**FOOD AND INTRACRANIAL STIMULATION
RESPONDING SUPPRESSED WITH
REGULAR-INTERVAL SHOCK**

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Attenuation of conditioned suppression during intracranial stimulation was compared with that during food reinforcement. Response rates controlled by food and by brain stimulation were equalized on a multiple schedule by adjusting the stimulating current. When foot shock was delivered during timeout periods separating response components, responding for food was significantly more suppressed than responding for brain stimulation. When components were shortened from 10 to 2 minutes, responding maintained by either food or brain stimulation showed a similar temporal pattern of suppression preceding each shock, but responding in the component involving food remained significantly more suppressed. Explanations for the attenuated suppression during brain stimulation based on neural disruption, stimulus blocking, and analgesic properties were questioned. The increased responding during brain stimulation seemed to reflect greater response strength relative to food reinforced responding.

Key words: suppression, intracranial stimulation, shock, temporal discrimination, differential suppression, response strength, lever press, rats

Response suppression during a brief conditioned stimulus paired with electric shock is the usual index of conditioned suppression (Estes and Skinner, 1941). Brady and Conrad (1960) noted a marked difference in suppression when intracranial stimulation (ICS) was compared to conventional reinforcers. Rats have typically failed to suppress responding during a conditioned stimulus (CS) with ICS as the reinforcer (Geller, 1970; Goldstein, 1966; McIntire, 1966). Merrill, Lott, and Bergen (1970) utilized procedural changes to discount several possible explanations for the attenuated suppression during ICS: neural disruption (Goldstein, 1966), blocked stimulus perception (Ball, 1967), resistance to distraction (McIntire, 1966), and analgesic effects (Breglio, Anderson, and Merrill, 1970). Russell (1975) reported that the intensity of the brain stimulating current was the determining factor, noting that response suppression was attenuated only with high-intensity ICS.

The present study employed a variation of the traditional (Estes and Skinner, 1941) conditioned suppression procedure, which focused

on the suppression of responding between, rather than during, the presentations of the CS and foot shock. A multiple schedule with alternating components of food and ICS reinforced responding was used, with presentation of CS and foot shock separating the components. The multiple schedule allowed a direct comparison of response suppression during food- and ICS-reinforced responding in the same animal. Nevin (1974) used a similar procedure to assess response strength under varying reinforcement conditions. He used multiple schedules with timeout periods, during which response-independent food deliveries were found to suppress component rates. Resistance to change in response rate was identified with response strength. Similarly, in the present study, differential response suppression could be identified with differential response strength for food- and ICS-reinforced responding. The possible contribution of analgesic effects during ICS was tested with brief and extended periods of extinction. As Blackman (1968) has shown that differential response rates in baseline conditions can lead to differential relative suppression during aversive conditioning, baseline response rates were matched during food and during ICS components by adjusting the current intensity of the ICS.

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METHOD

Subjects

Fifteen albino rats, 200 to 300 days old were maintained with restricted feeding at a growth rate of 2% of body weight per month. They weighed between 270 g and 345 g at the time of surgery. Five rats were eliminated from the experiment: one dislodged its electrode, two evidenced stimulus-bound eating, and two did not self-stimulate (see procedure).

Surgery and Histology

Bipolar stainless-steel electrodes (Plastic Products Co.) were stereotaxically implanted under sodium pentobarbital anesthesia (70 mg/kg) and methyl-atropine (6 mg/kg). Electrodes were placed in the posterior Medial Forebrain Bundle (MFB) in the hypothalamus, 3.5 mm posterior to bregma, 1.5 mm lateral to the midline, and 8.5 mm below the surface of the level skull, and secured with screws and dental acrylic.

Histological verification followed chloral hydrate overdose, perfusion with saline and 10% formol saline, further fixation, and frozen serial 40 μ sectioning. The sections were stained with cresyl violet and compared to the König and Klippel (1963) atlas.

