RESPONSE CONTROL WITH TITRATION OF PUNISHMENT¹

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Pigeons and rats were exposed to multiple schedules with different schedules of electric shock superimposed on identical schedules of food reinforcement during each of two components. During one component, (adjusting-intensity) the intensity of electric shock depended on responding. Each response increased the intensity while intensity decreased between responses. During the other component (constant-intensity) the intensity was fixed at the value at which it had been adjusted at the end of the immediately preceding adjusting-intensity component. In one experiment, shock was continuous during both components. In another experiment, instead of continuous shock, a brief pulse was delivered immediately after each response. During the adjusting-intensity component of both experiments, pigeons and rats responded at a rate just sufficient to keep the shock constant (critical rate). During the constant-intensity component, responding depended on whether shock was delivered continuously or in pulses. When shock was continuous, response rate during the constant-intensity component was higher than the critical rate. When shock was pulsed, response rate during the constant-intensity component was equal to the critical rate.

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The fractional escape procedure used by Weiss and Laties (1963) with rats arranged a small decrease in electric shock intensity after each bar press. Between bar presses, shock intensity increased. A recent experiment of Rachlin and Loveland (1971) inverted the fractional escape procedure. Pigeons' key pecks and rats' bar presses (reinforced with food according to various schedules) were followed by small increments of continuously present electric shock. Between responses the shock intensity automatically decreased. These conditions established one critical response rate that would increase shock intensity so as to compensate exactly for the automatic decrease between responses. Rachlin and Loveland found that pigeons and rats, regardless of food-reinforcement schedules, responded at this

critical rate. When the critical rate was changed (by varying the rate at which shock intensity decreased) rate of responding changed immediately to the critical rate.

It has been argued that punishment does not act symmetrically to reinforcement but merely suppresses behavior (Skinner, 1953; p. 184). By this it is meant that the subject's own control over the aversive stimulus (*i.e.*, the dependency of the aversive stimulus on behavior) has nothing to do with the reduction of responding. Rather, the aversive stimulus is said to act much like physical restraint, suppressing responses when it is imposed and releasing responses when it is removed. Such an explanation could account for the Rachlin-Loveland results. The intensity of shock at any moment would either be low enough to allow a response or high enough to suppress it. But if the pigeons or rats did not respond, the shock-intensity decreased. Thus, an initial high rate of responding would drive the intensity up to a value that suppressed further responding which would, in turn, lower the intensity and allow a further response. This mechanism could have generated the observed steady rates of responding.

On the other hand, responding could have been determined, not by the intensity of shock present at the moment of each response, but by the dependency of the aversive stimulus on

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behavior. According to the latter, more molar, explanation the emission or non-emission of a response at any moment would be predicted better by the consequences of responding than by the intensity of aversive stimulation at that moment. In other words, responses could have been governed by their consequences in the punishment procedure as they are supposed to be when controlled by reinforcement.

The degree to which the dependency (of aversive stimulation on behavior) governs behavior has been tested previously by comparing aversive stimulation dependent on responding with similar aversive stimulation delivered independently of responding (Azrin, 1958; Schuster and Rachlin, 1968). Such tests have invariably found significantly greater reductions in responding with aversive stimulation dependent on responding. Thus, in typical punishment situations, the dependency of aversive stimulation on behavior governs behavior. The present experiments attempted to explore the role of dependency in regulating behavior with titration of punishment.

The initial Rachlin-Loveland procedure was modified in two ways: (a) The dependency of shock intensity on responding was periodically removed so that shock intensity remained constant regardless of response rate, and, (b) the dependency was retained but shock was not continuous. Instead it was presented briefly after each response. The intensity of the brief pulse, however, was regulated as the continuous shock intensity was regulated.

EXPERIMENT I: CONTINUOUS SHOCK

METHOD

Subjects

Four male Silver King pigeons were maintained at 80% of their free-feeding weights. The pigeons had been trained to peck a key by autoshaping (Brown and Jenkins, 1968).

Apparatus

The experimental chamber was a standard sound-insulated box (Gerbrands Co.) with an overhead light and continuously present white noise. A 0.75 in. (1.9 cm) diameter key centered 8.75 in. (22cm) above the floor could be transilluminated with red or white light and required a peck of 0.18 N to operate. Operation of the key produced a feedback click. The

reinforcer was 3-sec presentations of Purina pigeon pellets from a hopper below the key. Electric shock was delivered through a commutator on the roof of the chamber to gold wires implanted beneath the skin and anchored around the pubis bones on each side of the bird (Azrin, 1959).

