60 Hz Electric Fields and Incandescent Light as Aversive Stimuli Controlling the Behavior of Rats Responding Under Concurrent Schedules of Reinforcement

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Several reports have shown that animals will sometimes engage in behaviors that reduce their exposure to a 60 Hz electric field (E-field). The field, therefore, can function as an aversive stimulus. In other studies, the E-field at equivalent strengths failed to function as an aversive stimulus. The present experiment, using rats, demonstrates how factors other than field strength can influence whether a subject engages in behavior that reduces field exposure. The general design consisted of giving the rat a choice between two alternatives, one of which included an added stimulus. Each subject was trained to press each of two levers to obtain food. Pressing one lever was reinforced intermittently under a variable interval 2 min schedule (VI 2); pressing the other lever was reinforced by a second VI 2 schedule operating independently of the first. Under this concurrent schedule the rat spent 50% of the daily 50 min session responding to each of the levers, indicating that they were equally ''valued.'' Next, while the schedules remained in effect, the first response to one of the levers turned on a 100 kV/m E-field which remained on until the rat pressed the other lever. The time spent responding under the schedule associated with the field was reduced by about 5–10%. When the procedure was changed so that no lever presses produced food, i.e., extinction, but the added stimulus contingency remained, the rats spent even less time in the presence of the field. Similar outcomes were observed during both the concurrent food or extinction schedules when incandescent light was used. Thus, both an E-field and incandescent light functioned as aversive stimuli, but the magnitude of the aversiveness was small. Aversiveness depended not only on stimulus intensity, but also on behavioral factors. *Bioelectromagnetics 19:210–221, 1998.* © 1998 Wiley-Liss, Inc.

Key words: aversive stimuli; incandescent light; electric fields; reinforcement schedules

INTRODUCTION

Exposure to 60 Hz electric fields (E-fields) can affect different behaviors of vertebrates. Perhaps the most consistent outcome observed across species has been detection of the field. Humans [e.g., Cabanes and Gary, 1981; Deno and Zaffanella, 1975; Graham and Cohen, 1985], baboons [Orr et al., 1995], and rats [Stern et al., 1983; Stern and Laties, 1985, Sagan et al., 1987] can detect the field; detection thresholds are approximately 5–15 kV/m both within and across species.

E-fields have also been shown to be aversive. A stimulus, or condition, is called ''aversive'' if an animal will respond to avoid, or terminate, exposure to it [Fantino, 1972]. The definition is operational, i.e., whether an event is aversive, or more generally, how the magnitude of its aversiveness varies, depends on the operations used in those assessments. This means that aversiveness is not a simple, inherent property of

an event. We focus, therefore, not on the question ''Is an event aversive?'', but instead on, ''Under what conditions is it aversive?'' Stimulus magnitude, i.e., field strength for 60 Hz E-fields, is only one parameter of the exposure conditions.

At E-field strengths on the order of 75–105 kV/m for rats [Hjeresen et al., 1980] and 30 kV/m for miniature swine [Hjeresen et al., 1982], animals sometimes will terminate or avoid exposure in a shuttlebox procedure. Lovely et al. [1992] showed that when magnetic

fields produced average induced currents equivalent to those that would be produced by the E-fields used by Hjeresen et al. [1980], the rats did not avoid exposures, leading to the conclusion that peripheral events during E-field exposures were controlling the behavior.

Lee et al. [1982] reported that grazing cattle spent more time near a 1200 kV prototype transmission line that produced a maximum field of 12 kV/m when it was de-energized than when it was energized. The magnitude of the effect apparently was minor; even when energized, the cattle frequently grazed and drank water immediately beneath the line.

Such higher-strength fields have not always been found aversive. Stern and Laties [1989] studied rats under two operant conditioning procedures that required a lever press to turn off 100 kV/m fields. In one, pressing a lever would turn the field on; pressing a second lever would turn it off. In the other, the field was turned on after a fixed interval had elapsed without a lever press. The rats did not reliably turn the field off under either procedure. Similarly, Rogers et al. [1995] found that baboons would not reliably press an operandum to terminate exposures at 65 kV/m, a field strength which, when scaled for species differences in peak fields encountered in uniform vertically oriented fields, would be even greater than that found sufficient for avoidance by rats in the shuttlebox studies. How can those observations be reconciled with the studies noted above indicating that E-fields can be aversive? To answer that question we must evaluate the role not only of stimulus intensity, but also of other conditions present during the exposures.

Most past laboratory studies designed to investigate aversiveness of E-fields can be considered to be studies of ''choice.'' If the subject engaged in one response (chose one outcome), it was exposed to the field; if it engaged in an alternative response, it was not exposed to the field. This algorithm describes the shuttlebox experiments with rats, the operant conditioning experiments with rats and baboons, and the small studies with grazing cattle.

Concurrent schedules of reinforcement [Ferster and Skinner, 1957; Catania, 1966] can be used to study choice behavior. Under concurrent schedules, each of the different responses emitted by a subject is maintained by its specified schedule of reinforcement that operates independently of, and concurrently with, the other schedules. Although an oversimplification of a vast literature, we note that the ''matching law'' has been proposed as a general description of behavior controlled by concurrent schedules. In its most general form, it states that the relative allocation of responses, or time, to each schedule is more or less directly proportional to the relative rate of reinforcement obtained under that schedule [e.g., Baum,

1976; Baum and Rachlin, 1969; Davison and McCarthy, 1988; Herrnstein, 1961, 1970; Rachlin et al., 1980].

Suppose, e.g., a hungry rat can obtain food by pressing either of two levers under a procedure in which the food becomes available for each lever independently on separate random schedules. If the schedules are such that the rat can obtain twice as many food pellets by pressing the first lever than by pressing the second, according to the matching law, we would expect it to spend twice as much time pressing the first compared to the second. It will switch back and forth between levers, however, because if it responded only to the first lever, it would not obtain one third of all possible pellets.

