EFFECTS OF ELECTRIC-SHOCK DELIVERY ON SCHEDULE-INDUCED WATER INTAKE: DELAY OF SHOCK, SHOCK INTENSITY, AND BODY-WEIGHT LOSS

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In each of four experiments, schedule-induced water intake in the rat was studied under fixed-time 40-sec food delivery. Experiments I and II studied the temporal relationship between response-independent electric-shock delivery and licking. Shock was delivered under a variable-time 60-sec schedule. A lick-dependent delay was imposed so that licking and shock delivery were systematically separated in time by a minimum of 1 to 15 sec. Over a wide range of shock intensities, the data failed to reveal a consistent delay-of-shock effect. Similar shock intensities led to similar reduction of water intake at each delay of shock interval. Experiments III and IV studied the effects of body-weight loss on water intake during independent shock delivery. In Experiment III, shock was delivered under variable-time 60-sec with a minimum separation between shock and licking of 5 sec. In Experiment IV, shock was delivered under variable-time 180-sec. The minimum separation between shock and licking was 10 sec. In each study, the resistance of water intake to suppression by shock delivery increased as the degree of body-weight loss increased. Schedule-induced water intake was affected more by shock when the animal was maintained at 90% of free-feeding weight than at 70%.

Key words: polydipsia, electric shock, body weight, rats

The effects of electric-shock delivery on schedule-induced water intake depend on the contingency between shock and other behavior. Shock that is dependent on lever pressing either has little, if any, effect on water intake (Bond, Blackman, and Scruton, 1973; Hymowitz and Freed, 1974) or increases it (Dunham, 1971; Hymowitz, 1973). In either case, food-maintained lever pressing may be suppressed by the shock.

Comparable shock that is delivered independently of lever pressing can reduce induced-water intake while having relatively little effect on lever pressing (Bond *et al.*, 1973; Hymowitz and Freed, 1974). It is important to note that the two modes of shock delivery differ in their temporal relationship to induced licking. While lever-press-dependent shock can hardly occur while the animal is licking, independent shock may be delivered at any time during a session. Since animals typically spend most of

the session engaged in postpellet licking (*cf.* Falk, 1961), independent shock is probably often delivered in close temporal association to licking. Might not the frequent and close association between independent shock delivery and licking account for the reduction of schedule-induced water intake?

The available data do not adequately answer this question. While shock that is dependent on schedule-induced licking suppresses licking (Bond *et al.*, 1974; Dunham, 1971), licking also is reduced by independent shock that is separated in time from licking by a minimum of 5 sec (Hymowitz and Freed, 1974). To clarify the relationship between licking and independent shock delivery, Experiments I and II varied the temporal separation of shock and licking. If reduction of water intake is a function of the association between shock and licking, shock that is delivered close in time to licking should produce a greater reduction of water intake than shock that never occurs in close temporal association to licking.

Recent studies of the effects of the delay of response-dependent shock on food-maintained responding (*e.g.*, Baron, 1965; Camp, Raymond, and Church, 1967) showed that response suppression was a monotonic function of the delay. As the delay between the response and

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shock delivery increased, response suppression decreased. The delay of independent shock delivery in Experiments I and II should reveal a similar effect. Failure to obtain a delay-of-shock effect would suggest that the reduction of polydipsia by independent shock delivery is not necessarily due to a specific association between shock and licking.

Experiments III and IV employed minimum delays between shock and licking of 5 and 10 sec, respectively. They also assessed the effects of body-weight loss on the resistance of schedule-induced water intake to the suppressive effects of shock delivery. Body-weight loss generally increases the resistance of food-maintained responding to dependent (*e.g.*, Azrin, 1960, Azrin, Holz, and Hake, 1963) and independent (Millenson and deVilliers, 1972) shock. Experiments III and IV determined whether the degree of body-weight loss similarly affects the resistance of schedule-induced water intake to suppression.

