COMPARISONS BETWEEN VARIABLE-INTERVAL AND FIXED-INTERVAL SCHEDULES OF ELECTRIC SHOCK DELIVERY

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Responding maintained in rats under a variable-interval 35-sec food schedule was suppressed more by 60-sec and 240-sec fixed-interval schedules of shock delivery than by 60-sec and 240-sec variable-interval schedules of shock delivery. When the delivery of shock was preceded by a 5-sec visual stimulus, little overall response suppression was found with either fixed-interval or variable-interval schedules. In a third experiment, the percentage of occasions on which a cue preceded each shock delivery was varied from 0% to 100%. For the fixed-interval shock condition, the most suppression occurred with the 0% treatment, the least with 100%, and an intermediate amount with the 50% treatment. For the variable-interval groups, the most suppression occurred in the 50% condition, the least in the 100% group, and an intermediate amount with 0%.

In considering variables that are related to the effects of noxious events on responding, the schedule of these events merits particular attention. Depending on the schedule conditions under which electric shocks are presented, they may decrease behavior (Azrin, 1956), maintain behavior (Kelleher and Morse, 1968), or serve as a discriminative cue for the occurrence of behavior (Holz and Azrin, 1961). The schedule of electric shock can also affect the pattern of responding (Azrin, 1956). Azrin trained pigeons to respond under a variable-interval (VI) food schedule that maintained a high uniform response rate. When a fixed-interval (FI) schedule of electric shock was superimposed on the VI baseline, responding was negatively accelerated before delivery of shock. A variable-interval schedule of electric shock, on the other hand, led to a low but uniform rate of responding.

Another aspect of schedules of shock is the degree to which the distribution of shocks in time affects response suppression. Camp, Raymond, and Church (1966) studied response

suppression in rats that were exposed either to VI or fixed-ratio (FR) schedules of electric shock, with shock frequency, intensity, and duration held constant. The group of rats exposed to the VI schedule of shock showed the greater degree of response suppression. Similarly, Azrin (1956) reported more suppression in pigeons during the component of a multiple schedule associated with a VI schedule of shock than during a component associated with an FI schedule of shock. Together, these studies suggest that variable-interval schedules of shock lead to greater response suppression than fixed-interval schedules of shock. A study by Ferraro (1967) suggested otherwise. Ferraro found more suppression in groups of rats exposed to FI schedules of shock delivery than to comparable VI schedules.

Clearly, the question of the differential suppressive properties of fixed-interval and variable-interval schedules of electric shock remains an issue for further research. The purpose of the present studies was to extend the analysis of VI and FI schedules of electric shock delivery by comparing response suppression in groups of rats exposed either to FI or VI schedules of response-dependent shock. Analyses based on the discriminability of the availability of electric shock under each schedule were undertaken to isolate variables that may account for the observed schedule differences.

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GENERAL METHOD

Subjects

Sixty naive male Sprague-Dawley rats, each weighing 225 to 250 g, were housed individually and were maintained at 80% of free-feeding weight on Purina Laboratory Rat Chow, with water freely available in the home cage.

Apparatus

Each of two Grason-Stadler sound-attenuated operant rat chambers, Model E3125A-300, contained a response lever, pellet dispenser, and white masking noise. Associated electro-mechanical equipment was located in a room separate from the experimental room, and responses were recorded by counters and cumulative recorders. Electric current to the grid floor and the response lever was provided by a Grason-Stadler shock generator (Model E6070B) and grid scrambler. Noyes laboratory rat food pellets (0.045 g) served as positive reinforcers.

Procedure

Pretraining and acquisition. After seven days of limited access to food for weight reduction to 80% of their free-feeding weight, the rats were introduced into the operant chamber and the lever-press response was shaped. Two sessions of 100 pellets each under an FR 1 schedule ensued. The chambers were illuminated by a dim houselight, and the start of each session was marked by the onset of white masking noise, which remained on during the entire session.

Ten daily half-hour sessions on a VI 35-sec food schedule followed. Two VI 35-sec scheduling tapes, each with a different distribution of intervals, arranged food delivery and were alternated daily. One tape consisted of random sequences of 0, 10, 20, 30, 40, 50, 60, and 70 sec, and the second tape consisted of random sequences of the intervals 10, 30, 40, and 60 sec. By the end of 10 daily sessions, the rats displayed stable uniform response rates.

Response-dependent electric shock. After acquisition, the animals were assigned to shock treatment groups and were studied for 10 daily sessions during which concurrent food (VI 35-sec) and shock (VI or FI) schedules were in effect as described in Experiments 1, 2, and 3. The groups were matched on the

basis of mean response rates during the last five acquisition sessions. The VI tapes that arranged shock delivery consisted of random sequences of the intervals 0, 20, 40, 60, 80, 100, and 120 sec for the VI 60-sec schedule and of random sequences of the intervals 0, 120, 240, 360, and 480 sec for the VI 240-sec schedule. Throughout the experiments, the rats were studied during six daily sessions per week.

