Changes in Rates of Food-Reinforced Bar-Pressing and Collateral Licking during a Signal Preceding Response-Independent Shock

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CHANGES IN RATES OF FOOD-REINFORCED BAR-PRESSING
AND COLLATERAL LICKING DURING
A SIGNAL PRECEDING RESPONSE-INDEPENDENT SHOCK

by

Sander Stern

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The author's wife Barbara and daughter Deborah Lynn were patient with the daily experimental schedule, and they provided the few moments of relaxation which were enjoyed during the course of the study.
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intensities and at 10 v during the descending sequence of shock intensities.

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When intermittent signaled response-independent shocks are presented concurrently with a positive reinforcement schedule, the emission of the response upon which reinforcer delivery is contingent frequently decreases in rate during the signal. This discriminative response rate decrease has been called conditioned suppression, conditioned fear, conditioned anxiety, and the conditioned emotional response (CER). In the classic experiment which demonstrated this phenomenon, Estes and Skinner (1941), trained rats to bar-press for food which became available on an intermittent schedule of reinforcement. When the rate of bar-pressing stabilized, the signaled response-independent shocks were introduced. During the signal the bar-press rate was lower than during non-signal portions of the session. The characteristic of this procedure which made the conditioned suppression phenomenon so interesting was the relationship between the responding maintained by positive reinforcement and the signal-shock presentations. The observed decrement of response rate affected neither signal nor shock presentation; however, such a decrement could result in partial or total loss of potential positive reinforcements during the signal.

Lyon's (1968) review of conditioned suppression indicates that the phenomenon can be reliably generated in several species although the characteristics of the behavior between species during the signal frequently differs for a given set of parametric values. Most of the environmental variables controlling conditioned suppression
may be described as belonging to one of two major procedural
categories – operant conditioning variables which directly control
baseline performance, and classical conditioning variables which
interact with operant conditioning variables to control response
rate during the pre-shock signal. Operant conditioning variables
which affect conditioned suppression include the type, frequency,
and schedule of reinforcement. Furthermore, the deprivation schedule
and the baseline rate itself affect conditioned suppression. Analysis
of these variables reveals that generally, under a given set of signal-
shock parameters, as the conditions of reinforcement maintaining
the operant baseline increase in reinforcing value, the operant
baseline response rate is suppressed less during the pre-shock
signal.

Pairing a pre-shock stimulus with shock independent of the
subject's behavior constitutes a classical conditioning procedure
(Gormezano, 1966). Generally the pre-shock stimulus is described
as the conditioned stimulus (CS) and the shock as the unconditioned
stimulus (US). Several classical conditioning variables affect
the rate and magnitude of acquisition of conditioned suppression.
These include intensity of both CS and US, temporal relationships
between the CS and US (Kamin, 1965), contingency relationships
between the CS and US (Rescorla, 1969), and amount of exposure to
CS prior to CS-US pairings (Carlton and Vogel, 1967). Relationships
between parameter values of both signal and shock which facilitate
the suppression of response rates during the signal are similar
to the relationships between parameter values of both CS and US.
which facilitate acquisition of classically conditioned responses.

Lyon (1968) discusses two interpretations of conditioned suppression data which emphasize each of the major procedures used in the general experimental paradigm. The punishment hypothesis emphasizes the similarities between conditioned suppression data and punishment procedure data. In both procedures the consequence of presenting specified stimuli to a subject whose behavior is being maintained by a positive reinforcement schedule is a reduction in the future probability of emission of that behavior. The major difference between the procedures according to the punishment interpretation is that in the case of punishment the specified stimuli are presented contingent upon emission of a specified response, whereas in the case of conditioned suppression the stimuli are presented independent of the subject's behavior. This independence, although procedurally defined, does not prevent the occurrence of adventitious punishment or delayed punishment effects.

The interference hypothesis places less emphasis on the relationship between the response-independent stimulus presentations and the behavioral baseline maintained by the positive reinforcement schedule. Instead, interest is directed towards postulated respondents acquired as a consequence of the classical conditioning procedure. It is assumed these respondents are incompatible with the baseline behavior and consequently the response rate is suppressed during the CS.

Both interpretations have been directed toward explanation of the suppression of response rate frequently observed during a
signal preceding response-independent shock. Yet under some conditions of signaled response-independent shock, acceleration of response rate has been detected. Interpretations of the effects of signaled response-independent shock need to account for the observation of both suppression and acceleration. Hoffman, Fleshler, and Jensen (1963) reported that suppression of key-pecking in pigeons during a tone followed by shock initially generalized to tones at adjacent frequencies. When a shock extinction procedure was instituted, key-peck suppression continued at the training stimulus, but key-peck acceleration occurred at the adjacent frequencies. Hendry and Van-Toller (1965) reported that the bar-pressing rate of rats accelerated during the first half of a signal which terminated with shock. The acceleration effect was so large that the average signal response rate was greater than the non-signal response rate in some subjects. Response rate acceleration has also been observed during the differential reinforcement of low rate (DRL) positive reinforcement schedule which requires that a minimum interresponse time (IRT) elapse between successive responses before a response may be reinforced. Finocchio (1963, reported by Migler and Brady, 1964, and Blackman, 1968a) found that DRL bar-pressing accelerated during the pre-shock stimulus at 1.2 ma but suppressed at 5 ma. Furthermore, the DRL rate suppressed even at 1.2 ma if the pre-shock stimulus duration was relatively brief in relation to the remainder of the session. Leaf and Muller (1964) reported suppression of DRL bar-pressing with a relatively brief pre-shock stimulus. Blackman (1968a) also found DRL acceleration during the CS at relatively low
shock intensities and suppression at higher intensities. He observed that initially each bar-press was followed by a regular chain of behavior, but that after shock was introduced, the behavioral chain was disrupted. According to Blackman, if the response chain provided discriminative cues for bar-pressing, the disruption of the chain could be the basis for the observed acceleration. This analysis supports Hodos, Ross, and Brady (1962), Laties, Weiss, Clark, and Reynolds (1965), and was supported later by Laties, Weiss, and Weiss (1969). If these observations are accurate, an analysis of such collateral behavior (Wilson and Keller, 1954) may provide a solution to some apparently divergent data resulting from signaled response-independent shock procedures. The present study was designed to investigate such a possibility.

