CONCURRENT PERFORMANCES: A BASELINE FOR THE STUDY OF CONDITIONED ANXIETY¹

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Three rats were trained to lever press on concurrent random interval 2-min random interval 2-min schedules of milk reinforcement. With a 5-sec changeover delay, relative response rate matched the relative reinforcement duration associated with each lever. A stimulus, during which unavoidable shocks occurred at random intervals, was superimposed on this concurrent baseline, and shifts in preference were found. However, data from this procedure were ambiguous, apparently confounded by shock-elicited response bursts. Termination of the shocks during the stimulus resulted in a rapid recovery of matching, which was preceded by a brief facilitation of responding on the less-preferred lever. The procedure was then changed to a conventional conditioned anxiety paradigm with a variable duration pre-shock stimulus. A marked shift in relative response rate towards the preferred lever was found in all three rats; that is, responding on the preferred lever was far less suppressed during the pre-shock stimulus than responding on the less-preferred lever.

Varying the duration of the grain reinforcer for responses under a single-key variable-interval (VI) schedule, Catania (1963) found that response rates of pigeons failed to change systematically with reinforcer duration. However, when subjects were allowed to choose between two keys associated with different durations of the reinforcer on concurrent VI 2-min VI 2-min schedules with a 2-sec changeover delay (COD), relative response rate on each key came to match the relative reinforcer duration associated with that key.

These results were confirmed and extended in an experiment by Neuringer (1967), who showed that whereas key preference in concurrent chain schedules varied directly with reinforcer duration, absolute rates of responding on each key in the terminal links were comparatively insensitive to changes in reinforcer duration. Neuringer noted that amount and frequency of reinforcement appear to influence the relative strength of a response among a set of response alternatives far more than the absolute strength of a response in isolation.

Other experiments indicate that not only parameters of reinforcement, but also param-

eters of punishment have a greater effect on responding in a concurrent than in a single-response situation. Azrin and Holz (1966) demonstrated that an intensity of shock that only slightly suppressed responding in a single-key punishment situation, when used as punishment of one response in a concurrent situation, produced complete suppression of that response, accompanied by an increase in the rate of the concurrent response. Similar results have been found using timeout, or a loud noise as the punishing stimulus (Azrin and Holz, 1966). However, when both component responses are punished in concurrent VI VI schedules in which reinforcement rates are asymmetrical, the absolute rate of each response is reduced but their relative rates are not affected. The organism's preference still matches relative reinforcement rate, even when overall response rate is considerably suppressed (Holz, 1968).

Catania (1966) emphasized that the isolated operant is a special behavioral case, and the analysis of behavior must also be directed to the interaction of two or more operants. Yet, in the study of emotional behavior, for example, much of the experimental work stems from Estes and Skinner's (1941) demonstration of "conditioned anxiety", and has been concerned with the disruption of a single operant, and with the identification and quantification of variables affecting this disruption (Davis,

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1968; Lyon, 1968). We have elsewhere (Millenson and de Villiers, 1970) suggested that a principal effect in conditioned emotional states is the modification of positive and negative reinforcement variables. In view of their sensitivity to these variables, concurrent schedules would seem to provide a particularly appropriate baseline for the study of such states. In common with Estes (1969), we regard the response suppression of conditioned anxiety as the behavioral consequence of a modification of the value of positive reinforcers maintaining the behavior. According to this view, superimposing a signal paired with shock on a food-maintained behavior results in a temporary decrease in the reinforcement value of food, and consequently a suppression of the behavior. Single-response studies showing that the conditioned emotional response (CER) is most pronounced on low-incentive, low-drive, and lean reinforcement schedules support such a motivational interpretation of conditioned suppression (Millenson and de Villiers, 1970).

It follows that if the suppressive effects of the CER are due to temporary losses in the value of the maintaining baseline reinforcer, this should affect two-response concurrent performances by affecting both schedules equally. By arranging different reinforcing values for the two schedules, thus producing asymmetric choice, superimposing a partial CER on such a baseline would be expected to enhance preferences (based on relative rates) still further during anxiety. The present study tested this prediction on a two-response concurrent performance in which the value of the two schedules was varied by varying the duration of the reinforcer associated with each response (*cf.*, Catania, 1963).

