SECONDARY REINFORCEMENT AND NUMBER OF PRIMARY REINFORCEMENTS¹

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Pigeons' pecks on either of two concurrently available response keys produced secondary reinforcers according to independent one-minute variable-interval schedules. Different secondary reinforcers, in the presence of which the rates of primary reinforcement were equal, were associated with each key. The rate of pecking maintained by each secondary reinforcer varied directly, but nonproportionally, with the number of primary reinforcements given in the presence of the secondary reinforcer.

Chained schedules of reinforcement provide a method for studying conditioned reinforcement (Findley, 1954; Reynolds, 1963; Nevin, 1964). Responding during the initial link of, for example, a two-link chain is reinforced by the presentation of a secondary reinforcer, which is in turn the discriminative stimulus for further responding reinforced by a primary reinforcer like food. Kelleher and Gollub (1962) summarized convincing evidence that responding during the earlier links of such a chain can be reinforced by the conditioned reinforcers correlated with subsequent links and not merely by the primary reinforcement occurring at the end.

In determining the strength of a secondary reinforcer, the frequency of pairings with the primary reinforcer may well be implicated, for in the extreme case, when pairings cease, the secondary reinforcer ultimately loses its power to reinforce. As a quantitative variable, however, frequency is ambiguous in that it may be specified in a number of different ways. The primary reinforcer occurs with a certain rate, probability, and absolute number in the presence of the secondary, and each of these specifications of frequency may have

some bearing on how reinforcing powers are imparted to the originally neutral stimulus. Herrnstein (1964a) showed that the strength of a secondary reinforcer, as measured by its effectiveness in a chained schedule, depended more heavily on the rate than on the probability of primary reinforcement in its presence. In that experiment, the role of absolute number of reinforcements, in and of itself, was deliberately excluded by being held constant throughout. In the present experiment, number of reinforcements in the presence of the secondary reinforcer was varied, while the rate of reinforcement was held constant. If number of reinforcements is a significant factor in its own right, the secondary reinforcer associated with a greater number of primary reinforcements should maintain a higher rate of responding in the initial link leading to it, despite the fact that the rate of reinforcement in the presence of the secondary reinforcer is constant.

METHOD

Subjects

Six adult, male White Carneaux pigeons were maintained at 80% of their free-feeding weights. Four (405, 406, 407, and 408) had been used in an earlier experiment on chained schedules; the other two (418 and 419) were experimentally naive.

Apparatus

A two-key experimental chamber (*cf.* Herrnstein, 1964a) was used. One wall of the chamber contained two pigeon-keys and one

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food magazine. The chamber was generally illuminated throughout the session with white light, and the keys were transilluminated with lights of various colors in accordance with the procedure (see below). All programming and recording were automatic. Each subject was run daily over a 16-month period, except for infrequent occasions when it was overweight.

Procedure

The procedure is diagrammed in Fig. 1, in which the three boxes correspond to the three alternative conditions of the two keys. At the start of an experimental session, each key was transilluminated by white light. Pecks at each key were effective according to a VI 1-min schedule. Identical, but independent, schedules were in force during this first link of the chain. The reinforcer for the first link was a change in key illumination and in the prevailing schedule. For the left key, the white light changed to yellow; for the right, it changed to red. In either case, the terminal link in the chain comprised an illuminated key, to which responses were reinforced with 4-sec access to food on a VI 15-sec schedule on one key, while the other key was inoperative. The only difference between the two second links, in addition to the color of the associated key-

light, was the number of primary reinforcements delivered before the concurrent first links recurred. Each successive primary reinforcement was delivered according to the VI 15-sec schedule. Table 1 lists the number of food reinforcements in each cycle for each key, and shows the order of experimental conditions and the number of sessions observed under each condition. A given pair of values

Table 1

Number of primary reinforcements in each cycle for each chain. The right column lists the number of sessions for each condition. The schedule in the first links was always VI 1-min while the primary reinforcements were always produced on VI 15-sec.

Order of Conditions	Number of Primary Reinforcements/Cycle		Number of Sessions
	Left Key	Right Key	
1	1	3	90
2	1	5	42
3	1	10	31
4	2	3	67
5	3	2	90
6	10	1	72
7	2	3	68

remained in effect for a minimum of 28 sessions and until each subject's responding appeared stable for at least 12 daily sessions. Each session terminated after 60 reinforcements.

The procedure may be characterized as a pair of two-link chained schedules, in which the two first links are concurrent, but the two second links are mutually exclusive. The independent variable is the number of times primary reinforcement is delivered each time either of the second links is attained. This is the general procedure used by Autor (1960), Herrnstein (1964a, 1964b), and Fantino (1967) to investigate other independent variables.

RESULTS

The actual rate of reinforcement in the terminal links was always four reinforcements per minute, as would be expected from the VI 15-sec schedule programmed. With the rate of reinforcement constant in the presence of the terminal-link stimuli, did number of reinforcements exert any effect on responding? This, the major finding of the experiment, is shown in Fig. 2 and 3 for individual and

Fig. 1. Diagram of one cycle of the experimental procedure. Each box represents one of the three possible states of the two response keys. At the start of a cycle (left box), both keys are illuminated and operative. Pecking on either key leads, on VI 1-min, to the state represented by the box either at the upper right or lower right, during which pecking on one key leads intermittently to food (S^R), while pecking on the other, which is now darkened, has no consequences.