GENERAL METHOD

Subjects

Three male albino Sprague-Dawley rats (320 to 340 g) served in Experiments I and II. Rats 2 and 3 also served in Experiment III. Three other male albino Sprague-Dawley rats (288 to 298 g) served in Experiment IV. All animals were housed individually and were maintained, except where otherwise stated, at 80% of initial free-feeding weight on Purina Laboratory Rat Chow. Water was freely available in the home cage.

Apparatus

A Grason-Stadler, sound-attenuated, operant rat chamber (Model 1101) was used in Experiments I, II, and III. A BRS-Foringer operant chamber (RC-002) located in a sound-attenuated experimental room was used in Experiment IV. Each operant chamber contained an electrically disconnected response lever, pellet dispenser (0.045 g Noyes pellets), and white masking noise.

Water was available within the chambers from a stainless-steel spout accessible from a slot cut in the chamber wall. The spout was connected to a calibrated cylinder and Grason-Stadler lickometer located outside of the chamber.

Electric shock to the grid floors was provided

by a Grason-Stadler shock generator (Model 700) and grid scrambler in Experiments I, II, and III, and by a BRS-Foringer shock generator (SG-901) and grid scrambler in Experiment IV. Recording and programming were by electromechanical equipment, counters, and Gerbrands cumulative recorders.

Procedure

Following 10 to 20 daily sessions under fixed time 40-sec (FT 40-sec) food delivery, electric shock was introduced concurrently under variable time 60-sec (VT 60-sec) in Experiments I, II, and III and under VT 180-sec in Experiment IV. Blocks of successive food-and-shock sessions alternated with blocks of successive food-alone sessions. Shock duration remained constant (0.50 sec), while shock intensity was increased between blocks of shock sessions in Experiments I and II, and held constant in Experiments III and IV. In each study, a lick-dependent delay was imposed so that shock was never delivered while the animal was licking. White masking noise was on during each experimental session. Each session terminated after 30 min (Experiments I, II, and III) or 20 min (Experiment IV).

EXPERIMENT I

Procedure

After subjects were reduced to 80% of their free-feeding weights and given 20 sessions under FT 40-sec food delivery, a VT 60-sec shock-delivery schedule was introduced. A lick-dependent delay was imposed so that a minimum of 1, 5, 10, or 15 sec separated licking and shock. Separate programming tapes, each with a range of 15 to 105 sec, assured that an equal number of shocks was arranged under each delay condition. Rats 1 and 2 were exposed to an ascending order of shock delay; Rat 3 was exposed to a descending order.

Five successive shock-and-food sessions alternated with three successive food-alone sessions. The shock intensity was increased between blocks of shock sessions to an intensity that reduced polydipsia to 25% of the preceding baseline session.

RESULTS AND DISCUSSION

Figure 1 shows the mean percentage of pellets that were followed by licking during the final baseline sessions that preceded each block

Fig. 1. The mean and range of the percentage of pellets followed by licking during baseline (0.0-mA shock intensity) and shock sessions of Experiment I. The baseline data points represent the mean and range of the final sessions that preceded each block of shock sessions. The shock data points represent the mean and range for five successive sessions at a constant shock intensity.

of successive food-and-shock sessions and for the mean of each block of five successive food-and-shock sessions. During the shock-free baseline sessions, the animals consistently engaged

in postpellet licking. As shown in Figure 1, the percentage of pellets followed by licking during baseline consistently approached 100% throughout the study for each animal.

The postpellet licking led to substantial water intake during the session. The mean water intake for Sessions 16 to 20 of acquisition were 20.80, 29.40, and 11.00 ml for Rats 1, 2, and 3, respectively. The numbers in the parentheses of Figure 2 indicate water intake during the food-alone session that preceded each block of successive food-and-shock sessions. The baseline water intake for Rat 3 was relatively low but remained fairly constant throughout the study. The water intakes for Rats 1 and 2 increased substantially during the study. At one point, Rats 1 and 2 consumed 40 and 49 ml per session, respectively.

Figure 2 also shows the mean per cent of baseline water intake for each shock condition. For Rat 2, the shock intensities required to reduce water intake to 25% of the preceding baseline session were 0.80, 0.50, 0.80, and 0.80 mA for 1-, 5-, 10-, and 15-sec delays, respectively. The degree of reduction of induced-water intake under 0.50- and 0.60-mA shock was similar for the 1-, 10-, and 15-sec delay conditions, each yielding close to 40% of baseline. With the 5-sec delay between shock and licking, 0.50-mA shock reduced water intake by more than 80%.