METHOD

Subjects

Three experimentally naive hooded rats, approximately three months old at the beginning of the experiment, were maintained at 80% of their free-feeding body weights for the duration of the study.

Apparatus

A standard two-lever Campden Instruments CI410 rodent operant conditioning chamber was housed in a ventilated metal chest that masked external noises. The chamber mea-

sured 13.5 in. long by 12 in. wide by 11 in. high (34 by 36 by 28 cm). On the front wall, protruding 0.5 in. (1.8 cm) into the chamber, were situated two 1.25-in. (3.7-cm) wide stainless steel levers, 2.28 in. (5.7 cm) above the grid floor and 4.5 in. (11.2 cm) apart. A downward force of 5 g (0.05 N) operating through a movement of about 3 mm sufficed to close a reed relay attached to this lever as it moved past a fixed magnet. Centered above the levers were situated three 2.8-w pilot lamps. The chamber was illuminated by a 2.8-w houselight situated in the middle of the roof of the box.

Between the two levers at floor level was a recessed food tray covered by a door of clear acrylic plastic. This door operated a switch, enabling the latency and number of tray entries made by the experimental animal to be measured. The reinforcer consisted of 0.1 cc of sweetened condensed milk (one part milk to four parts water) presented in a dipper, which was raised into an opening in the floor of the food tray, operating the tray door switch. The subject was thus given a set duration of access to the milk that was independent of the latency of tray-entry.

A white light illuminated the tray as soon as milk was available and was turned off as soon as the dipper was lowered.

The conditioned stimulus (CS) signal consisted of synchronous flashes of the three stimulus lights mounted on the front wall and five-per-second clicks. The unconditioned stimulus (US-) was scrambled electric shock delivered through a grid floor consisting of 16 bars spaced 0.5 in. (1.3 cm) apart. The shock source was a Campden Instruments constant current generator that produced half sine wave current at 50 Hz.

Procedure

Concurrent lever-press training and stabilization of matching. The rats were trained by reinforcement of successive approximations to a lever press to press either of the levers for 2-sec access to the condensed milk. Care was taken to shape the rats' lever-pressing behavior such that the topographies of the responses on the two levers were as similar as possible. As soon as all three rats had been trained to press both of the levers, they were exposed to concurrent random-interval 15-sec (RI 15-sec) RI 15-sec schedules (Millenson, 1963). Reinforcements were scheduled randomly with a mean

interval of 15 sec and a minimum interval of 1 sec between reinforcements. Two independent RI 15-sec schedules were arranged concurrently on the two levers and were simultaneously available to the animal. After two sessions on this schedule, when lever pressing was well established and there was frequent alternation of responding between the levers, the schedule was gradually changed to concurrent RI 2-min RI 2-min schedules with a 2-sec reinforcer duration on both levers. After five 1-hr sessions on this schedule, a stable pattern of responding had developed.

For the next four sessions, duration of the reinforcer was kept at 2 sec on both levers but a 2-sec changeover delay (COD) was introduced. The COD specifies a minimum time after a changeover from one lever to the other, during which a response cannot be reinforced (Catania 1966). The COD in this case was timed from the first response on the lever after a changeover. Frequent alternation of responding was reduced and response runs of approximately COD duration on each lever developed.

The 2-sec COD was retained for a further 10 sessions, but different durations of the reinforcer were associated with each lever. The reinforcer durations were changed from 2-sec/2-sec to 4.5-sec/1.5-sec. The shorter reinforcer duration was scheduled for the lever that had been slightly preferred by the animal in the previous training.

Since matching of relative response rates to relative reinforcer durations was not obtained within these 10 sessions, the COD was increased to 5 sec for a further 10 sessions.

Addition of fixed-period danger signals (i.e., signals in which there was a high probability of non-contingent shock presentation). The neutrality of the CS was tested by presenting it alone for four sessions, and observing whether there was any disruption of baseline performance. The CS duration was fixed at 3 min and the intertrial interval (ITI) was 6 min long, pre-CS response rate being measured in the last 3 min of the ITI. The first pre-CS measure period began a variable duration of time after the start of each session.

