposure into five field strength bands, found that little time is spent by transmission workers in fields greater than 4·5kV/m.[44] These investigators suggest that the most probable reason for higher estimates of exposure lies in the difficulty in making estimates which adequately allow for shielding by nearby structures—for instance, trees, fences, and buildings—although the well known difficulties of making accurate estimates may also be responsible. The 36 kV/m (simulated) field used in the present study therefore represents a considerably greater degree of exposure than is measured occupationally.

In conclusion, the present paper discusses the effects of human exposure to 50 Hz electric currents on self reports of mood and on performance in two types of verbal reasoning task. Apparent effects of current were found in self reports of arousal and in the more complex statements of a syntactic reasoning task. By contrast, no effects of current were found in self reports of stress and in performance in a semantic reasoning task. Whereas the pattern of results for the arousal scores suggests that arousal is lower after exposure than sham exposure, the results are open to more than one interpretation and may indicate a floor effect or some type of state dependent transfer phenomenon. Similarly, the pattern of results from the syntactic reasoning test is also consistent with the notion of state dependent transfer and suggests that the effect is localised to the processing (rather than memory) demands of the task.

Further work is required to verify (or otherwise) the effects of current on psychological functioning found here and to determine whether state dependent explanations underlie the observed pattern of results. It would be unwise to place too much reliance on the results of a single experiment, particularly when it is necessary to suggest an unusual hypothesis, because the biological effects of electric field exposure represent an area of investigation that is plagued by uncertainty due to poor replicability[45] and no previous work bears on the issues raised here. Because experimental designs for investigating state dependent phenomenon[46 47] are considerably more complex than the one used here, however, it seems initially more preferable to attempt a simple replication. It is worth noting that a within subject design includes half the conditions of a state dependent design—that is, the two non-transfer conditions are missing.

Finally, it should be recalled that the study examined the effects of a single exposure on the performance of healthy men who had not previously been exposed to electric fields. These considerations, together with the high strength of the simulated field, suggest that caution should be exercised in generalising to occupationally exposed populations who experience repeated exposures to low strength electric fields over an extended period.

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