The data for Rat 3 were quite similar to those for Rat 2. The shock intensities required to reduce polydipsia to 25% of baseline were 0.60, 0.60, 0.80, and 0.50 mA for 1, 5, 10, and 15 sec, respectively. While the performances of Rats 2 and 3 generally suggest that reduction of polydipsia was a function of shock intensity, they did not reveal a delay-of-shock effect. Schedule-induced water intake was similarly reduced under each delay of shock condition.

The performance of Rat 1, on the other hand, was quite different. When shock and licking were separated by a minimum of 1 sec, 0.25-mA shock reduced water-intake to 10% of baseline. With a 15-sec lick-dependent delay, a shock intensity of 1.60 mA was required to reduce water-intake to 25% of the preceding baseline session.

Figure 3 shows representative cumulative records for Rat 2 of responding under 0.60-mA shock delivery under each delay condition. As already noted in Figure 2, the most marked reduction of polydipsia occurred under the 5-sec delay. The frequency of engaging in postpellet licking (see also Figure 1) and the duration of the licking bursts were substantially diminished. More consistent and persistent

postpellet licking is shown for the other delay conditions.

During the food-and-shock sessions, licking often followed shock (Figure 3). Direct observation revealed that the animals ate the pellet but often did not engage in licking until a shock was delivered. The animals rarely drank in response to shock alone. When they did, it was only two or three quick licks.

When the shock was removed, water intake rapidly returned to baseline levels. The only "residual" effect of shock appeared to be a hesitancy to initiate licking during the first few minutes of the postshock session. Once the animals began to engage in postpellet licking, they continued to do so for the remainder of the session. This "warm-up" effect often was found during the second postshock session. By the third postshock session, the animals consistently engaged in postpellet licking throughout the session (Figure 1).

EXPERIMENT II

In Experiment I, two animals showed similar degrees of reduction of polydipsia under each delay-of-shock condition. A third animal revealed a marked difference in performance as a function of the shock delay. It is not clear whether the marked reduction of water intake for Rat 1 under the 1-sec delay condition was due to the close temporal association between shock and licking, *per se*, or to animals' often marked reaction to the first exposure to shock (*cf.* Azrin and Holz, 1966). Experiment II studied further the relationship between shock delivery and licking. The animals were alternately exposed to 1-sec and 15-sec delay-of-shock intervals in order to clarify the interpretation of Experiment I.

Procedure

Following five additional FT 40-sec food delivery sessions, the three animals of Experiment I were again exposed to VT 60-sec shock. The order of testing was as follows: Rat 1, 0.80 mA, 1 sec; 0.80 mA, 15 sec; 1.00 mA, 15 sec; 1.00 mA, 1 sec; 0.30 mA, 1 sec; and 0.30 mA, 15 sec; Rat 2, 0.60 mA, 1 sec; 0.60 mA, 15 sec; 0.30 mA, 15 sec; and 0.30 mA, 1 sec; Rat 3, 0.50 mA, 15 sec; 0.50 mA, 1 sec; 0.30 mA, 1 sec; and 0.30 mA, 15 sec. Three successive food-and-shock sessions alternated with three successive food-alone sessions.

Fig. 2. Mean percentage of baseline water intake and range for each shock condition of Experiment I. Each data point represents the mean of five sessions at a constant shock intensity. The numbers in parentheses indicate water intake (ml) during the preceding food-alone session.

RESULTS AND DISCUSSION

Figure 4 shows the reduction of water intake for each experimental condition. The numbers in parentheses indicate water intake during the previous baseline session. The performances of Rats 2 and 3 correspond closely to their performance in Experiment I. The reduction in water intake was a function of shock intensity but not shock delay. As shock intensity increased, water intake decreased. Rat 1 also failed to reveal a delay-of-shock effect. For each shock intensity, similar degrees of reduction were found at the 1-sec and 15-sec delays. Moreover, Rat 1 showed considerable resistance to shock under the 1-sec delay. Whereas 0.25-mA shock led to near-total cessation of licking in Experiment I, 0.30 mA reduced intake to only 55% of baseline in Experiment II.