Studies have examined how those choices would be altered by introducing other variables to the concurrent schedules. Deluty [1976] showed that when both food and electrical shocks were independently scheduled for one response, but only food for the other response, as the rate of brief, cutaneous electrical shocks increased for one response, the relative rate of responding of the other response increased. Higher rates of shock were more aversive than lower rates.

In the Deluty [1976] experiment, the aversive stimulus was a discrete temporal event. But it need not be. McAdie et al. [1996] first measured the allocation of pecking (both time and rate) at two plastic response keys by hens under concurrent variable interval schedules of food reinforcement. Then the procedure was changed so that the first peck to one key also turned on a 100 dBA auditory stimulus, and it remained on until the other key was pecked. The overall result was that the hens spent less time responding under a schedule when the noise was present than when it was absent.

The present experiment used a similar procedure to investigate further the aversiveness of 100 kV/m 60 Hz E-fields. In this experiment with rats, pressing each of two response levers was first established under a concurrent schedule consisting of two independent variable interval schedules. Next, while the baseline concurrent schedule remained in effect, a 100 kV/m 60 Hz E-field was turned on when the rat pressed one of the levers, and it remained on until the rat pressed the other lever. During some portions of the experiment illumination from an incandescent lamp served as the added stimulus instead of the E-field. Light aversion in the rat has been studied previously [e.g., Keller, 1941; Kaplan et al., 1965], and so the use of such illumination could serve as a useful positive control in the assessment of the aversiveness of the E-field. In addition, in our earlier study of the aversiveness of E-fields [Stern and Laties, 1989] in which we used the same exposure system and animal conditioning chamber, we demonstrated that the illu-

TABLE 1. Experimental Design*

Condition no.	Food reinforcement schedule	Field or light	Sessions	Subject no./gender						
				C01/F	C02/M	C03/M	C04/F	C05/M	C07/F	C08/M
				Lever producing field or light onset						
1	CONC VI 2 VI 2	None	80	n	n	n	n	n	n	n
		60 Hz E-Field								
2	↑	25 kV/m	3	A		B				A
3	CONC VI 2 VI 2	50 kV/m	3	A		B				A
4	↓	75 kV/m	3	A		B				A
		60 Hz E-Field 100 kV/m								
5	↑	On	15	A	B	B	A	A	B	A
6	CONC VI 2 VI 2	None	5	n	n	n	n	n	n	n
7	↓	On	10	B	A	A	B	B	A	B
8		None	20–30	n	n	n	n	n	n	n
		Light (75 W)								
9	↑	On	15	B	B	A	A	B	A	A
10		None	10	n	n	n	n	n	n	n
11	CONC VI 2 VI 2	On	10	A	A	B	B	A	B	B
12		None	22	n	n	n	n	n	n	n
13	↓	On	8	B	B	A	A	B	A	A
		Light (150 W)								
14	CONC VI 2 VI 2		5	B	B	Stop	A	B	A	A
15	VI 1 either lever		12	B	B		A	B	A	A
16	VI 1 either lever		15	A	A		B	A	B	B
17	CONC VI 2 VI 2		8	A	A		B	Stop	B	B
18	CONC EXT-EXT	On	5	A	A		B		B	B
19	CONC EXT-EXT		5	B	B		A		A	A
20	CONC VI 2 VI 2		18	B	B		A		A	A
21	CONC VI 2 VI 2 prefed		1	B	B		A		A	A
22	CONC VI 2 VI 2		1	B	B		A		A	A
		60 Hz E-Field 100 kV/m								
23	CONC VI 2 VI 2	None	18	n	n		n		n	n
24	CONC VI 2 VI 2		5	B	A		A		B	A
25	CONC VI 2 VI 2		8	A	B		B		A	B
26	CONC EXT-EXT	On	6	A	B		B		A	B
27	CONC EXT-EXT		10	B	A		A		B	A
28	CONC EXT-EXT		8	A	B		B		A	B

*Experimental conditions: schedule of food reinforcement; response-produced added field or light; number of sessions; and the lever designated for turning on the stimulus for each subject. An ''n'' indicates that neither response could turn on a stimulus; a blank space indicates that the treatment was not presented.

mination did function effectively as an aversive stimulus, whereas the E-field did not. Comparison of the effectiveness of the two stimuli was continued in the present experiment, now using the concurrent schedules paradigm rather than the presentation/termination method of the 1989 study.

The results from the earlier cited studies of the aversiveness of 60 Hz E-fields are consistent with a conclusion that, even at 100 kV/m, the fields are rela-tively ineffective under most choice conditions. This leads to the general prediction that a subject will chose an alternative that reduces field exposure, but only if that choice does not significantly reduce the rate (or magnitude) of reinforcement that would have otherwise occurred. A series of probes introduced into the general procedure enabled us to examine how such reinforcement variables influence the aversiveness of 60 Hz E-fields.

MATERIALS AND METHODS

Subjects

Three female and four male experimentally naive Long-Evans hooded rats (Charles River, Portage, MI) were approximately 150 days old at the beginning of training. Body weights were maintained at 220 g for the females and 270 g for the males by providing a limited amount of food (Charles River RMH 2000 Rat Chow) daily. The rats were housed individually in air-filtered plastic cages with hardwood shavings used for bedding; water was freely available. The cages were housed in a vivarium room, assigned exclusively to the experiment, in which the temperature was held constant (21 ± 1 °C) with a 0600–1800 fluorescent light-dark cycle. Two subjects were removed from the study, as noted in Table 1, when they were over 1.5 years old, due to apparent illness. Data from those subjects were not included in the t-tests.