EXPERIMENT 1

Procedure

Twenty four rats were assigned to one of four conditions according to factorial combinations of two schedules of shock delivery, a variable-interval schedule and a fixed-interval schedule, and two frequencies of shock, 60 sec or 240 sec. Shock intensities were 0.3 mA and 0.4 mA for the 60-sec and 240-sec groups, respectively. Shock duration was 0.5 sec for all of the groups.

RESULTS AND DISCUSSION

The response suppression data are reported as suppression ratios ($a/b + a$), where a is the number of responses emitted during a shock session, and b is the mean number of responses emitted during Days 8, 9, and 10 of acquisition. A ratio of 0.50 indicates no suppression, while a ratio of 0.00 indicates total response suppression.

Figure 1 shows mean suppression ratios for each group. The greater suppression in the FI groups was verified in a significant effect due to schedules of shock delivery ($F = 22.43$; $df = 1/16$; $p < 0.001$). Individual performances by the animals in each condition closely

Fig. 1. Mean suppression ratios during shock in Experiment 1. Each data point represents the mean of six animals.

reflected the group curves shown in Figure 1. Figures 2 and 3 show cumulative records of responding for animals that were representative of the VI 60-sec and FI 60-sec shock conditions, respectively.

Figure 2 shows for a single animal the transient response suppression and recovery that was characteristic of all the animals in the VI 60-sec group. Some disruption of the uniform rate of responding was apparent during the first shock session, a dramatic reduction of responding occurred during the second shock session, and recovery of responding was observed during the third shock session. By the end of the fourth shock session, responding recovered to near baseline levels.

Figure 3 shows for a representative FI 60-sec shock animal cumulative records of re-

sponding during the last baseline session and for each of the shock sessions. Compared to animals in the VI 60-sec condition, response suppression was less transient. Figure 3 shows dramatic response suppression during the earlier experimental sessions with a gradual recovery of responding occurring during Days 6 and 7. Although baseline levels of responding were not reached by Day 10, it is clear that full response recovery may have occurred if further experimental sessions were provided.

EXPERIMENT 2

One important difference between VI and FI schedules of shock delivery is the degree to which the delivery of shock is discriminable under each schedule. Whereas FI schedules of shock may provide temporal cues for impending shocks, few, if any, temporal cues are provided by VI schedules of shock. If the discriminability of the availability of shock is an important variable for understanding the observed differences in response suppression associated with each schedule in Experiment 1, then by making the delivery of shock under each schedule equally discriminable, the differences between the suppressive properties of the schedules should be significantly attenuated.

In Experiment 2, response suppression was compared in rats exposed to VI and FI schedules of shock in which the priming, or availability, of each shock was preceded by the onset of a 5-sec visual preshock stimulus.

METHOD

Procedure

Two groups of three rats each were formed on the basis of the mean number of responses emitted during the last five acquisition sessions. One group of rats was assigned to a VI 60-sec schedule of shock delivery, while the second group was assigned to an FI 60-sec shock condition.

Shock intensity was 0.3 mA, and shock duration was 0.5 sec. The preshock stimulus consisted of a 5-sec onset of three indicator lights located directly above, to the right, and to the left of the response lever. Offset of the stimulus primed the shock, *i.e.*, arranged that the next response would produce shock, so that the rats never obtained a shock in the

Fig. 2 Cumulative records of responding during Session 10 of baseline and Sessions 1, 2, 3, and 4 of VI 60-sec shock for a representative animal of Experiment 1. Shocks are indicated by the downward pip of the event pen; food, by pips of the response pen; and lever presses, by the vertical movement of the response pen.

Fig. 3. Cumulative records of responding during Session 10 of baseline and Sessions 1 through 10 of FI 60-sec shock for a representative animal of Experiment 1. Shocks are indicated by downward pips of the event pen; food, by pips of the response pen; and lever presses, by the vertical movement of the response pen.

presence of the stimulus. The stimulus added 5 sec to the inter-shock interval so that the minimum interval was actually 65 sec rather than 60 sec as was employed in Experiment 1.

RESULTS AND DISCUSSION

Figure 4 shows the mean suppression ratios per session for each group. Note the overall lack of response suppression. Figure 5 shows cumulative records of representative animals from each group. The records for Day 10 show the effects of the 5-sec stimulus. The rats in both groups maintained a steady rate of responding in the absence of the preshock stimulus, ceased responding during the stimulus, produced a shock and then resumed their uniform rates of responding. The cumulative records of earlier sessions show the gradual acquisition of the discriminative behavior.