For the next 26 sessions, the CS was associated with unavoidable foot shock presented independently of the animal's behavior. This danger-period procedure was essentially the same as that described by Azrin (1956, procedure C). During the fixed 3-min danger

signal, 0.25-mA, 0.5-sec shocks were administered randomly with a minimum interval of 22.5 sec and a mean interval of 1.5 min between shocks. The animal thus received on the average two shocks within the danger period, but occasionally received no shocks at all, or sometimes received up to four shocks in the period. This procedure avoided the temporal discriminations characteristics of fixed-duration warning signals terminating with a single US⁻ presentation (Millenson and Hendry, 1967). Thus, the CS was conveniently of fixed duration, but the organism was unable to discriminate when a US⁻ was to occur. Azrin (1956) reported that such a procedure produced the same response suppression as the conventional conditioned anxiety paradigm.

Extinction of fixed-period suppression (10 sessions). In view of ambiguous results from the fixed-period CS procedure, there followed 10 sessions in which the shocks were no longer presented during the CS and the rats were allowed to recover from conditioned suppression.

Variable-duration CS (40 sessions). When the response rates during the CS of all three animals had completely recovered to pre-CS levels, the procedure was changed to a conventional conditioned anxiety paradigm in which a single 0.5-sec shock was paired with the termination of each warning signal. The same complex stimulus was used as the warning signal. Temporal discriminations were avoided by a variable-duration warning period, with a minimum duration of 30 sec and a mean duration of 2 min. The probability of termination of the CS with shock after any 30-sec period was constant at 0.25. The ITI also varied randomly with a minimum of 2 min and a mean duration of 4 min. The 2 min immediately before each warning signal provided a pre-CS measure period. Shock intensity was decreased from 0.4 mA to 0.25, 0.125, and 0.075 mA in consecutive 10 session blocks.

RESULTS

The data are reported as two ratios. One of these, the relative response rate on the lever associated with the 4.5-sec reinforcer duration (hereafter abbreviated as the 4.5-sec duration lever), is a measure of preference and calculated as the number of 4.5 second lever responses divided by the total number of re-

sponses in the session. The other ratio, response rate during CS divided by the response rate during CS plus response rate during pre-CS period, is a measure of suppression and is calculated separately for each lever.

By the end of training with reinforcer durations of 1.5 sec and 4.5 sec and a 5-sec COD, all subjects were closely matching relative response rates to relative reinforcer duration. This matching performance is shown in the leftmost panel of Figure 1 as relative 4.5-sec response rates that, before shock was introduced, hover near the 0.75 point both in and out of the fixed-duration CS period. The addition of random unavoidable shocks during the CS initially eliminated all responding. Eventually, when some responding outside the CS returned (left-center panel), nearly all of it occurred on the 4.5-sec lever. This marked shift to the 4.5-sec lever continued for about 10 sessions, but as response rate outside the CS period recovered from the initial generalized suppression, the relative response rate at the same time returned to the 0.75 matching point, as shown by the squares in the right-center panel in Figure 1.

Relative response rates during the CS period itself were variable and inconsistent among rats. The right-center panel of Figure 1 indicates that over the last five sessions of the danger-period procedure, R5 and R7 made most of their responses during the CS period on the preferred 4.5-sec lever. The other subject, R6, however, showed very erratic preference, sometimes responding more frequently on the 1.5-sec lever.

The left panel of Figure 2 shows the corresponding suppression ratios for both responses during the last five sessions of the danger-period CS. As these data indicate, the preferences shown in Figure 1 were associated with strongly suppressed rates on both levers.

Removal of the shocks from the danger period (rightmost panels, Figure 1 and Figure 2) resulted in a rapid recovery of responding from conditioned suppression during the CS on both levers. Nevertheless, that recovery was consistently faster for all three animals on the less-preferred 1.5-sec lever (triangles). For at least one session (fourth, fifth, or sixth) in the extinction process, all three rats showed a marked facilitation in CS response rate on the 1.5-sec lever.