The reduction of water intake, again, was due to the omission of some, and shortening of other, licking episodes. Figure 5 shows that the percentage of pellets followed by licking, in most instances, decreased as the intensity of shock increased.

EXPERIMENT III

Experiments I and II suggested that reduction of induced-water intake was a function of shock intensity but not of the temporal proximity of shock and licking. Experiment III studied another variable, the degree of body-weight loss, which may influence the effects on schedule-induced water intake of response-independent shock.

Procedure

Rats 2 and 3 of the previous studies were alternately reduced to 70% and 90% of their original free-feeding weights. Seven days were required for weight changes from one extreme to the other. During that time, the animals were not studied in the chamber. The order

Fig. 3. Cumulative records for Rat 2 of Experiment I of responding during Session 57, 0.60 mA, 1-sec delay; Session 81, 0.60 mA, 5-sec delay; Session 97, 0.60 mA, 10-sec delay; and Session 121, 0.60 mA, 15-sec delay. The vertical movement of the response pen indicates licks; the downward movement of the response pen, pellets; and the downward deflection of the event pen, shock delivery. The response pen reset to the bottom of the scale after 550 responses.

Fig. 4. Mean percentage of baseline water intake and range for each shock condition of Experiment II. Each data point represents the mean of three successive sessions at a constant shock intensity. The numbers in parentheses indicate water intake (ml) during the preceding food-alone session.

of testing for Rat 2 was 90%, 70%, and 90%. For Rat 3, the order was 70%, 90%, 70%, and 90%. Three successive food-alone sessions under FT 40-sec food delivery alternated with five successive FT 40-sec food and VT 60-sec shock (0.60 mA) sessions. The minimum delay between shock and licking was 5 sec.

Fig. 5. The mean and range of the percentage of pellets followed by licking during baseline (0.0-mA shock intensity) and shock sessions of Experiment II. The baseline data points represent the mean and range of the final sessions that preceded each block of shock sessions. The shock data points represent the mean and range for three successive sessions at a constant shock intensity.

RESULTS AND DISCUSSION

Figure 6 shows the mean per cent of baseline water intake for each experimental condition. The number at the base of each column indi-

Fig. 6. Mean percentage of baseline water intake and range for each shock condition of Experiment III. Each data point represents the mean of five successive sessions at a constant shock intensity. The number at the base of each column indicates the water intake (ml) during the preceding food-alone session.

icates water intake during the preceding baseline session. The data clearly indicate that the resistance of schedule-induced water intake to suppression by response-independent shock increased as the degree of body-weight loss increased. This resistance was also reflected in the greater percentage of postpellet licking under 70% body weight than 90% (Figure 7). Figure 8 shows for Rats 2 and 3 cumulative records of responding under baseline and shock for each body-weight condition. Clearly, the postpellet licking behavior was much more affected under 90% than 70% of free-feeding body weight. While baseline licking patterns were quite similar under each body weight, the frequency and duration of postpellet licking during shock was much lower under 90% of body weight.

Fig. 7. The mean and range of the percentage of pellets followed by licking during the baseline (0.0-mA shock intensity) and shock sessions of Experiment III. The baseline data points represent the mean and range of the final three sessions that preceded each block of shock sessions. The shock data points represent the mean and range for five successive sessions at a constant shock intensity.

EXPERIMENT IV

Experiment IV systematically replicated the results of Experiment III in three naive animals. A lick-dependent delay was used so that licking and shock delivery were separated by 10 sec. These data, again, showed that polydipsia may be substantially reduced by shock that is not associated closely in time with licking.

Procedure

Following weight reduction to 80% of their free-feeding weights and 10, 20-min sessions under FT 40-sec food delivery, a VT 180-sec schedule of electric shock (0.40 mA) delivery was introduced. The distribution in time of shock ranged from 10 to 350 sec. A delay was imposed so that licking and shock were separated in time by a minimum of 10 sec. Blocks of five successive food-and-shock sessions alternated with blocks of three food-alone sessions.