Two aspects of the data of Experiment 2 are noteworthy. It appears that differences in the suppressive properties of VI and FI schedules of shock are attenuated when the delivery of shock is equally discriminable for each schedule. Furthermore, in contrast to

Fig. 4. Mean suppression ratios during shock in Experiment 2. Each data point represents the mean of three animals.

Fig. 5. Cumulative records of responding during Session 10 of baseline and Sessions 1, 2, 3, and 10 of shock for representative animals of the FI 60-sec and VI 60-sec 100% conditions of Experiment 2. Shocks are indicated by the downward pips of the response pen; food, by pips of the event pen; and responses, by the vertical movement of the response pen.

the VI and FI 60-sec groups in Experiment 1, little response suppression occurred in Experiment 2. These findings suggest that an important variable for understanding differences in response suppression associated with different schedules of shock is the degree to which the availability of response-produced shock is made discriminable by properties of the schedule.

EXPERIMENT 3

In terms of the relationship between the discriminability of the delivery of shock and response suppression, the data of the previous studies are somewhat inconsistent. Whereas FI schedules of shock, for which temporal cues specify the availability of shock, lead to more response suppression than VI schedules for which little, if any, temporal discriminations are possible (Experiment 1), schedules under which each shock is clearly specified by an exteroceptive stimulus (Experiment 2) lead to less overall response suppression than comparable schedules without the 5-sec preshock stimuli (Experiment 1). Experiment 3 further examined the relationship between the discriminability of the delivery of shock and response suppression.

METHOD

Procedure

Thirty rats were assigned to six experimental conditions in such a way as to equate response rates over the last five acquisition sessions. The six conditions were factorial combinations of two schedules of shock delivery, VI 65-sec and FI 65-sec, and three probabilities of stimulus presentation, 0%, 50%, and 100%. Animals in each condition received the same number of shocks per session, but the percentage of occasions on which the 5-sec stimulus preceded shock differed. In the 0% condition, shocks were never preceded by the stimulus; in the 100% condition, all of the shocks were preceded by the stimulus; and in the 50% condition, half of the shocks, in random order, were preceded by the stimulus.

RESULTS AND DISCUSSION

Figure 6 shows mean suppression ratios for each group during the nine shock sessions. As suggested by the previous studies, changes in

the probability with which the 5-sec stimulus preceded shock affected response suppression. The effect of these changes, however, was a function of the schedule under which the shocks were delivered.

Fig. 6. Mean suppression ratios during shock in Experiment 3. Each data point represents the mean of five animals.

For animals exposed to the VI schedule of shock delivery, the most suppression occurred when the probability with which the stimulus preceded shock was 50%, the least when the probability was 100%, and an intermediate amount when the probability was 0%. For the FI schedule of shock delivery, on the other hand, the most suppression occurred when the probability of occurrence of the preshock stimulus was 0%, the least when the probability was 100%, and an intermediate amount when the probability was 50%.

Figure 7 shows the relationship between response suppression and the probability of occurrence of the preshock stimulus for each schedule of shock delivery. The apparent opposed curvature for these functions is supported by trend analyses. The effect of schedules was significant ($F = 10.88$; $df = 1/24$; $p < 0.01$). The quadratic trend for cues failed to achieve statistical significance, although the schedule X quadratic trend was significant ($F = 5.27$; $df = 1/24$; $p < 0.05$). This suggests that the quadratic trend for cues failed to achieve significance because the quadratic trends associated with each schedule opposed each other and hence, cancelled each other out.

The performance of individual animals closely reflected the group data. Figures 8,

Fig. 7. The effect of changes in the probability with which the 5-sec stimulus preceded shock delivery upon suppression of responding.

9, and 10 show for representative animals cumulative records of responding during the 0%, 100%, and 50% conditions, respectively. In general, a greater degree of response suppression was observed in the 0% and 100% conditions than for comparable groups in the earlier studies.

Considering Figures 8 and 9, the performances of animals exposed to the 0% and 100% conditions were similar to the performances of comparable animals in Experiments 1 and 2. Considerably more suppression occurred when the probability of occurrence of the preshock stimulus was 0% than 100%. During the latter treatment, the animals maintained steady rates of responding in the absence of the 5-sec preshock stimulus and ceased responding during its onset. Although the difference between response suppression under FI and VI schedules of shock delivery

Fig. 8. Cumulative records of responding during Session 10 of baseline and Sessions 1, 2, 3, and 9 of VI 65-sec and FI 65-sec shock for representative animals of the 0% conditions of Experiment 3. Shocks are indicated by the downward pips of the response pen; food, by pips of the event pen; and responses, by the vertical movement of the response pen.

Fig. 9. Cumulative records of responding during Session 10 of baseline and Sessions 1, 2, 3, and 9 of shock for representative animals of the FI 65-sec and VI 65-sec 100% conditions of Experiment 3. Shocks are indicated by the downward pips of the response pen; food, by pips of the event pen; and responses, by vertical movement of the response pen.