In contrast to the inconsistent data obtained

Fig. 1. Relative response rates on the lever associated with 4.5-sec reinforcer duration during three danger-period phases: pre-shock CS alone, shock presentations during CS, and extinction. Complete data are shown for CS-alone and extinction phases; data from Sessions 11 to 15, and 22 to 26 (the last five) are shown for the shock phase.

in the danger-period procedure, the consistent effect of the variable-duration CS-US pairings on preference is shown in Figure 3 for four progressively decreasing shock values. Again, pairing the US with the CS produced a generalized suppression of all responding and a shift towards the 4.5-sec lever both in and out of the CS period. Return to the original relative response rate level of 0.75 in the pre-CS period progressed gradually throughout the diminishing shock-intensity series, approaching completion at the weakest shock used (right panel of Figure 3).

The consistent elevation of the solid circles above the squares in all panels of Figure 3 indicates that a considerable shift in preference towards the 4.5-sec lever was found during the CS at each shock intensity. Indeed, a shock value as low as 0.075 mA, 0.5 sec was sufficient to shift the animal upward from the relative response rate in the pre-CS period. At this shock intensity, the corresponding suppression ratios of Figure 4 show that respond-

Fig. 2. Suppression ratios for the last five sessions of danger-period shock presentations, and for the 10 subsequent sessions of extinction. Solid triangles represent data based on responses to the lever associated with 1.5-sec reinforcer duration. Open circles represent data based on responses to the lever associated with 4.5-sec reinforcer duration.

ing on the 4.5-sec lever had almost fully recovered to its pre-CS rate for R5 and R6, but responding on the 1.5-sec lever was still very suppressed.

Fig. 3. Relative response rates on the lever associated with 4.5-sec reinforcer duration during the last five sessions of the variable-duration warning signal at each of four diminishing shock intensities. Open squares represent data taken in a 2-min pre-CS period. Solid circles represent data taken during the CS warning signal.

Unfortunately, reinforcement rates during the CS and pre-CS periods were not separately recorded, although it is clear that at a relative response rate of about 0.9, when responding was considerably suppressed on the 1.5-sec lever, relative reinforcement rate would vary from the 0.5 baseline level. Thus, it is not possible to say whether relative response rate matched relative number of seconds access to the reinforcer during both the pre-CS and CS periods.

An analysis of variance using the mean suppression ratio on each lever from the last five sessions at each shock intensity showed that the differential suppression of the two responses was a reliable effect. There was a significant effect of reinforcer duration ($F = 22.33$, $df = \frac{1}{16}$, $p < 0.001$), shock intensity ($F = 19.18$, $df = \frac{3}{16}$, $p < 0.001$), and a rein-

Fig. 4. Suppression ratios for the lever associated with the 1.5-sec reinforcer duration (solid triangles) and for the lever associated with the 4.5-sec reinforcer duration (open circles) during the last five sessions at each of four diminishing shock values associated with a variable-duration warning signal.

forer duration $\times$ shock intensity interaction ($F = 4.38$, $df = 3/16$, $p < 0.025$).

The large preference in responding for the 4.5-sec lever during the variable CS paired with shock is clearly demonstrated in the cumulative record of Figure 5 for R6 at the weakest value of shock.

In spite of the probability of reinforcement of a response run on the 1.5-sec lever being much higher than the probability of reinforcement on the 4.5-sec lever during the CS, the subjects made few changeovers from the 4.5-sec lever to the 1.5-sec lever. Most of the responding on the 1.5-sec lever during the CS occurred in the first few seconds of a CS that chanced to commence (e.g., point 1) when the subject was in the middle of a response run on that lever. The tendency of the subject to complete the run to reinforcement, or until the 5-sec COD period had been completed, indicates

Fig. 5. Cumulative lever responding for R6 in the fourth session of exposure to a variable warning signal followed by 0.075-mA shock. Curves for responding on the lever associated with 4.5-sec reinforcer duration (top) and for responding on the lever associated with 1.5-sec reinforcer duration are in registration. Event pens mark reinforcement. CS onset occurs at *a*, US occurs at *b*.

the control of the COD and reinforcement over behavior.