Apparatus

A Lehigh Valley sound-attenuating chamber was fitted with a recessed food dish, a grid floor, and a response lever requiring 0.21 N operating force. Signal lights over the food dish and response lever were each 0.027 cd/m² intensity. A speaker emitted a signal of 88/dB white noise, 20/dB above the masking noise provided by a ventilating fan. The ICS circuitry delivered an isolated 60-Hz sine wave through a variable transformer, 500 K Ω resistor, and a double pole relay, which closed the circuit between the rat and the swivel during 500-msec pulse trains. Electromechanical programming equipment in an adjoining room controlled presentation of scrambled foot shock, signal lights, white noise, and reinforcement. Food reinforcers consisted of one 45-mg Noyes pellet. ICS reinforcement consisted of one 500-msec pulse train.

Procedure

Screening. One week after surgery, the rats were administered screening tests for stimulus-

bound behaviors. The rats were fed and allowed 10 min of habituation to a chamber containing scattered blocks of lab chow, a water spout, and a wood gnawing block. ICS then was administered for 30-sec periods in 500-msec pulse trains with 1 sec between pulse trains. ICS intensities were varied from 15 to 100 μ A. Two rats were eliminated from the experiment when they exhibited eating during stimulation. Other oral behaviors, evidenced in most rats at the highest intensities, such as carrying of chow blocks or the wood block, were not considered consummatory behaviors that would undermine the legitimacy of matching food and ICS response rates.

Training. The rats were first trained to press the lever for single 500-msec pulses of ICS with one pulse following each response, then shifted to a constant probability, variable-interval (VI) 30-sec schedule of reinforcement with 12 interreinforcement intervals (Catania and Reynolds, 1968). After responding stabilized on the VI schedule of ICS reinforcement, daily 1-hr sessions were initiated with alternating components of ICS-reinforced and food-reinforced responding. During the ICS component, the light over the response lever was on, and during the food component the light over the food dish was on. Finally, a timeout period was introduced between each response component. The timeout period was marked by 88/dB white noise and the turning off of the signal light over the lever or the food dish. A single tape coding the length of the intervals for the VI schedule was used for both response components, and the tape was stopped during the timeout.

Response rates during ICS and food components were equalized as nearly as possible by adjusting the ICS current intensity daily. Stability was sought both in a measure of relative rate during ICS components as compared to food components, and in overall average response rates for the sessions. When eight days passed wherein the variance on these two stability measures was no less for the last four days than for the first four days, the last four days were recorded as the baseline rate for ICS and food-controlled responding. The number of sessions required before the stability criteria were met varied from 26 to 34 days. After the four baseline days, the rats were exposed to unavoidable electric foot shock within each timeout period. Four days of foot-shock

administration were followed by four days of a return baseline.

Long components. The long-component schedule consisted of alternating 10-min food and ICS components separated by a 60-sec timeout: *mult* VI 30-sec (food), VI 30-sec (ICS), timeout (60 sec). Half the rats received food in the first component and half received ICS. Responses in the first component, which was not preceded by timeout, were not included in the analyses of response suppression on shock days or the return to baseline. On shock presentation days, 1.0-mA ac foot shocks of 0.5-sec duration were delivered through the grid floor at 20 sec and 40 sec of each 60-sec timeout. The latencies of the first response in each component following timeout were recorded and converted to logarithms for averaging. Seven rats were tested on the 10-min component schedule.

Short components. A schedule employing shorter response components and more frequent foot shock was instituted for two reasons: (1) Any interaction between the reinforcement in effect and the aversive foot shock should be highlighted by frequent, regular-interval shock while the same reinforcement remained in force. (2) A shorter intershock interval should also facilitate establishment of a temporal conditioned stimulus. With a temporal stimulus in addition to the auditory stimulus preceding shock, a temporal patterning of suppressed responding was expected. Such temporal patterns would allow an additional comparison of food- and ICS-suppressed responding.