When shock was scheduled it was continuously present and its intensity was controlled with a variac. The input to the variac was 60 Hz ac at 120 v. The output of the variac was boosted 4:1 by a transformer and fed through fixed and variable resistors to the pigeon. At the minimum position of the variac shaft, shock intensity was zero. The current through the pigeon increased linearly with rotation of the variac shaft. The variable resistors were adjusted so that at the maximum variac position, the output current would be about 20 mA. This current was monitored by an ammeter in series with the pigeon. In addition, a Heathkit recording voltmeter monitored voltage across the output terminals of the variac. The position of the variac shaft was controlled by a differential mechanism. One input to the differential converted pulses into upward shaft rotations of the variac. The other input converted pulses into downward shaft rotations of the variac. It required 230 pulses to drive the variac from either extreme position to the other. When the shock intensity was adjustable, each response produced an upward step of the variac shaft. A timer, producing pulses at fixed intervals stepped the shaft down. If a peck and a timer pulse occurred simultaneously the shaft remained still. When the shock intensity was not adjustable, neither response nor timer pulses moved the shaft. Each pulse (upward or downward) changed the shock intensity by 0.087 mA.

Procedure

The pigeons were given daily sessions of 36 min duration. The stimulus conditions were those of a multiple schedule with two components alternating every 3 min. The components were signalled by red and white key-lights. Reinforcement occurred according to independent 30-sec variable-interval schedules during each component (*mult* VI 30-sec VI 30-sec). The components differed with respect to whether shock intensity was adjustable. During one component (adjusting-intensity component) shock intensity decreased by one

step every 3 sec and increased by one step immediately after each response. Thus, exactly one response every 3 sec would keep the shock intensity constant. An average of 20 responses per minute would keep shock-intensity nearly constant with only small local variations. The adjusting-intensity component signalled by the red key was always the first component in a session. After 3 min of adjusting intensity the other component (constant-intensity) was presented. During the constant-intensity component, the shock remained constant at the last intensity adjusted during the immediately preceding component. Thus, 3-min periods of adjusting and constant shock intensity were alternated; the constant intensities depended on the value just previously adjusted.

The above procedure allows comparison between rates of response with shock intensity dependent on responding and with shock intensity constant. In such a comparison, the effective intensity of the constant shock should match that of the adjusting shock. Since sensitivity to shock might be expected to vary from pigeon to pigeon and for a given pigeon within a session, the periods of constant shock were kept brief (3 min) and were changed for each presentation according to the adjusted intensity. A consistent difference between response rates during the two components would more likely be due to differences in the response-shock contingencies during the components than to differences in shock intensity only.

The pigeons were exposed to the *mult* VI 30-sec schedules alone, without shock, for 32 sessions; then, the shock schedule described above was superimposed for 14 sessions; then, the shock was removed for five sessions.

RESULTS AND DISCUSSION

The upper part of Figure 1 shows rate of responding during each component of the multiple schedule for the second half of each session. For each pigeon, the last five sessions of no-shock, the 14 sessions of shock, and the five sessions of return to no-shock are included. The dotted lines, showing rate during the constant-intensity component, are higher than the solid lines showing rate during the adjusting-intensity component. Continuous shock at the adjusted intensities suppressed responding somewhat when it was superimposed independently of responding for three of the

four pigeons, but this suppression was highly variable and never as great as the suppression during the periods of shock adjustment.

Rate of responding during the adjusting-intensity component was always around 20 responses per minute, the rate just sufficient to keep shock intensity constant. This replicates the finding of Rachlin and Loveland (1971).

What bearing do these results have on the question of whether responding is controlled by the dependency of shock intensity on responding or by immediate intensity of shock? The sudden change in rate during the adjusting-intensity component in the first session of shock would lead one to suspect that some immediate property of the shock was directly controlling behavior. It would seem that a dependency should take time to have an effect. However, the consistently higher rates of responding during the constant-intensity component make it unlikely that immediate intensity of the continuously present shock was the sole regulator of responding. If the shock intensity as adjusted was just sufficient to suppress responding to 20 responses per minute, the rates of response should have been the same in both components. If the shock intensity alternately suppressed and released responding as it increased and decreased in the adjusting-intensity component then it would have either suppressed responding completely in the constant-intensity component or released responding completely. The cumulative record sections at the top of Figure 2 show that responding during the constant-intensity period was not all-or-none but varied in rate to about the same degree as during the adjusting intensity component.

At the bottom of Figures 1 and 2 are shown the average and immediate intensities of shock adjusted by the pigeons. The increase of intensities between and within sessions indicates considerable habituation to the continuous shock.