DISCUSSION

Catania (1966) pointed out that the characteristic pattern of responding on concurrent VI VI schedules arranged with a COD consists of response runs of roughly the duration of the COD on one operandum, alternating with runs of responses on the second. When reinforcer durations are equal and frequency of reinforcement differs, changeovers occur when the probability of reinforcement on the lower rate of reinforcement lever is greater than that on the greater frequency of reinforcement lever. But when frequency of reinforcement is constant and duration is varied, the probability of reinforcement on the lever associated with the briefer duration must

reach a higher value for a changeover to occur away from the preferred lever.

In the present experiment, even though the probability of reinforcement on the 1.5-sec lever approached unity during a long CS period (since there was no limited hold arranged in the schedules), the rats almost never switched from the 4.5-sec lever to the 1.5-sec lever during the CS. There was not simply a reduction in the tendency of the animal to change schedules from either lever during the CS, but an almost complete cessation of changeovers from the 4.5-sec to the 1.5-sec lever. The cumulative curves of Figure 5 show that the increased preference for the 4.5-sec lever even disrupted the control of the COD over responding on the 1.5-sec lever. For example, at point 3 in Figure 5, the rat twice made responses on the 1.5-sec lever during the CS, but instead of beginning a response run, immediately shifted back to the 4.5-sec lever.

These results are in accord with the shift in preference predicted by Millenson and de Villiers' (1970) reinforcement decrement theory of anxiety. A reduction in the value of the positive reinforcer maintaining baseline behavior by a constant amount determined by the CS and US parameters, would result in a shift in the *relative* value of the two reinforcement schedules towards the 4.5-sec lever, and thus an increased preference for this lever during the CS.

A possible explanation of the inconsistent results obtained from R6 in the danger-period procedure is suggested by data from an experiment by Weiss and Strongman (1969). These investigators found that rats with a history of positively reinforced lever pressing showed bursts of responding immediately after the presentation of unavoidable shock in a danger-period procedure. Analysis of the data from R6 in the present study showed that over 98% of its responding on the 1.5-sec lever occurred during those danger periods in which shocks were presented. This percentage was calculated from response rates in danger periods with and without shocks. Analysis of the data obtained from the other two animals showed that a greater proportion of their responding also occurred in those danger periods in which shocks were presented, although they showed a shift in preference towards the 4.5-sec lever. It seems likely, therefore, that the data obtained from all three rats in the danger-period

procedure were confounded by shock-elicited response bursts.

An aspect of the present results that requires further investigation is the shift in preference towards the less-preferred lever when the shocks were removed from the danger periods altogether. The temporary facilitation of responding (during the CS) on the 1.5-sec lever that was found in the recovery phase is possibly a similar phenomenon to that found by Azrin (1960) after the removal of punishment. Holz (1968) found the same "punishment contrast" (Azrin and Holz, 1966) effect on both levers in a two-response situation when continuous punishment of both responses was removed. In the present experiment, however, facilitation occurred only on the 1.5-sec lever and thus cannot be explained simply in terms of the removal of adventitious punishment of all responding. Rather, the removal of aversive stimulation had a selective effect on the response that was most suppressed.

The present results provide some evidence against an explanation of conditioned anxiety in terms of the adventitious punishment of responding. According to the punishment hypothesis of conditioned suppression, reduction of lever pressing results from the adventitious correlation of shock with either a lever-press response, or with one of the components of the response chain preliminary to lever pressing (Lyon, 1968). However, this would not fully account for the shift in preference towards the 4.5-sec lever in this experiment. When the first shocks were presented there was a greater probability that they would be correlated with the chain of responses supporting responding on the 4.5-sec lever, since the relative response rate on this lever was 0.75. Therefore, this responding should have been more suppressed during the CS than responding on the 1.5-sec lever. In fact, as can be seen from the cumulative records in Figure 5, even after many sessions of shock, responding remains so suppressed the 1.5-sec lever that nearly all shocks are presented while the animal is responding on the preferred lever.

Holz (1968) found that punishment of both component responses of concurrent performances resulted in suppression of both responses, but despite considerable suppression, the relative response rate remained at the same value for each of the shock intensities used. This contradicted a study by Church and Ray-

mond (1967), which found that lever pressing reinforced on a VI 0.2-min schedule was less suppressed by VI punishment than responding on a VI 5-min reinforcement schedule. However, it is possible to account for the different findings of these two studies on the grounds that in the experiment of Holz, relative response rate matched relative reinforcement rate. Since every response was punished, the number of punishments per reinforcement would be the same on both schedules and retention of matching would be expected.