Apparatus

The apparatus, located in an isolation chamber inside a laboratory room used solely for the experiment, was described in detail previously [Stern et al., 1983], and included modifications introduced later [Stern and Laties, 1989]. Briefly, it consisted of three 1 m^2 horizontal aluminum plates mounted in a vertical array 0.5 m apart with a Lexan plastic conditioning chamber centered on the middle plate, a high-voltage power supply consisting of two Hipotronics Model 730-1 CF transformers (Brewster, NY) and associated circuitry for producing a 60 Hz E-field, and a PDP 8/A computer (Digital Equipment Corp., Maynard, MA) for controlling the experiment through the SUPERSKED programming system [Snapper and Inglis, 1979; Snapper et al., 1982].

Field strength in this report refers to the strength (kV/m, RMS) of the unperturbed, vertical E-field measured using two measurement systems we used previously [Stern et al., 1983]. Using a 2.48 cm diameter disk probe [Kaune, 1979, 1981] that had been calibrated at the National Bureau of Standards, Washington, DC (now the National Institute of Standards and Technology), we found that the strength of the field varied less than 1% over the area occupied by the conditioning chamber and that, as expected [Kaune, 1979, 1981], the strength of the field was reduced by 2.5% when the chamber was centered over it.

During some portions of the experiment, as shown in Table 1, illumination was provided by a General Electric 75 or 150 W incandescent spot lamp; the lamp was in the isolation chamber only during conditions when it was used. The surface of the lamp, located 17 cm from the back of the conditioning chamber, was directed toward its center. The illuminance of the 75 W stimulus, measured previously [Stern and Laties, 1989] with a Sekonic Model 246 Illuminometer, was 362 foot candles (fc). Using calorimetric techniques, we found that the incident power density for the 75 W lamp at the locus of the rat was 5.6 mW/cm^2.
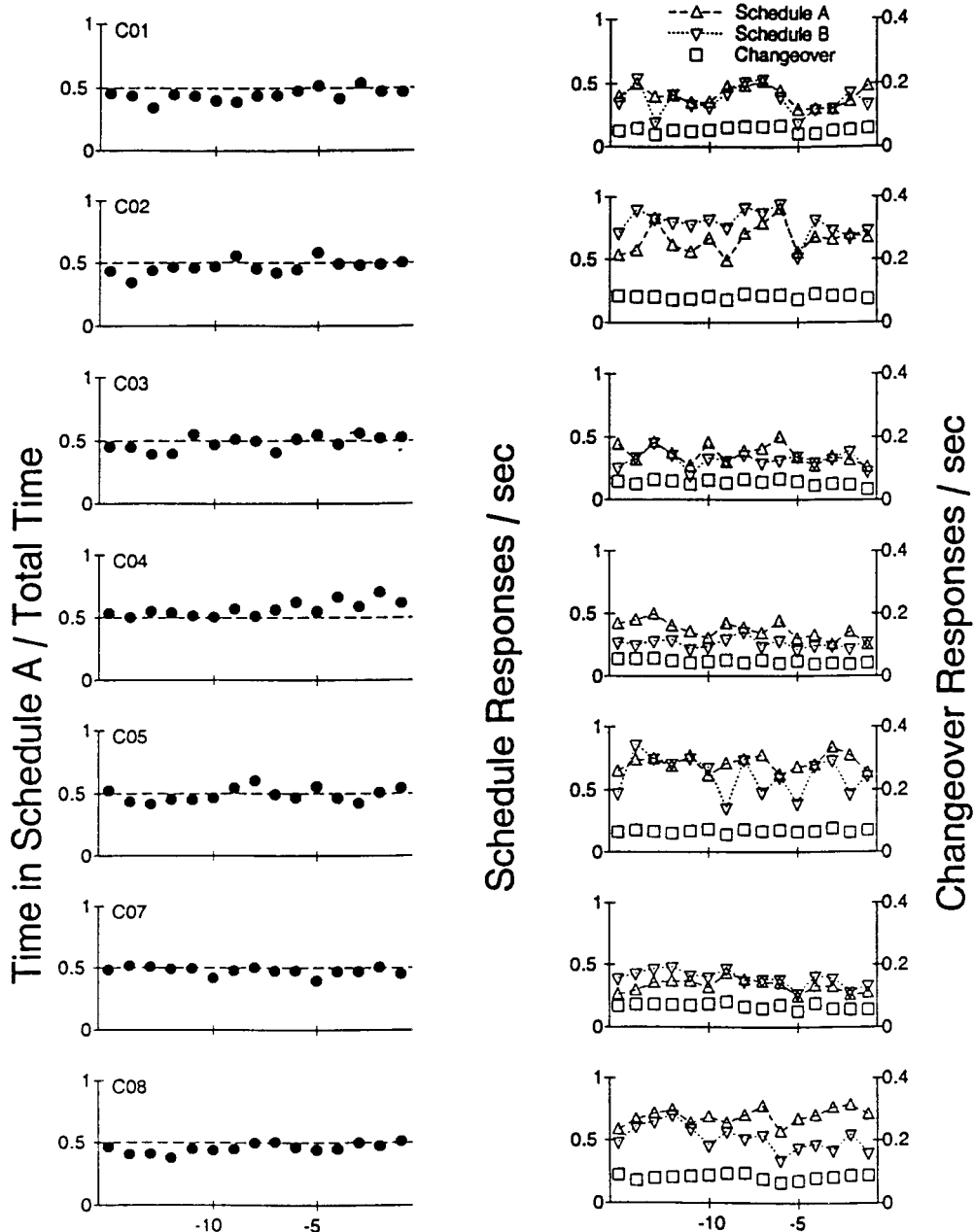
The 20.3 × 20.3 × 10.2 cm high Lexan® behavioral conditioning chamber was centered on the middle aluminum plate. The chamber contained two levers and a recessed food cup along one wall. The left lever was designated A and the right lever was designated B. Fiber optics were used to detect lever displacement. A pellet dispenser (Gerbrands Model D-1) located on the roof of the isolation chamber housing the plates dropped a 0.045 g pellet (Noyes Standard Laboratory Diet, P.J. Noyes, Lancaster, NH) through Tygon® tubing to the food cup. Ceiling fluorescent lamps located outside of the isolation chamber provided ambient illumination (2.3 fc) under all experimental conditions.