The adjusted shock intensities of the present experiment are lower than those that Rachlin and Loveland (1971) observed. The present intensities are more in keeping with previous determinations of pigeons' sensitivity to shock. Possibly some unmeasured resistance in the circuit or anomalies in the implants caused Rachlin and Loveland to obtain such high intensities.

Fig. 1. The upper set of curves shows, for each pigeon, rate of response during the last half of session during adjusting-intensity (solid lines) and constant-intensity (dotted lines) components of Experiment I. For each pigeon, the first and last five sessions shown contained no shock. The central 14 sessions show responding with shock superimposed. The lower curves show average intensity of shock for each pigeon during the last half of each session for which shock was present. The shock intensities were obtained by averaging the intensities during the last three constant-intensity components of each session.

EXPERIMENT II: PULSED SHOCK

If, in Experiment I, immediate intensity of shock preceding each response controlled that response, then removal of shock immediately preceding responses should reduce the degree of control. Experiment II provided only a brief pulse of shock immediately after each response. After the pulse was delivered, no shock was present by which responding could be controlled.

METHOD

The subjects, apparatus, schedules of food reinforcement, and shock presentation were the same as in Experiment I except that shock was no longer continuous. Instead, during both components, each peck except those that were reinforced was followed by a brief (35-msec) pulse. During the adjusting-intensity component, intensity of the pulse was regulated by the variac as before with pecks increasing, and timer decreasing, the intensity. Also, as before, the intensity at the end of each

Fig. 2. Cumulative responses (upper curves) and shock intensity (lower curve) during a single session for Pigeon P-53 on the seventh day of exposure to shock in Experiment I. The clear portions represent adjusting-intensity components; the shaded portions represent constant-intensity components. The cumulative recorder reset to zero with each change of components. Reinforcements are not shown.

adjusting-intensity component was maintained for each shock pulse during the subsequent constant-intensity component.

After the five session return to no-shock at the end of Experiment I, the pulsed shock condition was instituted for eight sessions at a timer setting of one downward pulse every 3 sec; then, for 12 sessions the timer was set to 2 sec.

RESULTS AND DISCUSSION

The upper part of Figure 3 shows rate of responding during each component of the multiple schedule for the second half of each session. The dotted lines, showing rate of response during the constant-intensity component are about equal in height to the solid lines showing rate of response during the adjusting-intensity component, except for one pigeon (P-54) where the dotted lines are slightly higher.

Responding during the adjusting-intensity component of the present experiment (with pulsed shock) immediately assumed the critical value that would keep intensity constant. In this respect, responding showed the same properties as during the adjusting-intensity component with continuous shock. The variability about the critical value was the same as, or less than, with continuous shock. Thus, the immediate drop in response rate when shock

was presented and the immediate rise in response rate when the interval between downward pulses was shifted from 3 sec to 2 sec could not have been due to immediate intensity of shock preceding each response.

It is conceivable that the after-effects of each shock pulse were sufficient to prevent responding for a time proportional to its intensity. But then, variability in rate of response would be greater when the after-effects of shock were controlling responding (as in this experiment) than when shock itself was controlling responding (as in Experiment I.) In fact, there was less variability in the present experiment. Also, if after-effects of shock governed individual responses, higher rates of responding could have been caused only by lower intensities of adjusted shock. The lower part of Figure 3, however, (except for P-54) shows no lowering in intensity with the shift to higher rate when the interval between downward pulses was changed from 3 to 2 sec.

Figure 4 shows a sample cumulative record and the intensity of the shock during a session. The intensity is shown as a continuous line (corresponding to the variac position), although in this experiment it was delivered to the pigeon in pulses only after each response. The regularity of responding of this pigeon during both components was typical of the pigeons.

Fig. 3. The upper set of curves shows rate of response during the last half of session during adjusting-intensity (solid lines) and constant-intensity (dotted lines) components of Experiment II. For each pigeon, the left set of curves shows response rates with a downward pulse every 3 sec. The right set of curves shows response rates with a downward pulse every 2 sec. The lower curves show average intensity of shock during the last half of each session obtained as in Figure 1.

Fig. 4. Cumulative responses (upper curves) and shock intensity (lower curve) during a single session for Pigeon P-53 on the seventh day of exposure to the 2-sec downward-pulse condition of Experiment II. The clear portions represent adjusting-intensity components; the shaded portions represent constant-intensity components.

The degree and precision of control of rate of response with pulsed shock and the constant intensity of shock across conditions in this experiment are evidence that the molar conditions of dependency of shock intensity on responding can control rate of response directly without the mediating regulation of individual responses by immediate shock intensity.

