THE EFFECT OF SHOCK INTENSITY ON CONCURRENT AND SINGLE-KEY RESPONDING IN CONCURRENT-CHAIN SCHEDULES¹

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Pigeons were trained to respond in a two-link, concurrent-chain schedule. Pecks on each key during the concurrent initial links occasionally produced a 5-min terminal link, during which only that key was operative. Food reinforcement and various intensities of shock were scheduled during the terminal links. When shock was contingent on response, the effect of shock was greater on terminal-link responding than on initial-link responding. When shock was independent of response, the effect was reversed, with larger changes in initial-link responding than terminal-link responding. In general, shock was found to affect behavior most drastically when behavior could, in turn, affect the rate of shock.

Recent experiments indicate that parameters of reinforcement, response requirement, and punishment can have a greater effect on responding in a concurrent than in a single-key situation. This has been shown by Catania (1963) for amount of reinforcement, by Chung (1965) for effortfulness of response, and by Azrin and Holz (1966) for intensity of punishment.

This difference in effect has also been found with the concurrent-chain procedure, which allows comparison between concurrent and single-key responding within the same experimental setting. Autor (1960) and Herrnstein (1964) with rate of reinforcement, and Reynolds (1963) with punishment, found that relative rate of response varied more during the concurrent initial links than during the single-key terminal links.

Reynolds varied intensity of punishment in one of two terminal links of a concurrent chain to show that differences in positive reinforcement could be balanced by differences in punishment. For this reason, the schedules of positive reinforcement were different during the punished and unpunished terminal links. The present experiment, on the other hand, sought to measure the effects of punishment

independently of reinforcement. Therefore, the schedules of reinforcement during the punished and unpunished terminal links were identical. Another difference between Reynolds' experiment and the present one is the range of shock intensities. Reynolds found that an imbalance in responding during the initial link, presumably caused by an imbalance in schedule of reinforcement, could be counteracted by low intensities of shock, around 2 ma. In the present experiment, intensity was varied over a wider range (from zero to 9.0 ma) to extend the function relating relative rate of response to intensity of punishment.

EXPERIMENT I

Subjects

Three adult, male, White Carneaux pigeons were maintained at about 80% of free-feeding weight. All were experimentally naive when the experiment began.

Apparatus

The experimental chamber was a modified standard apparatus designed for pigeons (Fester and Skinner, 1957). Two response keys, each operable by pecks of force greater than 15 g, could be transilluminated by red or white lamps. The positive reinforcer was 3-sec access to a standard grain magazine. The punisher was a 35-msec pulse of 60 cps ac through an 11 K ohm fixed resistance plus some variable resistance to two gold wires implanted around the pigeon's two pubis bones (Azrin,

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1959). Variations in the variable resistance produced a range of shocks from 3.0 to 9.0 ma.

Procedure

After initial training with the food magazine and the response keys, the subjects were exposed to the concurrent-chain schedule schematically represented in Fig. 1. This consisted of a chained schedule of two links on each key. The initial links were always concurrent, the terminal links never concurrent. During the initial links, when both keys were operative and transilluminated with white light, responding controlled entry into the terminal links in accordance with 3-min variable-interval (VI) schedules, programmed separately for each key. When a peck during an initial link produced a terminal link, the key color changed to red, while the other key became dark and inoperative. The terminal link lasted 5 min, after which both initial links were re-instated. The daily experimental session ended after a total of 10, 5-min terminal links, usually about 65 min.

Responses were reinforced according to a 1-min VI schedule during both terminal links. Each response was punished during one of the terminal links; pecks during the other terminal link and during the initial links were not punished. Over the course of the experiment

Fig. 1. Diagram of the experimental procedure (after Herrnstein, 1964). Each box represents one of the three possible states of the two response keys. During the initial link (left box) both keys are illuminated and operative. Pecking on either key leads on a 3-min, variable-interval schedule (VI 3'), to the terminal link represented by the box either at the upper right or lower right, during which pecking at one key may be rewarded and punished while pecking at the other, which is now darkened, has no consequences.

the intensity of the shock was increased from zero to 9.0 ma and back to zero in steps of 3 ma. Then the intensity was similarly varied for the terminal link on the other key. This cycle of increase and decrease on one key, then increase and decrease on the other, was run twice with 11 ± 1 sessions at each step, then once more with 6 ± 1 sessions at each step, a change which had no noticeable effect on the results. The intensity of punishment remained constant during any single session. The schedule of reinforcement remained constant throughout the experiment.