Procedure

Table 1 lists the conditions studied for each subject following initial training. Experimental sessions were conducted for 50 min, 5 days/week, with the ordering of the subjects remaining constant throughout the day.

Initial training. Each rat was trained initially to press one of the levers under a procedure in which each lever press was reinforced by delivery of a food pellet. Pressing the other lever was ineffective. The effective lever was alternated across successive sessions. After approximately three such sessions of training on each lever, the concurrent schedule was introduced.

Baseline training. The concurrent variable interval 2 min, variable interval 2 min (CONC VI 2 VI 2) schedule was structured as follows. Two identical variable interval 2 min (VI 2) schedules were in effect, one for each lever. Schedule A designated the one in effect for the left lever and schedule B for the right lever. Each schedule was constructed from a list of 25 intervals that ranged from 4.80 to 457.91 s, with a mean of 120 s [Catania and Reynolds, 1968]. At the start of the session, two interval values were randomly selected without replacement, one from each list. The schedules were totally independent of each other; a value selected from the schedule A list had no effect on the value selected from the schedule B list. Each interval started a countdown timer. The countdown period was continuous; it was not affected by which schedule was in effect, nor by whether a changeover delay (COD) was in effect (see below). Once the interval had elapsed, its timer stopped until the next response on the lever associated with that schedule produced a pellet. A left

Final Baseline Sessions

Fig. 1. Performances during the final 15 days of baseline training (Table 1; condition 1). Results from each of the seven subjects are plotted on pairs of axes. The left column shows the proportion of total session time spent responding on the schedule A response lever. The right column shows the rates of responding.

Local rates, which excluded both time and responses that occurred during the COD interval, are plotted for both schedule A and schedule B. The rate of changeover responding for the entire session time is also plotted.

lever press was reinforced by delivery of a food pellet only when the schedule A interval had elapsed. When a left lever press did so, the schedule A list was sampled again without replacement to select the next interval.

Left lever presses that occurred before the interval elapsed were ineffective. Left lever presses or pellet delivery had no effect on schedule B. Similarly, right lever presses had no effect on either the schedule A

interval countdown or schedule A pellet delivery. Schedule B operated for right lever presses just as schedule A did for left lever presses.

A COD of 2 s was included in the procedure to facilitate independent control by each schedule by reducing the likelihood of simple alternation between levers. Under the COD procedure [Catania, 1966], when the rat pressed a lever which was not the last one pressed, the COD 2 s interval started during which no presses could produce a pellet, even if the VI food reinforcement interval had elapsed. Each such switch between levers restarted the COD.

Training continued under the baseline CONC VI 2 VI 2 schedule for 80 sessions (condition 1).

Response-produced stimulus conditions. The CONC VI 2 VI 2 schedule remained in effect during the first several conditions in which responses could produce stimulus onset or offset. Other procedures were used during several later conditions as described below. Two types of stimuli were studied: 60 Hz E-fields and incandescent illumination. During these added-stimulus conditions, the session always started with the stimulus off. The stimulus was then introduced for the first response that occurred on the lever indicated in Table 1. The stimulus remained on until the rat responded on the other lever. In this fashion, the rat could turn the stimulus on and off throughout the session. The designated lever that produced the stimulus was counterbalanced across subjects and conditions. Initially the 60 Hz E-field was studied. Lower field strengths were introduced for three subjects (C01, C03, and C08) prior to 100 kV/m being studied for all subjects for 15 sessions (condition 5). After 5 sessions in which responding could not produce exposure to the field (condition 6), it was once again possible to do so (condition 7), but now only by pressing the lever that turned the field off during condition 5. For example, during condition 5, rat C04 was exposed to the field from the time it pressed the left lever, A, until it next pressed the right lever, B. Onset and offset of the field, therefore, were produced by successive changeover responses. The field remained on during the COD unless the rat switched back to the other lever during the COD. During condition 6, pressing neither lever could turn on the field, as indicated by ''n'' in Table 1. During condition 7, the outcomes were reversed with a lever B response producing onset of the field and then a lever A response producing offset.

Illumination from a 75 W lamp was similarly studied during conditions 9–13, and a 150 W lamp during conditions 14–22. The food reinforcement schedule was changed during conditions 15, 16, 18, and 19. During conditions 15 and 16, a *single* VI 1 min schedule was in effect for responding on either lever. A single list of intervals with a mean of 60 s was sampled to determine when the next pellet became available. When the interval elapsed, a response on either lever produced a pellet. The 2 s COD remained in effect. Under this VI 1 either lever procedure, then, the maximal rate of reinforcement was one pellet per minute whether or not switching between levers occurred.

During conditions 18 and 19, the schedule was changed to CONC extinction, extinction (EXT-EXT) during which responding on neither lever produced pellets. However, responding on the designated lever did produce illumination from the 150 W lamp.

Following the 18 sessions of CONC VI 2 VI 2 with the illumination during condition 20, each rat was provided with free access to food for 23 h preceding one session during condition 21 while the same concurrent schedule remained in effect. A single CONC VI 2 VI 2 recovery session followed (condition 22).

After reinstating the baseline procedure for 18 sessions (condition 23), the 100 kV/m 60 Hz E-field was added once again. During conditions 24 and 25, the CONC VI 2 VI 2 food reinforcement schedule was in effect, and during conditions 26–28 CONC EXT-EXT was in effect where responding never produced food, but continued to produce field onset and offset as indicated in Table 1.

Data Analysis

Several measures of performance were examined. Time spent responding under a schedule was the interval between the changeover to that schedule until the next changeover to the other schedule. The proportion of time spent responding under one schedule was the ratio of the time spent under that schedule to the total time. Total time was duration of the session excluding the latency to the first lever press in the session. Rate of responding during a schedule was the ratio of lever presses occurring on that lever after the COD had elapsed to the time in that schedule minus the COD time in that schedule. The rate of changeovers was the ratio of changeover responses, i.e., switches between levers, to the total session time.