Collateral behavior, behavior occurring in the presence of but not under explicit contingencies of reinforcement, has not been systematically studied in the signaled response-independent shock paradigm. Perhaps study of this behavior has been neglected due to 1) an unexamined assumption that such behaviors are maintained simply by adventitious reinforcement contingencies and will be affected by changes in the contingencies in a manner similar to the concomitant operant; 2) the difficulty in achieving for a state of affairs where the collateral behavior will occur frequently and consistently; and 3) the technological difficulties encountered in recording the behavior.

Study of collateral behavior is encouraged however, for two major reasons. First, at least under some conditions such as DRL
schedules, collateral behavior appears to perform a mediating function. Ferster and Skinner (1957, p. 729) define mediating behavior as "Behavior occurring between two instances of the response being studied (or between some other event and such an instance) which is used by the organism as a controlling stimulus in subsequent behavior." The DRL schedule appears to be conducive to the development of collateral behaviors due to both the relatively long periods of time when reinforcement is not available and the potential increase in reinforcement rate which exists when the subject is engaged in non-bar-pressing behaviors. Hodos, Ross, and Brady (1962) reported that when collateral head-jerking and drinking was disrupted in monkeys, DRL performance was disrupted and fewer responses were reinforced. Laties, Weiss, Clark, and Reynolds (1965) studied tail-nibbling in a rat whose bar-pressing behavior was maintained by a DRL schedule and found that when the tail-biting response was disrupted, the bar-press response rate increased and reinforcement rate decreased. Deadwyler and Segal (1965) found an initial disruption of DRL performance when collateral licking was disrupted by allowing a water bottle to dry out midway in session. Laties, Weiss, and Weiss (1969) reported a high correlation between duration of wood-nibbling behavior and reinforcement delivery on a bar-press DRL schedule in 5 rats. When the wood-nibbling behavior was disrupted, bar-press response rates accelerated and reinforcement rates decreased. Each of these studies presents evidence that disruption of collateral behaviors on DRL schedules results in an acceleration of the consequated operant and a concommitant reduction in
reinforcement rate. None of these studies included a signaled response-independent shock procedure. Although Blackman did report that on a DRL schedule disruption of collateral behavior was observed when bar-press rates accelerated during a signal preceding response-independent shock, he did not present quantitative data depicting the disruption.

Collateral behavior may be an interesting phenomenon to study in its own right. One of the difficulties in studying collateral behavior already mentioned was the seemingly idiosyncratic nature of the behavior. For instance, Blackman (1968a) names rearing, gnawing, and grooming as the basic collateral behaviors which occurred consistently within but not between subjects. Under some conditions, however, the environmental space can be so arranged that there is a high probability of a priori being able to specify the general characteristics of the collateral behavior. Polydipsia is a collateral behavior which reliably occurs when water is available during an intermittent food reinforcement schedule. These characteristics, as well as the ease in measuring the behavior, have provided researchers with a means of better understanding the characteristics of some collateral behavior, and the role of collateral behavior in relation to other measured behavior.

Polydipsia means excessive drinking. If water is available when food deprived rats intermittently receive 45 mg Noyes standard lab rat pellets, they consume several times the amount of water they normally would drink if the same number of pellets were available simultaneously or on a continuous reinforcement schedule (CRF),
(Falk, 1961a, 1961b). The rats are not water deprived, nor is pellet delivery contingent upon licking. Falk (1966b) reported that polydipsia does not occur when the average interpellet interval is less than 30 sec, but that as the average increases beyond 30 sec, the amount of water consumed increases, reaches a maximum, and then decreases at even longer intervals. This phenomenon of schedule-induced polydipsia has been replicated in the rhesus monkey (Shuster and Woods, 1966), but to the author's knowledge, it has not been demonstrated in any aviary species. Polydipsia is controlled by an on-going schedule of intermittent food delivery. Why does the subject consume excessive quantities of water under these conditions?

Simple physiological thirst variables do not appear to generate the phenomenon. Although dry food motility is facilitated when water is consumed close in time to food consumption, Falk (1967) found that polydipsia may occur even when a liquid food solution is delivered. Falk (1967) also found that at some average interpellet intervals more water was consumed following single 45 mg pellet delivery than following two 45 mg pellet delivery, if food motility was an important consideration, just the reverse result would be expected. In another study, Falk (1968) administered stomach loads of water 45 minutes before the session with minimal effect upon polydipsic behavior. This indicated that the water consumed was not necessary to rectify an electrolytic imbalance due to the ongoing digestive processes.

Another explanation of polydipsia is that the behavior is acquired and maintained by adventitious reinforcement contingencies.
According to this viewpoint, shortly following an occasional drink, the subject may receive food reinforcement. As a consequence of the close temporal contiguity between the two events, the drinking behavior is strengthened and maintained at a high rate. Several sources of data provide evidence opposing such an analysis. First, the drinking occurs in a characteristic burst of licks immediately following food delivery (Falk, 1961a). Although these data are insufficient to reject the adventitious reinforcement interpretation, they are important, for Hitzing (1968) later indicated that if reinforcement were made contingent upon the lick response itself, the pattern of licking immediately preceding reinforcement resembled other patterns of operant behavior controlled by identical reinforcement contingencies. Immediately following reinforcement, however, the licking was emitted in the burst pattern described by Falk. Falk (1964), Hitzing (1968), and Segal and Oden (1969) also used a change-over delay procedure (COD) between licking and reinforcement and found that the post-pellet burst was not affected by the procedure. Typically the COD procedure has been used to eliminate or prevent adventitious reinforcement effects. Furthermore, Falk (1966) reported that under conditions of intermittent food reinforcement, food-deprived rats would emit a second response which was intermittently reinforced by water presentation. When the water was no longer presented, the second response extinguished. If food pellet delivery adventitiously reinforced the second response-lick response chain, the removal of the water should have had only a mild effect upon the immediately preceding behavior. Finally, the
rapid speed of acquisition, the high degree of stability, and the ease of intersubject replication reported in polydipsia studies are not generally characteristics of behavior controlled by adventitious reinforcement contingencies.