Results

Figure 2 (left) shows the average relative rates during the initial and terminal links for each cycle, with ascending and descending series plotted on the same axis. Figure 2 (right) shows data for individual subjects, averaged across cycles. In all cases the terminal link curves are considerably steeper than the initial link curves. The separation between the ascending and descending curves is caused by the fact that variation in behavior lags somewhat behind variation in shock intensity.

Despite the differences in relative rates of responding during the initial link, the punished and unpunished terminal links occurred equally often and the rates of positive reinforcement during the two terminal links remained about equal. At 9.0 ma, for example, the relative rate of entry into the punished terminal link averaged 50% and the relative rate of reinforcement during that link averaged 47%, a deviation from equality well within the range of chance fluctuation with the concurrent-chain procedure.

Discussion

The results of Exp I appear to contradict previous comparisons of concurrent and single-key responding. Whereas previous experimenters found that concurrent responding is more sensitive to the independent variable than single-key responding, Exp I indicates the opposite. However, the relatively greater variation of single-key (terminal link) responding is understandable if it is assumed that relative rate during the initial link of Exp I was a function of rate as well as intensity of shock. Since shock is here delivered as punishment, rate of shock is absolutely dependent on rate of responding, the one neces-

Fig. 2. Average (left) and individual (right) relative rates during the initial links (solid lines) and terminal links (dotted lines) as intensity is varied. Increasing and decreasing intensities are superimposed for each curve. Starting at zero and following the arrows, the relative rates are shown as intensity increased on the left key, decreased on the left key, increased on the right key and decreased on the right key. For the average curves (left) the ordinates in the first two cycles were obtained by taking the median relative rate of the last five days at each intensity level for each subject, and then averaging across subjects. In the third cycle of the average curves the medians of the last three days were averaged. For the individual curves, the ordinates were obtained by taking the median relative rate of the last five days at each intensity level for the first two cycles and the median relative rate of the last three days for the third cycle and then averaging across cycles, for each subject. The following symbols are used to identify the various response rates:

Initial link rate of response on left and right keys = r_L, r_R

Terminal link rate of response on left and right keys = RR_L, RR_R

$$\text{Relative rates, initial link } (r_L, r_R) = \frac{r_L}{r_L + r_R}, \frac{r_R}{r_L + r_R}$$

$$\text{Relative rates, terminal link } (RR_L, RR_R) = \frac{RR_L}{RR_L + RR_R}, \frac{RR_R}{RR_L + RR_R}$$

Uppercase letters signify terminal link rates. Lowercase letters signify initial link rates.

sarily equaling the other. When intensity of punishment increases, rate of response, and hence, rate of shock, decreases. In this sense, Exp I contains an element of negative feedback; increasing intensity of punishment on the left key, for instance, decreased responding on the left key during both links. But a decreased rate of responding during the terminal link caused a decreased rate of shock, which, in turn, may have tended to restore responding on the left key during the initial link. The fact that an increasing intensity of shock tends to be counteracted by decreased rate of shock would explain the relative shallowness of the

initial link functions. Except for Reynolds' (1963) experiment, previous comparisons of concurrent and single key responding have not contained this element of negative feedback. The difference between the results of Exp I and those of Reynolds may have been due to the low intensities of shock and the asymmetry of reinforcement schedules in Reynolds' experiment.

EXPERIMENT II

The results of Exp I suggest a consideration of rate of shock as a possible influence on re-

sponding during the initial link. In Exp I, rate of shock was strictly dependent on the subject's behavior. In Exp II, shock was independent of behavior. The purpose of Exp II was to study responding during the initial and terminal links when both rate and intensity of shock were under the experimenter's control.

Subjects

Four adult, male, White Carneaux pigeons were maintained at about 80% of free-feeding weight. All were experimentally naive when the experiment began.