The three animals also were studied under 70% and 90% of body weight. Body weight was altered from one extreme to the other by seven day's alteration of home-cage feeding.

Fig. 8. Cumulative records for Rats 2 and 3 of Experiment III of responding under baseline and shock for 90% and 70% of body weight. For Rat 2, the records are, from top to bottom, for Sessions 156, 161, 148, and 169. For Rat 3, the records are, from top to bottom, for Sessions 156, 161, 148, and 153. See the caption to Figure 2 for the manner of recording.

During these occasions, the animals were not studied in the chamber.

RESULTS AND DISCUSSION

Figure 9 shows the mean water intake for each animal. At 80% of body weight, VT 180-sec shock markedly reduced water intake. When the shock was removed, water intake returned to preshock levels.

As in Experiment III, the effects of body-weight loss on the resistance of water intake during shock were fairly straightforward. As shown in Figure 9, at 70% of body weight, shock had relatively little effect on intake. At 90%, on the other hand, water intake was markedly reduced.

Cumulative records of the performance of Rat 5 under each body weight condition are shown in Figure 10. Under 80% of body weight, licking abruptly ceased when shock was introduced in Session 1. During Sessions 2, 3, and 4, licking was virtually eliminated. In Session 5, schedule-induced licking recovered. Under 90% of body weight, licking was markedly reduced with no recovery during the five sessions. In the 70% condition, licking was relatively unaffected throughout the five sessions.

GENERAL DISCUSSION

The present findings document further the reducing effect of response-independent electric shock delivery on schedule-induced water intake (*cf.* Bond *et al.*, 1973; Hymowitz and Freed, 1974). It should be noted, however, that shock delivery in the present studies was not strictly independent of responding. Due to the lick-dependent delay contingency, licking occasionally postponed shock delivery. It was possible for the animals to avoid all of the shocks by licking throughout the session. However, there was little evidence to suggest that licking was under the control of the avoidance contingency. Licking declined substantially during the shock sessions and was not differentially affected by the length of time that shock was postponed.

Experiments I, II, III, and IV suggest that reduction of schedule-induced water intake cannot readily be explained by some fortuitous association between shock and licking. It seemed not to matter whether shock and licking were separated by 1, 5, 10, or 15 sec. Similar shock intensities led to similar levels of suppression under each delay interval. These data support Church's (1969) conclusion that shock has suppressive properties over and above that which may be attributed to the association or contingency between responding and shock delivery.

Why, then, does response-independent shock so severely disrupt schedule-induced water in-

Fig. 9. Mean water intake (ml) and range during the baseline and shock sessions for each animal of Experiment IV. Columns with hatch marks indicate the mean water intake for three successive food-alone sessions. The initial baseline data point indicates the mean for Sessions 8, 9, and 10. The shock points indicate the mean of five successive sessions under a constant shock intensity.

take while comparable lever-press-dependent shock has little, if any, effect on water intake (*cf.* Bond *et al.*, 1976; Hymowitz and Freed, 1974)? The differential effects of response-dependent and independent shock may be consistent with studies (Hoffman and Fleshler, 1965; Hunt and Brady, 1955) that showed broader generalization of suppression for independent than for dependent shock delivery. Suppression of food-maintained lever pressing by dependent shock was confined to the period during which the stimulus associated with shock was presented. Under independent shock, considerable suppression occurred in the absence as well as in the presence of the discriminative stimulus. Thus, dependent shock seems specifically to affect lever pressing with little generalization to other behavior (*e.g.*, Hymowitz and Freed, 1974). Independent

shock, on the other hand, can affect a wider range of behaviors. Schedule-induced water intake may be particularly sensitive to the "generalized" effects of shock.