Fig. 10. Cumulative records of responding during Session 10 of baseline and Sessions 1 through 9 for an animal representative of the VI 65-sec 50% condition of Experiment 3 and during Session 10 of baseline and Sessions 1, 2, 3, 4, and 9 of shock for an animal representative of the FI 65-sec 50% condition of Experiment 3. Shocks are indicated by downward pips of the response pen; food, by pips of the event pen; and responses, by the vertical movement of the response pen. The arrows indicate the cessation of responding during the preshock stimulus.

was not as dramatic as in Experiment 1, the difference was in the same direction, with animals in the former group showing somewhat greater degrees of suppression of responding.

The performances of animals exposed to the VI and FI 50% conditions are of considerable interest. When the 5-sec stimulus was present before 50% of the shock deliv-

eries, the animals responding under the FI schedule of shock delivery showed transient response suppression followed by response recovery. With VI schedules of shock delivery, responding was severely suppressed during the nine shock sessions. The cessation of responding during onset of the 5-sec stimulus (arrows) indicates the acquisition of discriminative behavior on the part of the animals exposed to the FI 50% condition.

GENERAL DISCUSSION

The present findings indicate that differences in the suppressive properties of FI and VI schedules of electric shock presentation may be described in terms of the discriminability of shock delivery under each schedule. The present data also suggest that the relationship between the discriminability of shock delivery and response suppression may be nonmonotonic.

When the delivery of shock is highly discriminable, less overall response suppression occurs than when the delivery of shock is not so discriminable (100% *vs* 0%; 100% *vs* 50%). However, when the delivery of shock is only somewhat discriminable, *i.e.*, imprecise temporal discriminations, more response suppression occurs than when the delivery of shock is not at all discriminable (FI *vs* VI schedules of shock delivery). If the discriminability of shock under FI schedules is increased by the addition of a preshock stimulus on 50% of the shock occasions, less suppression occurs than if no external stimulus is provided (FI 50% *vs* FI 0%). On the other hand, if the exteroceptive preshock stimulus is added to a VI schedule of shock delivery on 50% of the shock occasions so that the delivery of shock is imprecisely rather than not at all specified, an increase in response suppression occurs (VI 0% *vs* VI 50%).

Although further studies are clearly in order, the present data indicate the need to modify existing theories (*e.g.*, Denny, 1971; Estes, 1969; Seligman, 1968) that assume that discriminable, or "predictable", shock situations are less aversive than shock situations in which the advent of shock is not discriminable. As noted by Denny, if no cues reliably predict impending shock, the organism remains in chronic "fear", and the aversiveness of the situation is increased. With the avail-

ability of appropriate discriminative stimuli, temporal or otherwise, "fear" may become more localized and opportunities to "relax" between shocks are provided, thus leading to a decrease in the relative aversiveness of the shock situation.

The empirical basis for this assumption derives from studies (*cf.* Seligman, Maier, and Solomon, 1971) that dealt exclusively with highly discriminable and highly indiscriminable shock situations. Rats and humans preferred signalled to unsignalled response-independent shock, immediate to delayed shock, and rats developed more ulcers when a signal did not reliably predict the advent of shock. If a wider range of degrees of predictability had been studied, perhaps a pattern of results more compatible with the present finding would have emerged. Under certain conditions, for example, animals may select the arm of a t-maze that contains no information about the advent of shock, and rats exposed to unsignalled shock may develop fewer gastric ulcers than rats provided with a signal on some of the shock occasions.

The suggestion of nonmonotonicity in aversive situations raises the question of whether a similar U-shaped function holds for positive reinforcement. Indeed, contemporary proponents of the Law of Effect (Rachlin and Herrnstein, 1969) would predict similar results for both positive and negative situations. A number of studies (Hendry, 1969; Mitchell, Perkins, and Perkins, 1965; Prokasy, 1956; Wyckoff, 1952) found that animals preferred signalled to unsignalled positive reinforcers. Hendry, for example, using pigeons and a concurrent chain procedure, found a decided preference for a multiple fixed-ratio fixed-ratio schedule to a mixed fixed-ratio fixed-ratio (mixed FR FR) schedule, with probability of reinforcement held constant.

On the other hand, Herrnstein (1964) showed that pigeons prefer VI to FI schedules of positive reinforcement, and Fantino (1967) showed that pigeons would change over from an FR schedule to a mixed FR FR schedule, with the mean ratio requirement held constant. Thus, while highly discriminable food deliveries are more preferable than indiscriminable food deliveries, moderately discriminable food deliveries are preferred to an even lesser extent, again suggesting a nonmono-

tonic relationship between the discriminability of the availability of reinforcement and the utility of positive reinforcement.

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