To determine the effect of adding a stimulus to one of the schedules, the mean proportion of time in that schedule during the preceding condition in which there was no added stimulus was subtracted from the mean proportion of time spent in the schedule during the condition with the added stimulus. The mean of the last 5 days under a condition was used, except when fewer days were studied, as noted. For example, for rat C01, the mean proportion time spent responding in schedule B during condition 6 when no stimulus was present was subtracted from the mean proportion of time spent responding in schedule B during condi-

TABLE 2. Summary of the Results During the Final 15 Sessions of the Baseline CONC VI 2 CONC VI 2 Procedure

Variable	Mean	SEM
Proportion time on schedule A	0.49	0.016
Schedule A responses/s	0.50	0.065
Schedule B responses/s	0.47	0.070
Changeover responses/s	0.07	0.005
Relative rate of responding on schedule A	0.52	0.020

tion 7 when a switch to the right lever B produced onset of the field.

The relative rate of responding on schedule A, examined during the original baseline condition, is defined as follows: relative rate $= r_a/(r_a + r_b)$, where r is the rate of responding in responses per second, during the schedule designated by the subscripts.

T-tests were conducted to examine whether the proportion of time spent in a schedule during stimulus exposure was less than the proportion of time spent in that schedule during the preceding condition when the stimulus could not be produced. To assess the role of the reinforcement schedule on the magnitude of aversiveness, additional tests compared the effects of extinction (or prefeeding) with the stimulus present to the effects of the CONC VI 2 VI 2 with the stimulus present. Since the experiment was designed as a series of probes, the repeated use of t-tests is justified.

RESULTS

When responding produced exposure to either an E-field or illumination, the subjects spent less time on that schedule than during the last preceding condition when there was no added stimulus. That outcome was observed under every condition examined.

Figure 1 shows the results for each subject during the final 15 days of baseline training and Table 2 presents summary statistics for those results across subjects. The mean proportion of total time spent responding on schedule A, shown in the left column of Figure 1, was 0.49, with there being little variability across sessions, within or between subjects. Rates of responding are shown in the right column of Figure 1. Changeover responding, i.e., switching between levers, occurred at a low rate, averaging 4.2 responses per minute, again with there being little variation within or between subjects. Rates of responding on schedule A and schedule B showed greater variability within subjects during sessions and across sessions as well as between subjects. Even so, systematic biases were not seen. The mean relative rate of responding on schedule A was 0.52.

The magnitude of the shift in the proportion of time spent on a VI schedule, shown in Figure 2, was small when the 100 kV/m E-field was introduced, the decrease in the proportion of time always averaging less than −0.15. Three of the subjects had been exposed to fields at lower strengths immediately preceding the initial exposure to 100 kV/m. Inspection of the individual subject data (not shown) revealed no effect of exposure during the blocks of three sessions at the lower field strengths, nor any difference during the first three sessions at 100 kV/m between those subjects and the others that were exposed initially to 100 kV/m fields.

When illumination was used instead of the E-field, the rats again spent less time on the schedule with the added stimulus, and again the difference in the proportion of time was generally less than −0.1. That outcome was observed for the 75 W stimulus during conditions 9, 11, and 13, and it continued when the 150 W stimulus was introduced in condition 14. Changing from the concurrent schedule to a single VI 1 min schedule during conditions 15 and 16 when a single VI 1 min schedule was used to reinforce responding on either lever was without effect.

When responding on neither lever produced food, i.e., CONC EXT-EXT, during conditions 18 and 19, the rats spent even less time in the presence of the 150 W stimulus than during the CONC VI 2 VI 2. After calculating a mean for each subject for conditions 18 and 19 (19–23% less), and for conditions 14 and 17 (6–10% less), a t-test that compared those conditions was significant (t = 3.10; df = 4; P = .02). When the CONC VI 2 VI 2 was reinstated, during condition 20, there was a tendency to spend more time in the presence of the 150 W stimulus than during CONC EXT-EXT (t = 1.78; df = 4; P = .07), as well as during condition 22. During condition 21, however, when the rat had been provided with free access to food for the 23 h period preceding the session, the rat spent less time in the presence of the stimulus than during the immediately preceding condition. A t-test comparing conditions 20 and 21 was significant (t = 4.95; df = 4; P = .004). Both EXT and prefeeding reduced exposure to the 150 W stimulus.