More recently Falk (1968) has offered another interpretation of polydipsia. He suggests that polydipsia is a stable preparation of what the ethologists typically refer to as "displacement activities". "Displacement activities" are behaviors which typically appear when powerful reinforcers are in close but not immediate temporal or spatial proximity. The emitted behaviors in such "thwarting" situations are determined by the species of the subject under observation, the reinforcer not immediately available, and the other stimuli which are available in the environment. For present purposes the interesting part of this analysis is the suggestion that under such conditions other environmental stimuli may act as reinforcers, perhaps in a hierarchal fashion. It is for this reason polydipsia has been called an adjunctive behavior, that water has been called an adjunctive reinforcer. Food-deprived rats do not consume much water except under conditions of food delivery within limited time intervals. The reinforcing characteristics of water are induced under such conditions: that is, drinking is an adjunctive behavior. Falk (1966a) demonstrated that food-deprived rats would emit an intermediate response in order to receive water while in the context of an intermittent schedule of food reinforcement. This datum not only rejects the adventitious reinforcement analysis of polydipsia, but also it explicitly demonstrates that at least some stimuli may
become powerful adjunctive reinforcers.

Just how powerful are these adjunctive reinforcers? They do sustain behavior on intermittent reinforcement schedules. But what effects do aversive or punishing stimuli have upon behaviors maintained by adjunctive reinforcers?

If those behaviors designated as adjunctive behaviors and collateral or mediating behaviors are similar, if not identical phenomena, then an analysis of polydipsia in more detail should increase the accuracy of predicting the results from procedures where other collateral or adjunctive behaviors are emitted. Polydipsia is one collateral behavior which occurs in a high percentage of subjects and under different intermittent schedules of reinforcement. Several studies have demonstrated that disruption of collateral behavior including polydipsic licking results in disruption of DRL performance. When Finocchio (1963) and Blackman (1968a) introduced signaled response-independent shocks upon a DRL baseline, the DRL response rate was disrupted and accelerated. Blackman (1968a) suggested the acceleration was due to suppression of behaviors which provided discriminative cues controlling DRL performance. Unfortunately, Blackman was unable to provide quantitative data to support his observations.

The present experiment was designed to investigate the effect of signaled response-independent shock upon polydipsic licking at a continuously available drinking tube when food-deprived rats bar-pressed for Noyes food pellets on a variable-interval (VI) schedule. Although Blackman's observations concerned the relation
between collateral behavior and DRL performance in a signaled response-independent shock procedure, the examination of the collateral behavior during the pre-shock signal may be confounded by relatively large changes in reinforcement rate resulting from the disruption of the DRL behavior. A VI food reinforcement schedule was used in the present study to minimize such confounding effects.

Since the effect of signaled response-independent shock upon polydipsia has not been reported previously, the subjects received four different shock intensities, 3 subjects in an ascending-descending sequence and 3 subjects in a descending-ascending sequence. The experiment was designed to provide data to begin answering the following questions.

1. Will there be a suppression of polydipsic licking behavior? Falk (1968) suggested that since the subject's behavior appears insensitive to the normally punishing effects of excessive consumption, the behavior may be relatively insensitive to other punishing stimuli. Furthermore, Hitzing (1968) indicated that when a DRO contingency of licking was used, the DRO contingency did not effectively suppress the lick response. Yet the use of a DRO contingency generally does result in suppression of the specified response.

2. If polydipsic licking suppresses, is the suppression closely correlated with similar rate changes in the food reinforced operant? Blackman's (1968a) analysis of DRL acceleration during a pre-shock signal suggests that collateral behavior patterns may suppress prior to maintained baseline operant behavior.
3. Will relationships between bar-press responding and lick-responding observed at one intensity be observed at all intensities independent of possible sequential intensity effects?

**METHOD**

**Subjects**

Six experimentally naive male albino rats, obtained from the Upjohn Company, Kalamazoo, Michigan, were maintained at 80% of their pre-experimental free-feeding weights. Each subject was separately housed in a wire mesh cage located within the same room as the experimental chamber. A speaker located in front of the home cages provided an 82 db white noise (Brul and Kjaer Sound Level Meter, C scale, measured about 5 cm in front of the cages) generated by a Grason-Stadler Noise Generator Model No. 455B and amplified by a Bogen CHB 50 amplifier. The white noise was used to maintain fairly constant auditory stimulation while the subjects were in their home cages. Generally, daytime home cage air temperature was about 70° ± 2° F during the first 3 months of the experiment and about 74° ± 2° F during the last 3 months of the experiment. Minimally once every two days, the paper below the home cages was changed and sprayed lightly with a 10:1 solution of Kane Kare (10 parts water: 1 part Kane Kare) (Airkem, Inc., Carlstadt, New Jersey).

Following an initial period of handling prior to the beginning of the experiment, subjects were rarely handled directly. Rather, they were trained to jump from their tilted home cage into a weighing
pan, from the weighing pan into the chamber, from the chamber back into the weighing pan, and from the weighing pan back into the home cage. Such a procedure was utilized to reduce the confounding effects of non-experimental variables due to inconsistent handling. With few exceptions sessions were conducted at approximately the same time daily. Following each session, each subject was returned to his home cage and fed a sufficient quantity of Wayne Feed Lab Blox to maintain his 80% body weight level. A bottle containing 150 ml tap water was placed on the front of the home cage, and it was removed just prior to that subject's next session.

At the beginning of training the age of R14B, R15B, R16B, and R17B was approximately 130 days; and the age of R6 and R10 was approximately 340 days. Throughout most of the experiment R6 appeared to have a slight infection in the tip of his tail, and he lost a few millimeters of it apparently due to the infection.

Apparatus

The 20.1 cm wide x 20.4 cm deep x 21.2 cm high experimental chamber was constructed of 3 stainless steel sides and roof, a stainless steel grid floor, and a plexiglass door. The operandum, a 5.0 cm wide x 1.1 cm high tapered and rounded stainless steel lever, protruded 1.7 cm through a side wall into the chamber. The top center of the operandum was located 7.5 cm above the grid floor and 5.8 cm from the back wall. A bar-press response was defined by a 0.5 cm downward displacement of the lever which required 17 g pressure. The food cup was recessed into the same wall 4.0 cm from the front plexiglass door.
A standard brown laboratory water bottle, containing 150 ml tap water at the beginning of each session, was inverted and held onto the plexiglass door by a spring. The drinking tube, which passed through the center of a rubber stopper in the bottle, was a glass spout which protruded 0.5 cm into the chamber, 4.1 cm above the grid floor centered from the sides of the chamber. (Initially the tube extended 3.0 cm into the chamber, but it was partially retracted on the 45th day of standard length sessions.) Licks were recorded by placing the shielded negative electrode of a BRS-Foringer DO-201 drinkometer circuit into the tube and by connecting the grid bars through a relay network to a common earth ground.