While the delay-of-shock interval did not affect the suppression of water intake, shock intensity and body-weight loss were highly influential. As the intensity of shock increased, water intake decreased (Experiments I and II). As body-weight loss increased, the resistance of water intake to suppression by independent shock increased (Experiments III and IV). The effects of each of these variables on schedule-induced water intake are similar to their effects on food-maintained lever pressing. Church (1969) showed that suppression of lever pressing by independent shock delivery was a direct function of shock intensity. Millenson and deVilliers (1972) reported that the resist-

Fig. 10. Cumulative records for Rat 5 of responding during Sessions 25 to 29, 70% of body weight; Sessions 14 to 18, 80% of body weight, and Sessions 36 to 40, 90% of body weight. The shock intensity was held constant (0.40 mA). The vertical movement of the response pen indicates the licks; the downward movement, pellets; and the resetting of the response pen, shock delivery. The response pen also reset to the bottom of the scale after 550 responses.

ance of lever pressing during independent shock (conditioned suppression paradigm) was directly related to the degree of body-weight loss.

Following an extensive review of the literature, Myer (1971) noted that too much of our knowledge about noncontingent aversive stimulation is based on studies in which food-maintained lever pressing was the dependent variable. He questioned the generality of these findings to other responses and organismic conditions. The present studies successfully extended the generality of some of the lever-press findings to another response, water intake, and another class of behavior, schedule-induced or adjunctive behavior (*cf.* Falk, 1971).

REFERENCES

- Azrin, N. H. Effects of punishment intensity during variable-interval reinforcement. *Journal of the Experimental Analysis of Behavior*, 1960, 3, 123-142.
- Azrin, N. H. and Holz, W. C. Punishment. In W. K. Honig (Ed.), *Operant behavior: areas of research and application*. New York: Appleton-Century-Crofts, 1966. Pp. 380-447.
- Azrin, N. H., Holz, W. C., and Hake, D. F. Fixed-ratio punishment. *Journal of the Experimental Analysis of Behavior*, 1963, 6, 141-148.
- Baron, A. Delayed punishment of a runway response. *Journal of Comparative and Physiological Psychology*, 1965, 61, 131-134.
- Bond, N. W., Blackman, D. E., and Scruton, P. Suppression of operant behavior and schedule-induced licking in rats. *Journal of the Experimental Analysis of Behavior*, 1973, 20, 375-383.
- Camp, D. S., Raymond, G. A., and Church, R. M. The temporal relationship between response and punishment. *Journal of Experimental Psychology*, 1967, 74, 114-123.
- Church, R. M. Response suppression. In B. A. Campbell and R. M. Church (Ed.), *Punishment and aversive behavior*. New York: Appleton-Century-Crofts, 1969. Pp. 111-156.
- Dunham, P. J. Punishment: method and theory. *Psychological Review*, 1971, 78, 58-70.
- Falk, J. L. Production of polydipsia in normal rats by an intermittent food schedule. *Science*, 1961, 133, 195-196.

- Falk, J. L. The nature and determinants of adjunctive behavior. *Physiology and Behavior*, 1971, **6**, 577-588.
- Hoffman, H. S. and Fleshler, M. Stimulus aspects of aversive control: the effects of response contingent shocks. *Journal of the Experimental Analysis of Behavior*, 1965, **8**, 89-96.
- Hymowitz, N. Effects of response-dependent and independent electric shock on schedule-induced water intake. *Psychological Record*, 1973, **23**, 487-497.
- Hymowitz, N. and Freed, E. X. Effects of response-dependent and independent electric shock on schedule-induced polydipsia. *Journal of the Experimental Analysis of Behavior*, 1974, **22**, 207-213.
- Hunt, H. F. and Brady, J. Some effects of punishment and intercurrent "anxiety" on a simple operant. *Journal of Comparative and Physiological Psychology*, 1955, **48**, 305-310.
- Millenson, J. R. and deVilliers, P. A. Motivational properties of conditioned anxiety. In R. M. Gilbert and J. R. Millenson (Eds.), *Reinforcement*. New York: Academic Press, 1972. Pp. 97-128.
- Myer, J. S. Some effects of noncontingent aversive stimulation. In F. R. Brush (Ed.), *Aversive conditioning and learning*. New York: Academic Press, 1971. Pp. 469-536.

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