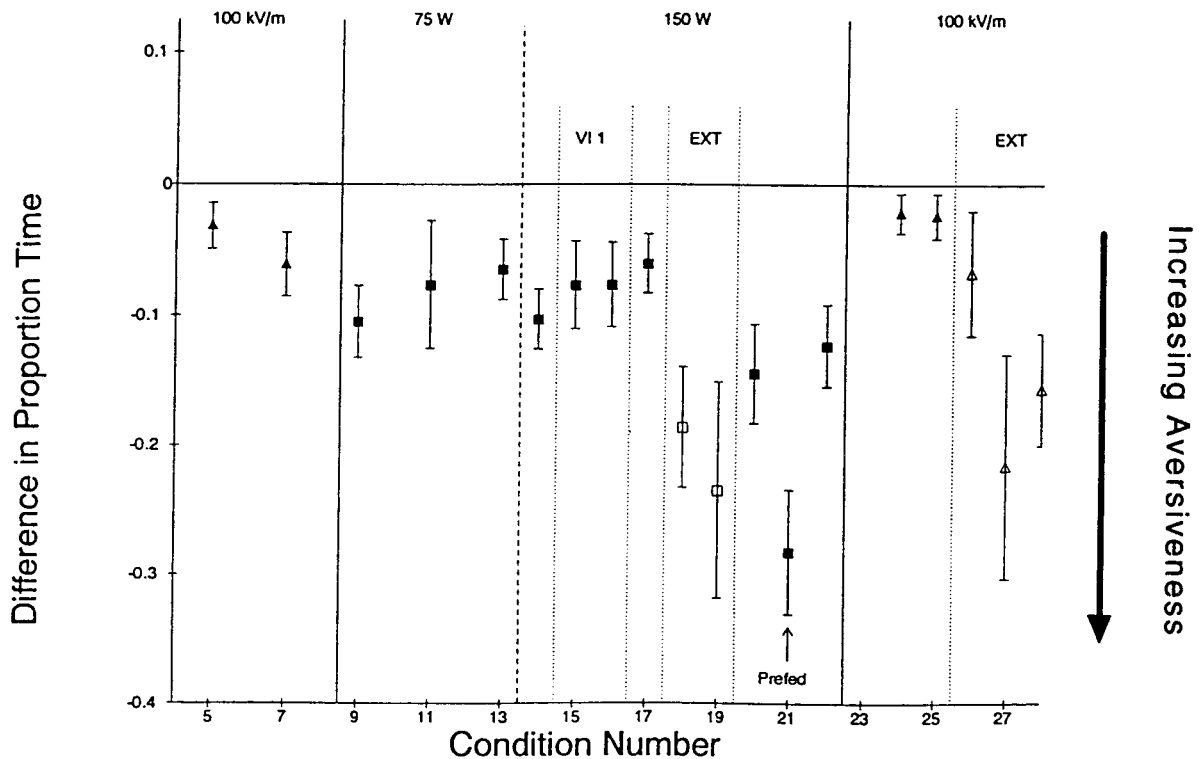When the 100 kV/m E-field was used again as the added stimulus in conditions 24 and 25, the data

Fig. 2. Mean difference in proportion of time (±SEM) for the last five sessions for each condition in which either a 60 Hz E-field or illumination from an incandescent lamp was turned on for a changeover response to one of the levers and turned off when there was a subsequent changeover to the other lever. Condition numbers correspond to those listed in Table 1. For each such condition with an added stimulus, the relative amount of time spent in the schedule with an added stimulus was determined. The difference between that value and the proportion during the last condition in which the stimulus was not presented is shown. A negative value indicates an increase in aversiveness, i.e., that less time was spent in that schedule when the stimulus was present.

tended once again to show a small difference, now a 2–3% decrease, in the proportion of time spent in the schedule. When the schedule was CONC EXT-EXT for food during conditions 26–28, there was a tendency to spend even less time in the field (7–22% less); the data were highly variable, however, with fewer rats responding as training continued. An arbitrary criterion of 10 changeover responses per session was required for including the data of a subject in the analysis. During those conditions, all 5 rats were included for condition 26, 4 for condition 27, and 3 for condition 28. After calculating one mean for conditions 24 and 25, and one for conditions 26 and 27, for each of the subjects that were included in condition 27, a t-test that compared those conditions was not quite significant (t = 1.97; df = 3; P = .07).

T-tests of the hypothesis that the difference in proportion time spent in a schedule equaled zero were significant ($P \leq .05$, 1-tailed) for every condition in which a stimulus was added, with the exceptions of conditions 24–26.

Figure 3 shows representative cumulative re-

cords of responding that were typical of those seen for all rats. Under the CONC VI 2 VI 2 baseline established during condition 1, responding was maintained at a nearly constant rate on both schedules with changeover responding occurring throughout the session. During condition 5, the performances were similar to those seen in the absence of the field, although for this particular session, the rates of overall responding and changeovers increased. Nearly a year later, during condition 23, which replicated condition 1, the performances were similar to those seen originally. During the CONC EXT-EXT condition 26 in which the field was turned on for changeover responses to lever B, rates of overall and changeover responding declined, and the rat spent less time in schedule B than schedule A.

DISCUSSION

The 60 Hz E-field functioned as an aversive stimulus for rats in the present experiment. The magnitude of the effect, i.e., the "aversiveness" of the
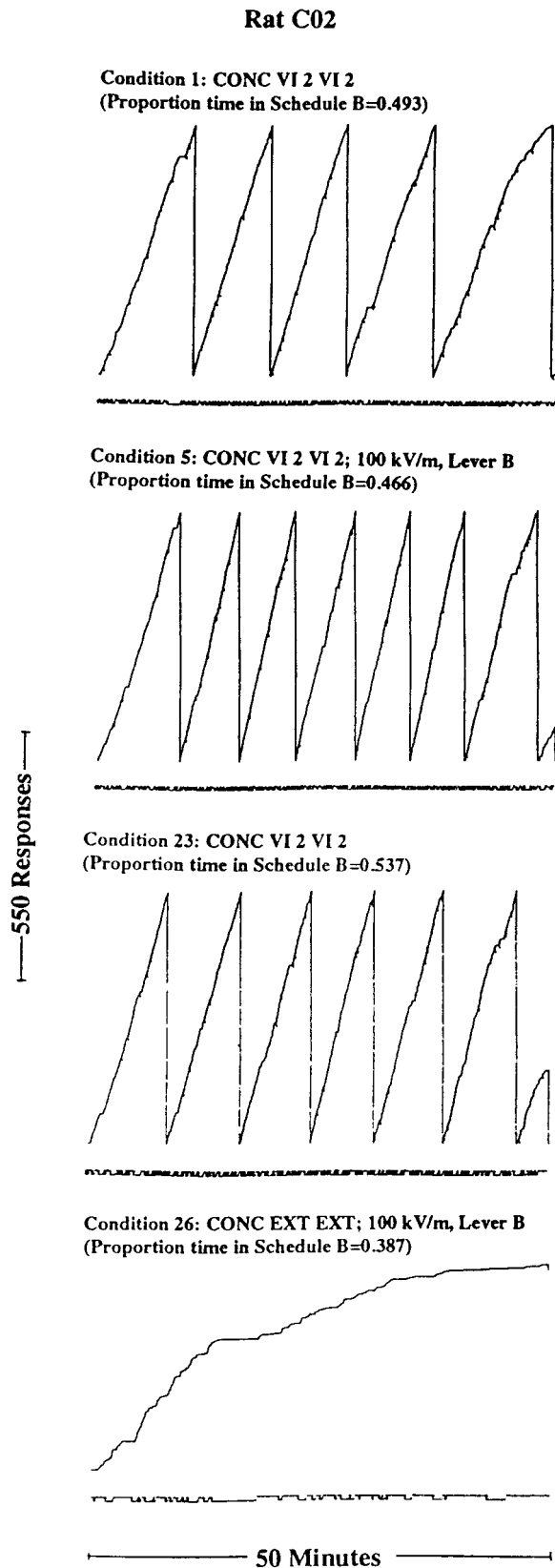
Rat C02