The grid floor consisted of 10 rods 0.7 cm in diameter centered 2.0 cm apart which were aligned parallel to the door holding the drinking tube and perpendicular to the wall containing the operandum and food cup. Prior to each session the grid floor was polished with steel wool; and a bare stainless steel pan located 7.0 cm beneath the grid floor was removed, rinsed with water, and sprayed lightly with a 10:1 solution of Kape Kare. The entire chamber was washed with water and dried following the final session each day. A Gerbrands pellet feeder, located beside the experimental chamber, was advanced by a stepping motor and an interface relay to deliver 45 mg Noyes lab rat food pellets as the reinforcer. When pellet delivery occurred, both electrical devices provided simultaneous audible clicks signaling the event. Both the experimental chamber and the pellet feeder were mounted on a piece of fiberboard which was placed on the shelf of a refrigerator shell used for sound attenuation.
A 25 watt 110 vac incandescent bulb located on the ceiling of the refrigerator provided dim houselight illumination for the interior of the experimental chamber. A Sonalert Model No. 628 (P.R. Mallory & Co.) provided a 2800 Hz auditory signal during the CS interval. The Sonalert, centered 6.3 cm directly above and facing the experimental chamber, was in series with 1100 ohm resistance and was powered by 28 vdc. Beneath the chamber on the floor of the refrigerator was a speaker facing upwards which provided white noise from the same source as that in the room, but at a slightly less intense level. Additional noise as well as forced air circulation was provided by a centrifugal blower attached to the outside of the refrigerator shell. Generally the air temperature inside the refrigerator shell at the end of session was approximately 3° - 4° F warmer than the simultaneously determined home cage air temperature. A plexiglass window permitted observation of the subject through the front door of the refrigerator shell.

The 60 Hz ac electric shock source consisted of a Variac (General Radio Co.) autotransformer, a Stancor PC-8302 plate transformer, and a 30K ohm resistor. A relay closure placed the subject in series with the circuit. Approximately 100 msec prior to shock onset, a relay network isolated the grid bars from the common ground and switched the drinkometer out of the circuit. Shock was then applied through a high-speed mercury-wetted relay polarity scrambler (Anger, personal communication) through the grid, stainless steel walls, and food cup, but not through the bar. Shock duration was calibrated by using a BRS-Foringer MV-4S
clock to measure the duration of contact closure of the shock relay. All reported shock intensities were determined by the voltage output of the Variac which was measured by a Heathkit VTVM Model IM-21.

In an adjacent room BRS-Foringer solid state programming apparatus including a variable-interval tape programmer, and mechanical switches were used to program the experiment. Sodeco impulse counters and Veeder-Root impulse counters recorded cumulative bar-press responses, cumulative lick responses, and cumulative reinforcements in each of the 3 intervals in a cycle; and a Gerbrands Model C-3 cumulative recorder provided a monitor of both bar-pressing and licking behavior. A 50 ml graduate cylinder was used to measure both session and home cage water consumption.

Procedure

The rats were adapted to their deprivation schedule for a minimum of 30 days prior to training day 1. Water intake was measured during the first 4 days of the 5 days preceding training day 1. By the time the home cage baseline of water intake was determined, each subject required a constant amount of food to maintain an 80% weight level. On the day before training day 1, each subject was adapted to the experimental chamber for approximately 15 min. During the short adaptation session, neither food nor water was available; the houselight was not illuminated; and the refrigerator door remained open. The refrigerator door was closed during all subsequent sessions.

On training day 1 each subject acquired the bar-press response. During the first 5 min of the session, neither food nor water was
available, but the houselight was illuminated. Next the experimenter used a manual push-button switch to activate the pellet feeder once. When the rat's nose was inside the recessed food cup, nine more food pellets were delivered. Following this magazine training, single 45 mg food pellet reinforcements were delivered automatically immediately following each bar-press response. On this continuous reinforcement schedule (CRF) most subjects responded regularly by the end of the first hour. In the few instances where bar-pressing frequency was low and irregular after one hour, a successive approximation procedure was used to train subjects to bar-press. Approximately 225-250 pellets were delivered to each subject while on the CRF schedule on training day 1. The houselight was turned off at the end of the session.

On training day 2 25 CRF food pellets were delivered to each subject, but again water was not available. Immediately following delivery of the last CRF pellet the houselight was turned off, and no reinforcements were available for about 1 min during which the refrigerator door was opened and the water bottle was placed on the door of the experimental chamber. A standard length session followed during which the schedule of food reinforcement was a variable-interval 2 min schedule (VI 2).

A standard length session consisted of 6, 15 min cycles with each cycle broken into 3 fixed-sequence 5 min periods designated as the pre-CS interval, the CS interval, and the post-CS interval. One additional 5 min interval preceded the 6 cycles and another 5 min interval followed them. Thus the duration of each session was
100 min. Initiation and termination of the experimental contingencies were signaled by the onset and offset of the houselight. Preceding and following each session the subject remained in the darkened chamber for a minimum duration of 1 min.

The VI 2 min (mean interreinforcement interval equal to 121.5 sec) schedule of food reinforcement consisted of 20 intervals ranging between 3 sec and 384 sec which generated a relatively constant reinforcement rate ranging between .0077 and .0066 reinforcements per sec (Catania and Reynolds, 1968). When reinforcement became available the VI tape programmer stopped until that reinforcement was delivered contingent upon emission of a bar-press response. Since this unlimited-hold procedure was utilized, the probability of reinforcement availability was high at CS offset if the subject failed to bar-press during all or most of the CS interval. To reduce the adventitious reinforcement of not bar-pressing during the CS interval, reinforcements were never delivered during the first 10 sec following shock onset. Frequently, but not always, one non-scheduled reinforcement was available at the onset of the session.