The short-component schedule consisted of five consecutive 2-min components of food responding, with each component followed by a signalled 20-sec timeout, then five consecutive ICS components also separated by timeout, *etc.*: *mult* VI 30-sec (food), VI 30-sec (ICS), timeout (20 sec). Responses during the initial 2-min food component were not counted. Responses on this schedule were cumulated for each successive 20-sec segment (bin) of the respective food and ICS components. Thus, the average response rate in each successive bin of the components revealed the temporal pattern of responding between timeout periods. First response latencies were also recorded for each component. Food and ICS rates were less closely equated, except to ensure that ICS response rates approximated or fell below food

response rates. On shock presentation days, a single 0.5-sec foot shock was delivered at the end of each 20-sec timeout. The shock intensity was 0.3 mA for the first two days, and 0.5 mA for the second two days. Six rats were tested on the 2-min component schedule, three from the first group and three naive rats that were trained and brought to stabilization criteria following the procedure described above.

Extinction. To assess the possible analgesic properties of ICS, two extinction procedures were instituted. (1) Selected component extinction: food or ICS reinforcement was withheld during six randomly selected 2-min response components. The selected component extinction occurred on two shock days, with two baseline days intervening. (2) Consecutive component extinction: food or ICS reinforcement was withheld during five consecutive 2-min components. Consecutive component extinction occurred on one shock day.

RESULTS

Response rates were suppressed during the 10-min and 2-min response components between foot shocks (Figure 1). Response rates during ICS components were clearly less suppressed than during food components. Table 1 shows the average individual response rates over four baseline days, four shock test days, and four days of return to baseline. The differences between response rates under food and ICS, collapsed over the four shock days, were tested with correlated *t* tests for both the 10-min and 2-min schedules. The differences for the seven rats on the 10-min component schedule and for the six rats on the 2-min component schedule were both significant (10 min, $p < 0.005$; $df = 6$; 2 min, $p < 0.01$, $df = 5$). When shock was removed from the timeout periods in the return-to-baseline condition, response suppression to the white noise alone extended for one or two days. Responding during timeout was at a low rate during baseline and dropped still further during shock days, from 10.6 to 5.2 responses per minute. There were no clear differences in timeout response rates between food or ICS components.

Equal response rates were obtained for all rats except R 280. Responding for this rat was suppressed completely during shock days, but showed a differentially faster recovery of responding for ICS during the return to base-

Fig. 1. (a) Average response rates for the baseline and shock sessions for six rats. (b) Average rates for 2-min component schedule, also for six rats. (c) Latencies for the first response in each 2-min component, averaged in logs for six rats.

Table 1

Response rates for individual rats and groups on the long- and short-component multiple schedules in the baseline and shock conditions. Responses per minute for food and ICS components, and the ICS current intensity for each rat.

<i>Rats/</i>	<i>Groups</i>	<i>Baseline</i> (<i>†</i>) <i>Days</i>	<i>Shock Test</i> (<i>†</i>) <i>Days</i>	<i>Return to Baseline</i> (<i>†</i>) <i>Days</i>	<i>ICS Current</i> (μ A <i>Peak-Peak</i>)
10-MIN COMPONENTS					
R 78	ICS	55	22	44	70 μ A
	Food	56	12	60	
R 89	ICS	53	12	52	66 μ A
	Food	53	4	48	
R 90	ICS	71	41	53	100 μ A
	Food	64	6	49	
R 218	ICS	37	19	45	80 μ A
	Food	45	8	29	
R 279	ICS	65	34	63	79 μ A
	Food	60	14	54	
R 282	ICS	45	28	32	80 μ A
	Food	52	15	18	
R 280*	ICS	68	1	42	107 μ A
	Food	108	1	5	
Group Means	ICS	54	24	50	
	Food	54	10	43	
2-MIN COMPONENTS					
R 218	ICS	42	33	49	80 μ A
	Food	36	16	36	
R 264	ICS	32	16	25	97 μ A
	Food	19	2	10	
R 265	ICS	56	28	54	107 μ A
	Food	74	6	51	
R 266	ICS	46	35	42	117 μ A
	Food	70	15	47	
R 279	ICS	59	72	62	79 μ A
	Food	82	33	75	
R 282	ICS	58	42	51	80 μ A
	Food	65	18	48	
Group Means	ICS	49	38	47	
	Food	59	15	45	