Apparatus

The apparatus was the same as that used in Exp I except that the chamber contained three response keys instead of two.

Procedure

As in Exp I, the subjects were magazine and key-trained and then exposed to a concurrent-chain schedule. The characteristics of this schedule have been previously described. Its parameters in this experiment were as follows:

- 1. There was a chained schedule of two links on each of three keys. The three concurrent initial links were indicated by white key lights, the three non-concurrent terminal links by red key lights. Because the occurrence of each of the terminal links was programmed on a separate 3-min VI schedule, and because the animals had relatively high rates of responding, the average duration of the concurrent initial links was 1 min. Each terminal link lasted 5 min,

after which the three concurrent initial links were restored.

- 2. Responses were reinforced on a 1-min VI schedule during all three terminal links.
- 3. Throughout the terminal links, trains of shock pulses, uncorrelated with responding, were delivered. The pulse rate was different during each of the three terminal links.
- 4. The intensity of the shock was equal in each of the three terminal links. When the intensity was changed it was changed for all three terminal links.

Initial training on this schedule consisted of 20 sessions without shock. Then, 3.0-ma pulses at 30 pulses per min were introduced during all three terminal links. Then, the pulse rates were changed to 60-30-15 pulses per min for the three keys. Next, the pulse rates were changed to 120-30-6 pulses per min. These pulse rates were maintained while the shock intensity varied from 3.0 to 10.0 ma. Three keys were used to provide a wider but at the same time more detailed range of shock rates than two keys would allow. The 60-30-15 condition was an exploratory one during which the separation in relative rate of response in both links proved to be very low. For this reason, the rates of shock were changed to 120-30-6 pulses per min. The sequence of conditions is shown in Table 1.

Results

Figure 3 shows the average relative rates in the initial and terminal links on key 1 and key 3 for the various conditions. The first

Table 1
Conditions of Experiment II

Condition		Pulses of Shock per Minute			Intensity (Milliamperes)	Number of Sessions in Condition
		Key 1	Key 2	Key 3		
Pre-experimental conditions	No shock	0	0	0	0	20
	Equal pulse rate	30	30	30	3	22
	Low difference in rates	60	30	15	3	54
Experimental conditions	High difference in rates	120	30	6	3	50
		120	30	6	5	15
		120	30	6	10	15
		120	30	6	7	15
		120	30	6	5	15
		120	30	6	3	15

Fig. 3. Average relative rates during the initial and terminal links on two of the three keys as a function of experimental conditions. Abscissa point 0 represents the no-shock condition. Relative rates were calculated as in Exp I. Abscissa point EP (equal pulse rate) shows performance when the shock rate on all three keys in the terminal link was equal to 30 pulses per min. Abscissa point LD (low difference in rates) shows performance when the pulse rates were 60, 30, and 15 pulses per min on keys 1, 2, and 3 and the intensity was 3.0 ma. The remaining abscissa points show performance when the pulse rates were 120, 30, and 6 pulses per min on keys 1, 2, and 3, and the intensity was as indicated on the abscissa. The intensity increased from 3.0 to 10.0 ma and decreased back to 3.0 ma. The ordinates were obtained by taking the median relative rate of the last five days at each abscissa point for each subject, and then averaging across subjects.

three points on the abscissa represent no shock, equal rates of shock during the three terminal links, and the 60-30-15 condition. The remaining points represent performance with pulse rates at 120-30-6 pulses per min on the three keys as the shock intensity was increased in steps from 3.0 to 10.0 ma and then decreased to 3.0 ma. Relative rates on the middle key (always 30 pulses per min) are strictly dependent on the relative rates on the other two keys and are therefore not shown. Figure 4 shows individual relative rates during the initial and terminal links.

As in Exp I, relative entry into the terminal links and relative rate of positive reinforce-

ment was about the same for the three terminal links under all experimental conditions. However, contrary to Exp I, relative rates during the terminal link varied less steeply with intensity of shock than did rates during the initial link. Despite the considerable variation in the steepness of individual initial and terminal link functions, all subjects showed greater variation in the initial link than the terminal link. In this sense the average functions of Fig. 3 are representative of the individuals of Fig. 4.