The most obvious difference in behavior between the pulsed and continuous conditions is in the rate of response during the constant-intensity components. When shock was continuous (Experiment I), rate of response during the constant-intensity component was higher than during the adjusting-intensity component. However, when shock was pulsed (Experiment II), rates of response during the constant-intensity and adjusting-intensity components were about equal. Note that on the average, the shock intensity was about the same for downward pulse rates of 2 sec and 3 sec in Experiment II. Thus, while there was no difference in conditions during constant-intensity components at the two downward pulse rates (downward pulse rates had meaning only during the adjusting-intensity components), the response rates during the constant-intensity components varied along with the response rates during the adjusting-intensity components. In other words, with pulsed shock, there was no discrimination between adjusting-intensity and constant-intensity contingencies while there was such a discrimination with continuous shock. Evidently, with continuous shock, the presence of unvarying shock between responses during the constant-intensity component could serve as a signal that the response-rate-shock-intensity relationship was disrupted. With pulsed shock, on the other hand, no such signal was present. The pigeons continued to respond at the rate that was effective during the preceding adjusting component. Because the intensity of shock was held constant, the effectiveness of responding at the critical adjusting rate could have been adventitiously maintained. The lack of discrimination of this change in conditions bears a similarity to the lack of discrimination in extinction of avoidance. In both cases, a functional relation between responding and aversive stimulation is established. While extinction by removal of all aversive stimulation (in the case of avoidance conditioning) or maintenance of constant intensity (in the present ex-

periment) removes the functional relation itself, continuation of responding as before still represents a point on the originally established function. In the case of avoidance conditioning, it is the point at which responding is paired with no-shock. In the present experiment, it is the point at which a certain rate of responding is paired with constant intensity of shock.

EXPERIMENT III: NINE-MINUTE COMPONENTS

Experiment II showed that pigeons can maintain a constant rate of response for extended periods without any environmental signal immediately preceding individual responses. It is obvious, however, that a constant rate of response could not be maintained indefinitely without some environmental control. Experiment III was an effort to test the limits of the pigeon's ability to maintain a constant rate of response by extending the period over which constant rates had been observed.

METHOD

The subjects, apparatus, and procedure were identical to those of Experiment II (pulsed shock) except that instead of 12 components of 3 min each, the experimental session was divided into four components of 9 min each. The first and third were adjusting-intensity components; the second and fourth were constant-intensity components.

After Experiment II, downward pulses were returned to 3-sec intervals and the 9-min components were introduced for seven sessions. Then, retaining the 9-min components, the downward pulse time was changed to 2 sec for seven sessions.

RESULTS AND DISCUSSION

Figure 5 shows response rates during Experiment III. The response rates during the adjusting-intensity components were about equal to the critical rates as before. The response rates during the constant-intensity components, however, departed from the critical rates, (above and below) and varied over a considerable range.

It would seem that while pigeons can respond at a constant rate for 3-min periods, they do not maintain a constant response rate much beyond that time without some sort of

feedback under the present conditions. If the constant intensity adventitiously reinforces some specific response rate, then any other rate will be equally reinforced and drift, in one direction or another, would be expected.

EXPERIMENT IV: REPLICATION WITH RATS

In order to explore the generality of the procedures of Experiments I, II, and III they were repeated with rats.

METHOD

Subjects

Six hooded rats, about six months old, were maintained at 80% of their free-feeding weights. The rats had been trained to press a bar with a conventional shaping procedure.

Apparatus

The experimental chamber contained a two-lever panel (Gerbrands Co.). The right lever was always inactive; three 7-w white lights above the left lever were occasionally lit; presses of the left lever produced a feedback click. The reinforcer was a 3-sec presentation of condensed milk from a Gerbrands Co. feeder centered between the levers. Electric shock was delivered through a Grason-Stadler shock scrambler to the floor and walls of the chamber and to the levers.

The intensity of shock was arranged as for the pigeons except that maximum current through the rat was set at 6 mA and each step (upward or downward) was 0.026 mA.

Procedure

The session length and reinforcement schedule was as for the pigeons. For the rats, the adjusting and constant intensity components were signalled by buzzer-on with lights (above the lever) off and buzzer-off with lights on.

After 60 sessions of exposure to the multiple schedule without shock, the rats were divided into two groups of three and exposed to the conditions described in Table I.