* Data not included in group means; see text.

line (Table 1). The data for this rat were included in the statistical analysis but not in the group averages shown in Figure 1. The three rats tested first on the 10-min and then the 2-min component schedule evidenced somewhat less suppression on their second exposure to shock, but the differential suppression during food as compared to ICS components remained similar (R 218, 279, 282; Table 1). The three rats new to shock administration on the 2-min component schedule were more suppressed during both food and ICS components than those having had prior experience with shock, but again food responding was markedly more suppressed than ICS responding (R 264, 265, 266; Table 1).

Records of typical baseline and shock-day performance are shown in Figure 2. Response patterns in individual components tended to remain similar through the session, except for some attenuation of suppression for both food and ICS responding toward the end of each session. During the 10-min component schedule, responding also showed a consistent pattern across the session, but responding during food components was occasionally completely suppressed for the entire 10-min component.

Average latencies for the first response in each component were variable on the 10-min component schedule, but latencies in the component associated with ICS reinforcement were shorter than latencies in the component as-

Fig. 2. Cumulative records for baseline and shock days showing responding as upward movements of the pen, and food or ICS reinforcement as oblique pips. The pen reset after each 2-min response component and each 20-sec timeout. The differential suppression was consistent for each component. Responding was minimal during timeout.

sociated with food reinforcement. This was true for both baseline and shock conditions. For the 2-min component schedule, latencies were marginally shorter for ICS during baseline. During shock, latencies in the food components lengthened while latencies in the ICS components remained near the baseline values (Figure 1c). A correlated *t* test for the logarithms of differences in latencies during food and ICS components collapsed over the four shock days revealed a significant difference ($p < 0.05$, $df = 5$).

Figure 3 shows the temporal pattern of responding between timeouts for baseline and shock days during the 2-min component schedule. The temporal distributions of responses are shown for the six rats averaged and for

two rats individually on successive shock days. The temporal distributions were generated by averaging the responses in each successive 20-sec segment (bin) of the response component between timeouts. The pattern of responding through the components on shock days is best characterized by a curvilinear decay in rate as the next timeout and shock is approached in time. The major difference between the temporal patterns for food- and ICS-controlled responding was a lower initial rate for food responding. The rate of decay of responding was similar for food and ICS responding. Suppression was attenuated over successive days, but the increment in shock intensity from 0.3 mA to 0.5 mA partially reversed this trend (Figure 1b).

a Temporal Distributions

b R 265 Shock Days

c R 266 Shock Days

Fig. 3. (a) Temporal distributions of responding between timeouts or timeouts with shock on the 2-min schedule. Each bin represents successive 20-sec segments of the 2-min components; averages for six rats. (b) and (c) Temporal distributions for two rats on shock days. The distributions were similar in shape for food and ICS reinforcement components, but food responding decayed to a lower rate preceding shock.

Fig. 4. Temporal distributions of responding compared for reinforcement components and those randomly selected for extinction (selected component extinction). The right-hand graph shows the result of extinction over a series of five components (consecutive component extinction). Responding during extinction remained similar to that during reinforcement. Data are averages for six rats.

Figure 4 shows the results of the selected component extinction and consecutive component extinction procedures. During baseline with selected component extinction, some change in the temporal distribution of responding was apparent for the ICS components without reinforcement. On shock days with selected component extinction, little difference in response rates or pattern was found. During the one shock day with extinction extended over five consecutive components, the difference between suppressed food and ICS

Fig. 5. Electrode tip placements for the 10 rats tested. Plate #37 of the Konig and Klippel (1963) atlas is shown. The millimeter values give the anterior (+) or posterior (-) orientations to the cross-section shown. Electrodes were near or within the MFB, roughly delineated by the semi-circular area.

responding was diminished during the components without reinforcement.