Table 1 presents both the sequence and number of sessions each subject was presented with each experimental condition. Following the initial VI 2 min standard baseline sessions, the audio signal generated by the Sonalert was presented simultaneously with each CS interval. Next the signaled response-independent shock procedure was introduced. During this portion of the experiment every CS interval terminated coincidentally with the offsets of both the audio signal and a 200 msec shock. The subjects, listed in Table 1, were divided into two groups.
Sequence and number of sessions of each condition. When the number of sessions of an experimental condition was the same for all subjects within a group, the number of sessions appears in parentheses. When the number of sessions was not the same for each subject, the number of sessions are individually listed for each subject.

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<tr>
<td>2.5 v</td>
<td>(15)</td>
<td></td>
<td>20 v</td>
<td>(15)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tone (Shock extinction)</td>
<td>15</td>
<td>25</td>
<td>10</td>
<td>Tone (Shock extinction)</td>
<td>10</td>
<td>25</td>
</tr>
</tbody>
</table>
which received identical treatment except with respect to the sequence of shock intensities presented during the remainder of the experiment. The Ascending group received a sequence of low intensity, high intensity, low intensity shocks; whereas the Descending group received a sequence of high intensity, low intensity, high intensity shocks. Finally, a shock extinction condition which was identical to the original tone procedure was presented to each subject.

In order to determine the differential rate of responding during the CS interval when compared to the rate of responding during the pre-CS interval, a relative rate index was calculated in the following manner. The response rate during the interval with the lower rate of responding was divided by the response rate of the other interval. If the response rate during the CS interval had been greater than that during the pre-CS interval, the quotient was preceded by a "plus" (+) symbol and described as an "acceleration index". If the response rate during the pre-CS interval had been greater than that during the CS interval, the quotient was preceded by a "minus" (−) symbol and described as a "suppression index". Note that the calculation of a suppression index but not an acceleration index, is identical to the calculation of the suppression ratio employed by Stein, Sidman, and Brady (1958). Two relative rate indexes were computed for each session: one comparing the two bar-press response rates, and one comparing the two lick response rates.
RESULTS

An estimate of the median ml water ingested per gram food available before bar-press training, prior to exposure to shock, and following exposure to shock is presented in Table 2. This estimate is based upon measured water loss from the available water bottle and an estimate of amount of food consumed. Following adaptation to the food-deprivation schedule and prior to bar-press acquisition each subject consumed approximately 12.5 g Wayne Feed Lab Blox per day. During the experiment each subject consumed approximately 2.5 g Noyes lab rat pellets within each session and approximately 10 g Wayne Feed Lab Blox following each session. The data presented in Table 2 indicate that preceding and following the shock procedure all subjects were polydipsic with respect to the estimate of ml water ingested per gram food available in session as compared to home cage, that is, each subject consumed more water per gram food during the session than in the home cage following the session. Subject R6 consumed excessively large quantities of water in the home cage, but was still polydipsic in session. It should be noted that relative number of licks corresponded closely to the relative measured session water consumption within subjects, but not between subjects. Generally during shock sessions the water consumption remained high except during initial exposure to 20 v. Data showing water consumption during shock sessions are not presented, since licking was not distributed evenly throughout the 3 intervals within each cycle. Such non-homogeneous data would not be amenable to a simple definition of polydipsia;
### TABLE 2

Estimate of median ml water ingested per gram food available during 4 of the 5 days preceding the first bar-press acquisition session, the last 5 tone days preceding the first shock session, and the first 5 tone days following the final shock session.

<table>
<thead>
<tr>
<th>Subject</th>
<th>Pre-Experimental Session</th>
<th>Pre-Shock Session</th>
<th>Home Cage (Post-Session)</th>
<th>Post-Shock Session</th>
<th>Home Cage (Post-Session)</th>
</tr>
</thead>
<tbody>
<tr>
<td>R14B</td>
<td>3.0</td>
<td>12.0</td>
<td>2.6</td>
<td>12.0</td>
<td>2.6*</td>
</tr>
<tr>
<td>R15B</td>
<td>3.3</td>
<td>15.2</td>
<td>2.2</td>
<td>17.2</td>
<td>2.5</td>
</tr>
<tr>
<td>R6</td>
<td>5.1</td>
<td>18.4</td>
<td>5.1</td>
<td>20.0</td>
<td>5.5</td>
</tr>
<tr>
<td>R16B</td>
<td>3.1</td>
<td>15.6</td>
<td>2.0</td>
<td>14.4</td>
<td>2.9</td>
</tr>
<tr>
<td>R17B</td>
<td>2.8</td>
<td>13.6</td>
<td>2.6</td>
<td>16.0</td>
<td>2.6</td>
</tr>
<tr>
<td>R10</td>
<td>3.2</td>
<td>10.4</td>
<td>2.1</td>
<td>12.0</td>
<td>2.0</td>
</tr>
</tbody>
</table>

*median of 4 of the 5 days*
however, an estimate of water consumption may be derived from the presented data.

Median response data of the individual Ascending group subjects for each experimental condition are presented in Fig. 1. The upper portion of Fig. 1 depicts pre-CS (pre-signal) rates of bar-pressing and relative rate indexes of bar-pressing. Changes in shock intensity did affect pre-CS rates of bar-pressing, but the magnitude of most effects was small. Pre-CS rate of bar-pressing was suppressed at 20 v in each subject relative to the rate of bar-pressing at other intensities during both ascending sequence and the descending sequence of shock intensities. In each subject, pre-CS rate of bar-pressing was lower at 10 v during the descending sequence of shock intensities than at 10 v during the ascending sequence. Pre-CS rate of bar-pressing for R14B and R6 was also lower at 5 v and 2.5 v during descending sequence shock intensities than comparable ascending sequence shock intensities. Although rate of bar-pressing for all Ascending group subjects at a given intensity was usually lower during the descending sequence than during the ascending sequence, pre-CS rates of R15B and R6 generally did increase as shock intensity decreased.