RESULTS AND DISCUSSION

The performance of the rats on each procedure was the same as that of the pigeons except that the rate of responding of the rats was slightly more variable at all phases. Also, rats tended to adjust shock intensities to lower

Fig. 5. Rate of response of each pigeon during the last half of each session during adjusting intensity (solid lines) and constant intensity (dotted lines) components of Experiment III with 9-min components.

values than pigeons. These differences between rat and pigeon performance may reflect genuine species differences, may be due to differences in the kind of response (key peck *vs.* lever press), may be due to the kind of shock administered (implanted electrodes *vs.* scrambled foot shock) or, most likely, some combination of the above. Because of this ambiguity, little purpose would be served by including a detailed report of rat data (although it is available by request) that looks

Table 1
Order of conditions in Experiment IV

Condition	Kind of Shock		No. of Sessions	Time Between Downward Steps (sec)	Component Duration (min)
	Group A	Group B			
1	continuous	pulsed	20	5	3
2	pulsed	continuous	20	5	3
3	pulsed	continuous	12	10	3
4	continuous	pulsed	15	10	3
5	continuous	pulsed	33	5	3
6	continuous	pulsed	22	5	9
7	pulsed	continuous	22	5	9

like a more variable version of the pigeon data already presented. The only reason for including any data from rats in this report is that interresponse-time distributions of rats' responding were taken during certain sessions (to determine, in more detail, how shock was controlled) whereas such distributions were not taken for pigeons' responding. Therefore, data from only eight of the 144 sessions with rats is presented and discussed.

During the last eight sessions of Condition 5, interresponse times were measured with a printout counter. The printout counter added with each second, printed with each bar press, and was reset only at the end of each session. For the first four of these eight sessions, interresponse times were measured only during the last three adjusting-intensity components of each session. For the last four sessions, interresponse times were measured only during the last three constant-intensity components of each session. The distributions were cumulated over the four sessions in which they were taken and an interresponse time per opportunity (IRT/op) distribution was calculated for each. The IRT/op distribution is a measure of probability of response at each IRT. Random responding would result in a rectangular IRT/op distribution (Anger, 1956). The IRT/op statistic was used because deviations from a rectangular distribution showing bursting or spaced responding are more obvious than deviations from the exponential distribution that random responding would yield if IRTs were plotted in a regular frequency distribution.

During Condition 5, with the timer regulating downward steps set at 5 sec and component duration of 3 min, three of the rats received continuous shock and three received pulsed shock. Figure 6 shows rate of respond-

Fig. 6. Rate of response of each rat during the last half of session during adjusting-intensity (solid lines) and constant-intensity (dotted lines) components of the eight sessions for which interresponse-time measurements were taken. Rats 1, 2, and 4 were exposed to continuous shock. Rats 3, 5, and 6 were exposed to a 35-msec pulse of shock immediately after each response.

ing during the adjusting and constant-intensity components for both groups of rats for the eight sessions during which IRTs were measured. The critical rate of response was 12 responses per minute and all rats responded around that rate during the adjusting-intensity component. During the constant-intensity component, rate of response varied considerably and was more variable and higher, on the average, with continuous than pulsed shock.

Figure 7 shows IRT/op distributions. For each rat, the general forms of the adjusting and constant-intensity distributions (taken during different sessions) are almost identical regardless of whether shock was continuous or

Fig. 7. Interresponse-time per opportunity distributions for each rat for eight sessions. For four of these sessions, interresponse times were taken during the adjusting-intensity component only (solid lines). For the other four sessions, interresponse times were taken during the constant-intensity component only (dotted lines). An IRT/op distribution is obtained from a standard IRT distribution by dividing the number of IRTs of a given value by the sum of IRTs of that value plus all IRTs of higher values. Each abscissa interval below 14 sec contained at least 10 IRTs.

pulsed. The differences in absolute rate of responding in the two components are due mostly to differences in IRTs of less than 1 sec (bursts). Distributions for rats receiving steady shock showed many bursts in both adjusting and constant-intensity components. Distributions for rats receiving pulsed shock show fewer bursts. In other respects, however, there is little difference between continuous-shock and pulsed-shock distributions.

The distributions of Figure 7 show how rate of response was controlled. If a specific interresponse time were the directly controlled dependent variable, the distributions of Figure 7 should show a peak around 5 sec. Only one rat (R-6) shows any evidence of such a peak. Three other distributions (Rats 2, 3, and 4) indicate greater probability of responding with longer IRTs, while the other two distributions (Rats 1 and 5) are fairly horizontal. A rectangular distribution indicates no greater probability for one IRT *vs.* another but random emission of IRTs at a rate that remains constant.

The similarity of interresponse-time distributions in the two components, even when overall response rates differed considerably, indicates that rate was varied by increasing or decreasing the average number of responses in a burst, while the distribution of pauses between bursts remained fairly constant.

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