In the present experiment, relative response rate on either lever matched received relative duration of reinforcement before pairing of the shock with the CS, and thus response output per second of reinforcement was the same on both schedules. A generalized punishment of all responding by the shock should thus result in the same matching point being retained throughout suppression, rather than the upward shift in the relative response rate that was found during the CS.

However, there are a number of differences between the present experiment and that of Holz that could perhaps account for the differing results. The most important of these would appear to be the difference between the continuous punishment procedure in which shock is contingent upon a response, and the conditioned anxiety paradigm in which a single non-contingent shock is paired with a previously neutral stimulus. In the latter procedure, rate of shock does not vary directly with response rate as it does in the case of punishment. Moreover, in the conditioned anxiety procedure, since the CS periods alternate with "safe" intertrial interval periods, the schedule becomes in essence a multiple schedule. Thus, while Holz punished every response throughout the experimental session, the present procedure was a multiple concurrent schedules with variable duration components. The stimulus signalling one of these components was paired with an unavoidable shock. Numerous studies have demonstrated complex interactions between the reinforcement conditions of the components of a multiple schedule (Herrnstein, 1970).

REFERENCES

- Azrin, N. Some effects of two intermittent schedules of immediate and non-immediate punishment. *Journal of Psychology*, 1956, **42**, 3-21.
- Azrin, N. Sequential effects of punishment. *Science*, 1960, **131**, 605-606.
- Azrin, N. and Holz, W. C. Punishment. In W. K. Honig, (Ed.) *Operant behavior: areas of research and application*. New York: Appleton-Century-Crofts, 1966. Pp. 380-443.
- Catania, A. C. Concurrent performances: A baseline for the study of reinforcement magnitude. *Journal of the Experimental Analysis of Behavior*, 1963, **6**, 299-300.
- Catania, A. C. Concurrent operants. In W. K. Honig (Ed.) *Operant behavior: areas of research and application*. New York: Appleton-Century-Crofts, 1966. Pp. 213-270.
- Church, R. M. and Raymond, G. A. Influence of the schedule of positive reinforcement on punished behavior. *Journal of Comparative and Physiological Psychology*, 1967, **63**, 329-332.
- Davis, H. Conditioned suppression: A survey of the literature. *Psychonomic Monograph Supplements*, 1968, **2**, 283-291, (Whole No. 30).
- Estes, W. K. Outline of a theory of punishment. In B. A. Campbell and R. M. Church (Eds.) *Punishment and aversive behavior*. New York: Appleton-Century-Crofts, 1969. Pp. 57-82.
- Estes, W. K. and Skinner, B. F. Some quantitative properties of anxiety. *Journal of Experimental Psychology*, 1941, **29**, 390-400.
- Herrnstein, R. J. On the law of effect. *Journal of the Experimental Analysis of Behavior*, 1970, **13**, 243-266.
- Holz, W. C. Punishment and rate of positive reinforcement. *Journal of the Experimental Analysis of Behavior*, 1968, **11**, 285-292.
- Lyon, D. O. Conditioned suppression: operant variables and aversive control. *Psychological Record*, 1968, **18**, 317-338.
- Millenson, J. R. Random interval schedules of reinforcement. *Journal of the Experimental Analysis of Behavior*, 1963, **6**, 437-443.
- Millenson, J. R. and Hendry, D. P. Quantification of response suppression in conditioned anxiety training. *Canadian Journal of Psychology*, 1967, **21**, 242-252.
- Millenson, J. R. and de Villiers, P. A. *Motivational properties of conditioned anxiety*. In Symposium on schedule-induced and schedule-dependent phenomena. Toronto: Addiction Research Foundation, 1970, Vol. II. Pp. 37-100.
- Neuringer, A. J. Effects of reinforcement magnitude on choice and rate of responding. *Journal of the Experimental Analysis of Behavior*, 1967, **10**, 417-424.
- Weiss, K. M. and Strongman, K. T. Shock-induced response bursts and suppression. *Psychonomic Science*, 1969, **15**, 238-240.

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