Changes in shock intensity also affected the relative rate indexes of bar-pressing of the Ascending group subjects. The initial shock intensities during the ascending sequence did not produce consistent or large detectable effects upon the relative rate index of bar-pressing. At 20 v, however, the median relative rate indexes ranged between -0.47 and -0.58 showing partial but not total
Fig. 1. Intensity of shock function for the three Ascending group subjects. Upper small figures present bar-press data of individual subjects. Lower small figures present lick data of individual subjects. Each data point for each measure depicts the median performance for all sessions during each shock intensity except initial tone baseline (0 v) and the initial 2.5 v condition. The initial tone baseline data represents the median of the final five tone sessions. The initial 2.5 v shock intensity data represents the median of the final 15 sessions at that shock intensity. Filled shapes represent pre-CS responses per minute. Open shapes represent the relative rate index. Dotted lines and solid lines represent the ascending sequence of shock intensities.
suppression of the bar-pressing rate during the CS (pre-shock signal). During the descending sequence of shock intensities the relative rate of bar-pressing remained moderately suppressed at 10 v for R15B and R6, and it was slightly accelerated for R14B. The relative rate index of bar-pressing at 5 v was very slightly accelerated during the descending sequence for each subject when compared to its ascending 5 v relative rate index. At 2.5 v this slight acceleration was detected again during the descending sequence.

The data presented in Fig. 1 indicate that the bar-press response rate of Ascending group subjects was not significantly affected during the ascending sequence of shock intensities until 20 v was administered. At 20 v both baseline pre-CS rate and relative rate index of bar-pressing were suppressed. Following the suppression at 20 v the two measures showed recovery of response rate towards the ascending sequence values and finally slight acceleration of the relative rate index both absolute and relative to the ascending sequence values.

The lower portion of Fig. 1 depicts pre-CS rates of licking and relative rate indexes of licking. Pre-CS lick response rates were more variable within subjects than bar-press response rates, and no consistent trends were noted among all 3 Ascending group subjects. The pre-CS lick response rates of R14B and R6 were accelerated in relation to the tone baseline during the final portion of the experiment.

The relative rate index of licking showed significant suppression at 10 v and even greater suppression at 20 v. At a given shock intensity, the ascending and descending relative rate indexes were
almost identical for R14B and R15B, whereas the relative rate index of licking was lower during the descending sequence of shock intensities for R6.

A comparison of the lick response data to the bar-press response data indicates that at 20 v for R14B and R15B the relative rate index of licking was significantly lower than the relative rate index of bar-pressing. Furthermore, comparison between the relative rate indexes reveals that although almost no suppression of bar-pressing was detected in any subject at 10 v during the ascending sequence of shock intensities, suppression of licking did occur consistently at 10 v in each subject during both sequences of shock intensities.

Median response data of the individual Descending group subjects for each experimental condition are presented in Fig. 2. The upper portion of Fig. 2 depicts pre-CS rates of bar-pressing and relative rate indexes of bar-pressing. Changes in shock intensity affected pre-CS rates of bar-pressing but the magnitude of most effects was small. All Descending group subjects showed suppression of pre-CS bar-pressing at 20 v. Other intensity effects upon pre-CS bar-pressing were inconsistent during the descending sequence of shock intensities between subjects.

The data presented in Fig. 2 indicate that relative rate indexes of bar-pressing were almost totally suppressed during exposure to 20 v during the descending sequence of intensities, and also, in subjects R16B and R17B, during the ascending sequence. The relative rate index of bar-pressing of each of the 3 Descending group subjects, however, was higher during the ascending sequence exposure to 20 v than the
Fig. 2. Intensity of shock function for the three Descending group subjects. Upper small figures present bar-press data of individual subjects. Lower small figures present lick data of individual subjects. Each data point for each measure depicts the median performance for all sessions during each shock intensity except initial tone baseline (0 v) and the initial 20 v condition. The initial tone baseline data represents the median of the final five tone sessions. The initial 20 v shock intensity data represents the median of the final 15 sessions at that shock intensity. Filled shapes represent pre-CS responses per minute. Open shapes represent the relative rate index. Dotted lines and solid lines represent the descending sequence of shock intensities.
descending sequence exposure to 20 v.

Subjects R16B and R17B showed similar relative effects between the descending sequence and ascending sequence relative rate indexes of bar-pressing at both 10 v and 5 v. Subject R10 also showed an increase in the relative rate index of bar-pressing as shock intensity decreased (except at 2.5 v) but descending sequence values were higher than ascending sequence values.

The lower portion of Fig. 2 depicts pre-CS rates of licking and relative rate indexes of licking. Following introduction of shock, each of the 3 Descending group subjects showed a gradual increase in pre-CS rates of licking throughout the experiment.

During both the descending sequence and the ascending sequence the relative rate index showed severe suppression of licking at both 20 v and 10 v with almost consistent total suppression at 20 v. At 5 v and 2.5 v during the descending sequence the relative rate index showed recovery of licking during the CS; however, during the ascending sequence at 5 v the effects were not consistent.

A comparison of the lick response data to the bar-press response data indicates that for each Descending subject consistently at 20 v and 10 v, and frequently at 5 v, the relative rate index of licking was significantly lower than the relative rate of bar-pressing at the same shock intensity.

Caution is required in comparing the results of the Ascending group subjects to the results of the Descending group subjects since the experimental design was not counterbalanced for number of days of exposure to each shock intensity. For example, if 2.5 v and 5 v

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were considered low shock intensities, and if 10 v and 20 v were considered high shock intensities, then the Ascending group received high intensity shock for 45 days whereas the Descending group received high intensity shock for 75 days.

One result which suggests that some of the sequential effects might have occurred independent of such confounding was that the relative rate index of bar-pressing was much higher at 20 v for Ascending group subjects than for Descending group subjects. Another general result which avoids the potential effects of confounding was the differential suppression observed between bar-pressing and licking, since it was observed in both groups of subjects.