Condition 1: CONC VI 2 VI 2
(Proportion time in Schedule B=0.493)

Condition 5: CONC VI 2 VI 2; 100 kV/m, Lever B
(Proportion time in Schedule B=0.466)

Condition 23: CONC VI 2 VI 2
(Proportion time in Schedule B=0.537)

Condition 26: CONC EXT EXT; 100 kV/m, Lever B
(Proportion time in Schedule B=0.387)

550 Responses

50 Minutes

Fig. 3. Cumulative records show lever press responding during entire 50 min sessions under four conditions of the experiment

field, was small; however, for every condition in which the 100 kV/m field was added to one of the schedules, the rat spent relatively less time in that schedule, as shown in Figure 2.

The baseline data shown are those expected based upon a large literature. Under the baseline CONC VI 2 VI 2 food reinforcement schedule the rats showed equal preference for the two schedules. Time allocation to the two schedules was about 50%. The rates of changeover responding also varied little among the subjects, even though individual differences in rates of responding to the individual schedules were observed. The rats distributed the time spent responding equally between the two alternatives because the payoffs were matched; had they spent all of the time responding on only one schedule, the rate of food reinforcement would have decreased by about 50%.

When a changeover response to one of the schedules under the CONC VI 2 VI 2 schedule also produced exposure to the field there was a small, but consistent, reduction in the proportion of the time spent in that schedule (generally 10% or less). Even so, the presence of the field did not disrupt the overall pattern of responding, as shown in Figure 3. The effect depended directly on which lever had to be pressed to turn on the field. When the lever producing onset of the field was reversed, e.g., condition 5 vs. condition 7, the preferences for the schedules also reversed. Thus it was not simply field exposure, but rather the contingency between responding and field onset or offset, which altered the behavior. The absence of a statistically significant outcome during some of the later conditions of the experiment might be due to the smaller sample size, the past history of the subjects, or other variables.

Had the rats responded only on the lever associated with the absence of the field, they could have

for rat CO2. The upper pen moved a vertical step for each response on either lever and reset after 550 responses. Chart speed remained constant. Slope of the upper pen, therefore, corresponds with the rate of responding. A downward hash mark of the upper pen indicates pellet delivery. The lower pen was displaced downward for a changeover response to schedule B, where it remained until the next changeover response to schedule A. The proportion of time spent in schedule B by rat CO2 for that session is indicated. Records show the final session under the CONC VI 2 VI 2 baseline condition 1, the 15th session of exposure to 100 kV/m during condition 5, the 15th session under condition 23, which replicated condition 1, and the 3rd session under the CONC EXT-EXT with 100 kV/m as the added stimulus for condition 26. A changeover response to lever B turned on the field during conditions 5 and 26, as indicated; a changeover response to lever A turned off the field during those conditions. Lever presses could not produce food under CONC EXT-EXT during condition 26.

completely avoided exposure to the field, but at a cost of a reduction in the rate of food reinforcement by 50%. That cost of losing food obtained under the VI 2 schedule would have been greater than the gain of preventing exposure to the field, and therefore the rats continued to respond in the presence of the field. Although the value of the VI 2 schedule when combined with the field was less than that of the VI 2 schedule by itself, it was greater than that of the value of the EXT schedule when it was combined with the field as shown by the comparison of conditions 25 and 28. During EXT the rat did not have to lose pellets to gain the reduction in time spent in the presence of the aversive stimulus.

Three of the seven rats were initially exposed to fields at lower strengths over several sessions immediately preceding the first session of exposure to the 100 kV/m field. This was done to assist us in addressing questions that would have been provoked had the 100 kV/m field been found to be highly aversive. Since that outcome was not seen, and since the data did not show differences based on the initial treatment (not shown here), we pursued the matter no further.

When the incandescent lamp was the source of the added stimulus, the rats also showed a small, but consistent, preference for the absence of the added stimulus. (For present purposes, the relative contributions of light and heat for the observed aversiveness were not determined and are not important.) During CONC VI 2 VI 2, however, initially there was no apparent difference in performances between the 75 and 150 W added-stimulus conditions during conditions 14 and 17, in contrast to our earlier results [Stern and Laties, 1989], which showed that as lamp intensity increased, the rat kept it off longer. With the additional training during conditions 20 and 22, however, the rat reduced its exposure to the 150 W stimulus. In the present experiment, therefore, because the value of the food was much greater than the difference in values between 75 and 150 W, those latter differences emerged only slowly. Even so, as with the E-field, the rats would not turn the lamp off for an entire session when that behavior would have cost them 50% of the available food. In our 1989 experiment, food was never available. Similarly, in this experiment, when the rat could not lose pellets, i.e., during EXT, it spent even less time in the presence of the light.