The electrode locations are shown in Figure 5. All electrode tips were near or within the Medial Forebrain Bundle.

DISCUSSION

The procedure for evaluating response suppression differed from the traditional procedure (Estes and Skinner, 1941), but in so doing allowed a relative measure of suppression on a more dynamic base. The suppressive effects of foot shock were found to extend in time over response components, as well as during a CS immediately preceding shock, on two different multiple schedules. With short response components, over which a temporal discrimination might better have been established, a time-dependent response suppression effect was found. LaBarbera and Church (1974) found a similar temporal decay in food response rates with shock at regular intervals. The rate of responding soon after shock was higher for ICS but decayed at a similar rate for both food and ICS. The similar rate of decay implies that the temporal stimulus acted identically in both components, which makes stimulus blocking or neural disruption implausible as explanations for attenuated suppression during ICS (Ball, 1967; Goldstein, 1966).

Explanations for the differential suppression in terms of possible analgesic properties of ICS (Cox and Valenstein, 1965), or reduced pain threshold (Breglio, Anderson, and Merrill, 1970) were obviated by the procedure. The rats were not responding during shock, and ICS was not available as an analgesic during shock. During the selected component extinction, where food and ICS were withheld for 2 min, a change in ICS response suppression due to loss of an hypothetical sustained analgesic effect did not appear.

Any analgesic effect would have to have lasted no more nor less than the 10-min periods of alternating food and ICS availability to produce the differential suppression within successive components. While Rose (1974) reported analgesia enduring as long as 10 min, an examination of cumulative records such as those in Figure 2 showed no evidence of analgesia in the pattern of responding. Both food and ICS responding decayed similarly preceding each shock.

The possibility that the attenuated suppression during ICS components might have been attributable to a combination of analgesia and a higher obtained reinforcement rate during ICS components on shock days was negated by the extinction test over consecutive components. Even with no reinforcement for a 10-min period, the difference between food and ICS response suppression was maintained.

Russell (1975) pointed to the intensity of the brain stimulation as the major determinant of suppression. The present study provided support for this contention, in that less-suppressed rats were generally responding for higher ICS intensities (Table 1). However, a uniform rank ordering of ICS intensities and response suppression was not present. The intensities used were within the lower range in which Russell also found suppression. Nevertheless, in our rats these intensities were associated with attenuation of suppression for ICS as compared with food-reinforced responding.

Baseline response rates equalized for food and ICS components minimized the possibility that a rate-dependency effect such as that found by Blackman (1968) was the cause of the differential suppression. With the 10-min components, where an absence of apparent temporal patterning was taken to indicate little temporal control, a local rate-dependency effect could not be called upon to explain the differential suppression.

A parallel between the concept of response strength as differential resistance to change (Nevin, 1974) and the differential suppression in the present case is indicated by the similarity of the procedures. Nevin (1974) used multiple schedules with timeouts during which response-independent food deliveries suppressed responding. Differences in the magnitude of response suppression were not equivalent to differences in the base rates, but were equivalent to differences in extinction, the more traditional measure of response strength. In the present study, the effects of shock as a challenge to responding, rather than response-independent food delivery, produced a similar differential response suppression. ICS-reinforced responding was less susceptible to this challenge than food-reinforced responding. Although this measure would indicate that ICS-reinforced responding is stronger than food-reinforced responding, it should be noted that

there would appear to be no difference in strength within 2-min components, because both performances decayed at the same rate relative to the initial component rates. Clearly, a better understanding of the variables underlying local temporal control of responding suppressed by shock will be required in order to bring meaning to response strength in this context.

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Received 8 August 1976.

(Final Acceptance 3 September 1976.)