Consistent differential relative rate indexes were obtained between bar-pressing and licking at 10 v and 20 v shock intensities. The data presented in Fig. 3 and Fig. 4 compare relative rate indexes between bar-pressing and licking for the Ascending group subjects and the Descending group subjects for each session at 10 v. The Ascending group data depicted in Fig. 3 indicates that the lick response rapidly suppressed during the CS when 10 v shock was first introduced whereas the bar-press response appeared to be relatively insensitive to the increase in shock intensity. During the descending sequence at 10 v both bar-pressing and licking showed some recovery from the suppression observed at 20 v (not shown in Fig. 3); however, the lick relative rate index remained lower than the bar-press relative rate index for 2 of the 3 subjects. In 92% of the 88 pairs of observations at 10 v in the Ascending group, the relative rate index of bar-pressing was greater than the relative rate index of licking.
Fig. 3. Relative rate index of bar-pressing (open circles) and relative rate index of licking (open triangles) for each Ascending group subject for each session at 5 v and 10 v during the ascending sequence of shock intensities and at 10 v during the descending sequence of shock intensities.
Fig. 4. Relative rate index of bar-pressing (open circles) and relative rate index of licking (open triangles) for each Descending group subject for the final 15 sessions at 20 v and each session at 10 v during the descending sequence of shock intensities and for each session at 10 v during the ascending sequence of shock intensities.
A similar effect is shown in Fig. 4 for the Descending group at 10 v. The lick response rate of R17B and R10 remained suppressed following 20 v shock while the bar-press response rate did recover toward baseline. All 3 subjects in the Descending group showed more suppression of licking than bar-pressing during the ascending sequence at 10 v. (Again note that other shock intensities were administered between the two series of 10 v shock.) In 87% of the 86 pairs of observations at 10 v in the Descending group, the bar-press relative rate index was greater than the lick relative rate index.

In summary, the bar-press relative rate index was larger than the lick relative rate index in 89.6% of the 174 pairs of observations at 10 v. For 4 of the subjects the observed effect was consistent, and the difference between relative rate indexes was large. Subjects R14B, R15B, and R10, in particular, showed the differential suppression effect in every 10 v observation; and R17B showed the effect in all but two observations at 10 v.

At 20 v the same differential effect between relative rate indexes was consistently observed in all subjects except R6. The magnitude of the observed differences was smaller since both responses were severely suppressed at that shock intensity.

When bar-pressing was almost totally suppressed the number of reinforcements received decreased to almost zero. This result was frequently observed at 20 v. However, although some suppression of bar-pressing was detected in most subjects at 10 v, generally the number of reinforcements delivered during the signal remained within the range of the number of reinforcements delivered during the pre-CS.
and the post-CS intervals for each subject.

DISCUSSION

Licking was suppressed more frequently and more extensively than bar-pressing during the signal preceding response-independent shock. This differential suppression of responding during the pre-shock signal was most evident at 10 v when generally moderate or no suppression of bar-pressing occurred while relatively extensive suppression of licking occurred. The differential suppression effect was also detected at 20 v but the magnitude of the difference between relative rate indexes was not as large as at 10 v, since both behaviors were severely suppressed during the pre-shock signal. Finally, the differential suppression effect was occasionally observed during low intensity shock (2.5 v and 5 v) following high intensity shock (10 v and 20 v).

The observed differential suppression effect was not the result of local changes in reinforcement density during the pre-shock signal, a variable to which polydipsic behavior is quite sensitive. Although the number of reinforcements during the pre-shock signal at 20 v was lower than during the control pre-CS interval, the number of reinforcements during the pre-shock signal at 10 v did not systematically differ from the number delivered during the pre-CS interval. Yet the differential suppression effect was observed consistently at both 20 v and 10 v.
The differential suppression effect was not a statistical artifact resulting from differential effects of shock upon the pre-CS response rate. The data in Fig. 1 and Fig. 2 indicate that there were no consistent differences between changes in the pre-CS rate of bar-pressing and changes in the pre-CS rate of licking during the shock conditions of the experiment.

The observed differential suppression effect was not due to delivery of shock through the mouth while the subject was licking, an event which would undoubtedly be severely punishing. A protective relay circuit prevented shock onset prior to isolation of the shielded drinkometer circuit. Furthermore, in this laboratory, in an unpublished experiment similar in basic design to the present one, the differential suppression effect was observed in one of two rats during shock extinction sessions following several signaled response-independent 20 v shock sessions during which the water spout had not been available. Since the water spout had not been present during shock sessions, accidental primary shock punishment of the lick response could not have occurred. The bar-press relative rate index and the lick relative rate index recovered at the same rate in the second rat.

One analysis which can account for the observed differential suppression effect assumes that in the present experiment pressing the bar was more reinforcing than licking the water spout. One method of testing this assumption would consist of determining how much behavior these events could independently maintain. Falk (1966) demonstrated that, in the presence of an intermittent food
reinforcement schedule, the opportunity to lick a water source could sustain the emission of some other behavior. Unfortunately, Falk did not attempt to assess the relative reinforcing magnitudes of the opportunity to bar-press for food and the opportunity to bar-press for water while in the presence of an intermittent food reinforcement schedule.

The assumption that the relative magnitude of reinforcement is one variable which may control relative rates of responding during a pre-shock signal has been made in the interpretation of several other studies where differential suppression of responding was observed during a pre-shock signal. For instance, Geller (1960) reported that food-deprived rats responding for a milk solution showed less response suppression than water-deprived rats responding for water when other conditions were held constant. The data were interpreted as showing that the opportunity to respond for milk was more reinforcing than the opportunity to respond for water.

A similar analysis in terms of relative reinforcement value was made by Brady and Conrad (1960) when it was observed that brain-stimulation reinforced behavior was more resistant to suppression than food-reinforced responding (in monkeys) or water-reinforced responding (in rats).

Stein, Sidman, and Brady (1958) found less suppression as the pre-shock stimulus duration increased relative to non-pre-shock stimulus durations. They suggested that the tendency for responding to be suppressed during a pre-shock stimulus is increasingly attenuated as an increased degree of suppression would lead to fewer
reinforcements during the pre-shock stimulus.

Lyon (1963) reported that pigeons showed less suppression in the presence of a pre-shock stimulus during a VI 1 min component of a multiple schedule than during a VI 4 min component of the schedule. Blackman (1968b) found that when bar-press rates in rats were held constant, response suppression was greater as reinforcement rate decreased.

In past studies the comparison of the effects of a pre-shock stimulus upon rate of one response (A) to rate of another response (B) has been made between subjects, within subjects during multiple schedules, or within subjects over successive sessions. In the present study, however, the effects of a pre-shock stimulus were observed upon two responses which were concurrently available to the subject. The one common suggestion in the interpretations of these studies is that if the opportunity to emit one response (A) is relatively less reinforcing than the opportunity to emit a different response (B), and if all other conditions are held constant, the first response (A) will be more suppressed during a pre-shock stimulus than the second response (B).