Discussion

The results of Exp II show a greater effect of the independent variable on concurrent responding than on single-key responding. In this respect they confirm previous findings and appear to contradict Exp I. But this apparent contradiction vanishes when rate of shock is fully accounted for. In Exp I rate of shock was controlled by the subject's responding during the terminal link whereas, in Exp II, the subject could affect rate of shock only by differential responding during the initial link. In both experiments the greater effect of aversive stimulation was in the link in which the aversive parameters were themselves most responsive to the behavior of the subject.

If responding in the initial link is a joint function of both rate and intensity of shock, what is this function? Because all combinations of rate and intensity of shock were not compared, the present experiments cannot answer this question fully, though they do furnish a clue.

Figure 5 shows average relative rates during the initial link of Exp II as a function of rate of shock, with intensity as a parameter. The rates are adjusted with respect to the rate on key 1 (corresponding to the lowest rate of shock during the terminal link). Figure 6 illustrates how Exp I and II may be considered in the same context. It is a three-dimensional plot of the data in Fig. 5 with 5.0 and 7.0 ma averaged at 6.0 ma and with smooth curves instead of straight lines connecting the points. A series of points in the horizontal rate-intensity plane is determined by the rates and intensities of shock during the terminal links. These may be either set by the experimenter or result from the subject's behavior. Once these points are determined, the heights of the vertical lines drawn from the points to the

Fig. 4. Individual relative rates during the initial link (left) and terminal link (right) on two of the three keys as a function of experimental conditions. For an explanation of the points on the abscissa see the legend of Fig. 3.

Fig. 5. Decrement in relative rate during the initial link as a function of rate of shock in the terminal link. Intensity of shock is the parameter. The ordinates were determined as follows: (1) Median relative rates during the initial link for the last five days at each intensity level were calculated. (2) Arithmetic mean was taken across subjects. (3) Arithmetic mean was taken for increasing and decreasing series of intensities. (4) Average relative rates on keys 1 and 2 (120 and 30 pulses per min) were subtracted from average relative rate on key 3 (6 pulses per min) at each intensity level. These differences are shown on the ordinate.

curved surface above are proportional to the decrement in relative rate during the initial link. Such a surface could be constructed from the data for each individual subject of Exp II. In this illustrative case the averages of Fig. 5 were used. Additional points on the surface were obtained by averaging results of Exp I. In Exp I, each intensity level of shock resulted in a rate of shock determined by the subject's responding. For each intensity, these rates were averaged across subjects. The intensities and their corresponding average rates are plotted as points *a*, *b*, and *c* on the intensity-rate plane of Fig. 6. From these points, vertical lines were drawn proportional to the average decrements in relative rate during the initial link of Exp I. These decrements were determined in the same way as those for Exp II.

The vertical lines *aa'*, *bb'*, and *cc'*, generally increase in height with increasing intensity, but the increase in height is small, reflecting the fact that responding during the initial link of Exp I did not vary greatly.

It should be noted that in Exp I the decrement in relative rate during the initial link was determined with respect to a key associ-

Fig. 6. Idealized three-dimensional plot of the data shown in Fig. 5. For explanation of dotted lines see text.

ated with zero intensity and zero rate during the terminal link. In Exp II the decrement in relative rate during the initial link was determined with respect to a key associated with a rate of 6 shocks per min and a non-zero intensity (see legend of Fig. 5). This discrepancy probably distorts the shape of the curve in Fig. 6. The two experiments are comparable on the basis of Fig. 6 only if 6 shocks per min is assumed to be effectively zero as contrasted with 30 and 120 shocks per min. Another assumption necessary for comparison of the two experiments is the implicit one that shock as punishment, contingent upon response, and shock as delivered independently of response have different effects on relative choice only insofar as punishment decreases the rate of shock—not as it affects the rate of response. Some justification for this assumption is the fact that in concurrent-chain experiments concerned with positive reinforcement, initial-link responding was shown to be a function of relative rate of reinforcement and independent of rate of response during the terminal link (Herrnstein, 1964).

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