When the single VI 1 schedule for responding on either lever was in effect (conditions 15 and 16), the rats could have responded 100% of the time on either lever with no loss in reinforcements. Yet responding continued to occur to both levers. When responding on one of two alternatives produces a relatively intense aversive stimulus, responding may readily shift to the alternative if there is no cost for doing so. Azrin and Holz [1966: p 405] showed that pigeons readily switched key pecking maintained by a fixed-ratio schedule of food reinforcement from one key where responding also produced electric shock to one where the same fixed-ratio schedule was in effect, but no shock was produced. There was no loss in food reinforcement for allocating all responding to one key. In our experiment, since responding on both levers continued to be directly reinforced, and since the 150 W lamp was only moderately aversive, changeover responding continued to occur, and the rats continued to be exposed to the stimulus. Even so, when the lever producing the stimulus was reversed between conditions 15 and 16, the time spent on the two schedules switched just as before, demonstrating that the 150 W stimulus was aversive. We would predict that with continued training, the rats would have eventually distributed most of the time to the schedule in which the stimulus was absent.

When the rats were prefed during condition 21, the value of the food decreased even though it was available under the concurrent schedule; the rat, therefore, once again spent less time in the presence of the 150 W stimulus. We would have expected a similar outcome under a similar condition of prefeeding with the E-field, but that condition was not studied.

The presentation/delay procedure used in our 1989 experiment was *identical* to the CONC EXT-EXT procedure used here, i.e., one changeover turned the stimulus on, the other changeover turned it off. The main differences between experiments were the experimental history of the subjects and their state of food deprivation. In the present experiments, the hungry rats continued to switch between levers. Had the number of sessions been increased, we would have expected the food reinforced responding to extinguish almost totally with only the onset and offset of the lamp serving to control the behavior. We then would have expected the rats to keep the illumination off most of the time, i.e., during conditions 18 and 19, just as they had in our earlier experiment.

In our 1989 experiment, the rats did not terminate exposure to a 90 kV/m E-field under the presentation/termination procedure, nor did they terminate the field under a procedure similar to that employed by Rogers et al. [1995]. Yet comparable fields were aversive in the shuttlebox experiments and grazing study. In the shuttlebox and foraging (grazing cattle) experiments, choice behavior that was already occurring at a high rate was altered by the field. In both the Stern and Laties [1989] and the Rogers et al. [1995] studies, operation of the response operandum required to terminate the field did not occur at a high rate under baseline conditions in which there were no explicit consequences for responding. The choice analysis can also

be extended to these cases. One choice was to operate the operandum. The other choice consists of all of the other behavior, whatever it might be, that is emitted in this situation. What remains undefined, and is not explicitly controlled by the experimenter, is the payoff, or reinforcing consequences for the behavior of these two classes. In these experiments, then, the rats spent most of the time in not-lever-pressing behavior. The cost, i.e., the negative value, of responding to turn the field off by engaging in the less preferred activity of lever pressing was greater than the value of not responding, regardless of the presence vs. absence of the 100 kV/m field.

An alternative, but not mutually exclusive, explanation for the failure of the rats to terminate field exposure during our 1989 study is that since lever pressing occurred at a low frequency, learning could not occur because there were insufficient opportunities for field termination to effectively reinforce the behavior. Since, however, shuttling behavior in the shuttlebox studies occurred at high frequency prior to field exposure, there was a sufficient opportunity for such reinforcement to occur. It seems likely that this factor also could have played a role in the different outcomes between studies. But the critical assessment is not whether field exposure is aversive, but just how aversive is it? Our results demonstrate that, when scaled against other variables, a 100 kV/m field has relatively little negative value. Had it been more aversive, the rats would have spent less time in it during this experiment, and they would have learned to lever press to terminate it in our 1989 study. In addition, even at 105 kV/m, during one of the shuttlebox studies [Hjeresen et al., 1980], although the rat spent less time in the field than out of it, it entered the field 30–50 times/h, an outcome that would not occur if the field were highly aversive.

The results from the present experiment demonstrate that the aversiveness of 60 Hz E-fields depends on not only the field strength, but also on other variables that are controlling behavior in that situation. At sufficient field strengths, an animal may show a preference to remain out of the field. Yet even 100 kV/m for the rat is not very aversive when scaled against other conditions valued by the subject. It is not willing to ''pay'' much for that outcome. It is not willing to pay by giving up food pellets; it is not willing to pay by engaging in responding that is less preferred to other activities; the cost is too high.

Although E-fields at the higher strengths employed in the cited laboratory studies, as well those found in natural settings, may, at most, be slightly aversive, it is quite plausible that there are conditions under which fields, even at lower strengths, may become highly aversive through learning. When large electric potential differences are established between an animal and other objects (including other animals) spark discharges may occur between the two and provoke pain and startle reactions [e.g., Reilly, 1978]. Although laboratory studies of bioeffects of 60 Hz E-fields have gone to great lengths in apparatus design to prevent such electrical events, the conditions where 60 Hz E-fields are frequently encountered outside of the laboratory by humans or other animals are not so designed. If the E-field is temporally paired with a high frequency of spark discharges, or very painful or startling ones, it may become a conditioned aversive stimulus, through the process of classical conditioning. Pairing field exposure with loud, unpleasant noise that may occur in high E-field environments could also produce conditioned aversiveness of the field. A subject will respond to prevent or escape from exposure to a classically conditioned aversive stimulus, with such responding maintained by the absence of the stimulus.

In addition, through the process of operant conditioning, which can occur in the same setting, the E-field may function as a discriminative, or warning, stimulus that controls behavior that turns off the stimulus, i.e., the animal leaves the field. Such behavior would be reinforced by the reduction in the probability of the aversive shock or noise that is highly correlated with the presence of the field.

All such learning factors may contribute to the observed aversiveness of the E-field. In the laboratory we can vary them systematically in order to determine their contribution. In the present experiment, we have shown that the aversiveness of a stimulus depended not only on stimulus strength, but also on reinforcement schedules that operated concurrently to control those behaviors. This outcome helps us understand the seemingly disparate results of earlier reports. Under no condition, however, was the field highly aversive, an outcome consistent with those of earlier reports.

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