On the basis of these earlier different lines of evidence it appears reasonable to assume that in the present study at least some of the observed differential suppression effect was directly related to the relative reinforcing value of licking the water spout as opposed to bar-pressing while on an intermittent food reinforcement schedule.

The differential suppression effect may be magnified when response rates are calculated in terms of absolute responses emitted per
total minutes of a sampled interval, in particular the pre-shock interval, due to the fact that if there is a greater absolute tendency for suppression of Response A than Response B during the interval, then time previously spent in the emission of Response A becomes available for the emission of Response B. Under these conditions, the resultant relative rate index could be attenuated since the statistic does not correct for changes in the "time available" or opportunities to emit a response. Distributions comparing pre-CS IRTs with CS IRTs would be useful in this type of analysis, but unfortunately those data were not recorded in the present experiment.

Future research designs should include a measure of the conditional probabilities of responding as well as the absolute response rate. Analysis of the conditional probabilities of responding during the pre-shock signal in a signaled response-independent shock paradigm may resolve some of the reported contradictions between the effects of response-contingent shock and response-independent shock. Reported differences between the procedures may be due to the differences between the suppressive effects of the procedures upon the opportunities to emit the consequated operant, rather than upon the operant response itself. Such an analysis may be applied to Blackman's (1968a; 1968b) data which indicated that amount of suppression during a pre-shock signal was a function of baseline response rate. In particular, Blackman reported that high response rate baselines were more suppressed than moderate and low rate baselines. The potential relative increase in opportunities for emitting the consequated operant due to suppression of collateral...
behavior would be greater for initially low rate operant baselines than high rate baselines.

At mild shock intensities, it seems likely that weak collateral behaviors may be suppressed easily, whereas the maintained operant baseline behavior may not be suppressed easily. The observed result of the signaled response-independent shock procedure upon the operant baseline has been little suppression, no suppression, or even acceleration. Perhaps analysis of the effects of signaled response-independent shock upon collateral behavior would provide greater understanding of such apparently divergent results.

The present data indicated differential suppression would occur between two observed response classes. It seems quite possible that, had other response classes been observed, differential suppression might have been detected among bar-pressing, licking, and the other observed responses. If the present analysis is relevant the degree of differential suppression would be determined by both the absolute and the relative reinforcing value of the opportunity to emit those other responses.

Although past studies Hoffman, Fleshler, and Jensen (1963); Hendry and Van-Toller (1965) did not include observations of changes in collateral behavior during the pre-shock stimulus, it is interesting that the differential suppression analysis could account for their results. In particular, stimulus conditions most similar to those prevailing at time of shock delivery would be the most suppressive. In both studies, however acceleration was detected while subjects were in the presence of stimulus conditions which would be mildly
suppressive in relation to some of the other stimulus conditions during the experiment. Perhaps collateral behaviors were suppressed under those conditions, an effect which would produce an increase in opportunities for the emission of the baseline operant response and thereby produce the observed acceleration.

Acceleration reported in other studies may also be amenable to the differential suppression analysis. Ray and Stein (1959) reported rats' bar-pressing rates were accelerated during a 200 Hz tone when shock was presented only at the termination of a 1000 Hz tone. Leitenberg (1966) reported acceleration of pigeons' key-pecking rates during a pre-time-out (TO) period signaled by a change in key color when, during other portions of the session, a change to a different key color preceded shock presentation. Leitenberg attributed the acceleration to the pairing of the pre-TO key color with TO presentation. An alternative account of the results of each study would be that the observed acceleration in both studies was due to moderate stimulus generalization of the suppression tendency which could have produced the differential suppression effect.

The present data and analysis support Blackman's (1968a) observations and interpretations of the rate of changes in collateral behavior at mild shock and/or relatively long CS durations in producing acceleration during the CS on a DRL schedule. Although consistent acceleration was not observed in the present study, there may be three reasons both Finocchio (1963) and Blackman (1968a) observed the acceleration effect, none of which would detract from the present analysis. First, an animal could emit collateral behavior.
during most of the time spent on a DRL schedule (Hodos, Ross, and Brady (1962); Laties, Weiss, Clark, and Reynolds (1965); Laties, Weiss, and Weiss (1969). If the CS were only mildly suppressive, the collateral behaviors may be suppressed while the opportunities for bar-pressing would greatly increase. This relative increase in time available for bar-pressing on a DRL schedule would generally be much greater than that increase in the present study. Second, collateral behaviors on DRL schedules appear to perform mediating roles controlling operant response rates, perhaps more than on other schedules. Removal of these discriminative stimuli controlling response rate per se, while other discriminative stimuli for emitting the response remain present, could provide an additional basis for the observed acceleration effects. Finally, the shock intensities selected in the present study may have been too weak or too strong to be optimal for acceleration of bar-pressing during the pre-shock signal. If the shock intensity were too weak, neither bar-pressing nor licking would be suppressed as was frequently observed at 5 v; whereas, if the shock intensity were too strong, both responses would be suppressed as was frequently observed at 10 v. The possibility that an intermediate intensity between 5 v and 10 v would result in acceleration of the bar-pressing during the pre-shock signal is currently being investigated.

Although the present study was directed primarily towards examining the relation between the observed rates of bar-pressing and collateral licking during the signal preceding response-independent shock, it also provided some data indicating that initial exposure
to relatively mild shock intensities may attenuate the suppressive effects of later exposure to relatively high shock intensities.

In particular this effect may be observed in a comparison between the Ascending group's and Descending group's relative rate index of bar-pressing at 20 v. These data support other results showing such attenuation effects (Azrin, 1960a, 1960b; Azrin and Holz, 1961; Miller, 1960; Karsh, 1963; Hendry and Van-Toller, 1965; Hake, Azrin, and Oxford, 1967.)

In conclusion, the major results of the present study indicated that signaled-response independent shock can produce changes in rates of collateral behavior as well as explicitly reinforced operant behavior. The generality of the differential suppression interpretation of the data is limited, however, due to several factors. The only major parameters varied in the present study were shock intensity and sequence of shock intensities. Subjects were only one strain of rats. Finally, the only collateral behavior investigated was licking at a continuously available water bottle. The data warrant systematic replication.
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