Fig. 2. Responses per minute during the first link as a function of number of reinforcements during the second link, for each of the six pigeons.

averaged animals, respectively. In each figure, the number of reinforcements per cycle of the schedule is the abscissa and the rate of responding during the first link is the ordinate. Because all animals showed an unaccountable bias in favor of the right key, the rates for the two keys are plotted separately. The data for the fourth and seventh conditions (see Table 1) were averaged since these procedures were identical. In Fig. 2, each of the six panels shows responses per minute for one pigeon, averaged over the final four sessions under a

Fig. 3. Responses per minute during the first link as a function of number of reinforcements during the second, showing the mean rates of the six pigeons.

given condition. The unfilled squares show rate of responding on the right key; the filled circles that on the left key. Figure 3 shows the arithmetic means of the six rates of responding at each condition and appears to be a good summary of the individual results. It is evident that the first-link responding varied directly, but nonproportionally, with the number of primary reinforcements per cycle. No more precise characterization of the curves seems warranted by the data.

In contrast with the first link, responding during the second link showed no systematic relation to the changes in the number of reinforcements. Figures 4 and 5 again show the data for the individual and averaged animals and were obtained from the same sessions used for Fig. 2 and 3. The bias in favor of the right key is evident here as well, although its relative magnitude was smaller, perhaps

Fig. 4. Responses per minute during the second link as a function of number of reinforcements during the second link, for each of the six pigeons.

Fig. 5. Responses per minute during the second link as a function of number of reinforcements during the second link, showing the mean rates of the six pigeons.

because of the higher overall rates of responding during the second links. There is a suggestion of a rising function in the curve for the right key and of a falling function for the left key. On balance, it appears that the variations in number of reinforcements did not materially alter the rates of responding during the second links.

DISCUSSION

Number of primary reinforcements has been found to be a significant factor in determining the potency of a secondary reinforcer, as shown by the increasing rate of responding during the first link of a chain with increasing numbers of primary reinforcements during the second link. Rate of responding during the second link, however, has been found to be essentially independent of the number of reinforcements delivered during its course. This shows that the rates of responding during the two links were differentially affected by the number of reinforcements; this further substantiates earlier suggestions (Kelleher and Gollub, 1962; Herrnstein, 1964a) that the changes in behavior during the first link of a chain are not simply anticipatory manifestations of changes that are to occur during the second link, a hazard noted most recently by Logan and Wagner (1965, p. 58).

Herrnstein (1964a) showed that the absolute rate of responding during the initial link was

directly proportional to the relative rate of reinforcement delivered during the terminal link. Thus, the rate could be increased a given amount during a given initial link either by increasing the rate of primary reinforcement during the terminal link associated with it, or by a proportionally equal decrease in the rate of primary reinforcement associated with the other terminal link. Unfortunately, the bias toward the right key in the present experiment precluded any direct test of a comparable effect of relative number of reinforcements, since such a test would entail the rather arbitrary assignment of parameters to compensate for the bias itself. The data in Fig. 2 and 3 seem, however, to indicate that no such direct proportionality would be found in the case of reinforcements as a variable determining the strength of a secondary reinforcer, since there is a nonproportional relation between number and strength for each key taken individually.

The earlier experiment found an approximate equality between the relative rate of responding during the initial link and the relative rate of reinforcement during the terminal link. In a plot of these relative quantities, such as the present Fig. 6, the earlier data were well described by the 45-degree diagonal. Figure 6, for the present data, however, shows no such equality. The points

Fig. 6. Relative rates of responding (right key) as a function of relative number of reinforcements per cycle (right key) for first (filled circles) and second (unfilled circles) links. Points are mean values for the six pigeons.

in Fig. 6 are averages of the relative quantities for the six pigeons, with first-link rates of responding as filled circles and second-link rates of responding as unfilled circles. The position bias complicates slightly the interpretation of these data, but a straightforward assessment is possible. The second-link data show, by their horizontality, that number of reinforcements per cycle is not an effective variable as regards responding during the second link. The approximately 4% elevation of these points above the 0.5 level of the ordinate is the position bias in favor of the right key. The first-link data also show the effect of the position bias, but here by the fact that the curve does not pass through the expected coordinates of 0.5, 0.5, but through something in the vicinity of 0.5, 0.6. The slope of the function indicated by these points is clearly and substantially less than the 1.0 of the 45-degree diagonal of the earlier study. It may therefore be concluded that with number of reinforcements, as opposed to rate of reinforcement, a given change in the relative magnitude of the independent variable does not have an equal effect on the relative rate of responding during the first link. Over the range of values examined here, the relative change in responding is smaller than the relative change in number of reinforcements.

Still another indication that number of reinforcements does not affect the strength of a secondary reinforcer in the same manner as rate of reinforcement, is seen by examining data for certain values of the independent variable that were tested more than once. For the left key in conditions 1, 2, and 3, one reinforcement was obtained in each cycle while reinforcements per cycle on the right key varied. Similarly, when three reinforcements were obtained for each cycle on the right key, either one or two reinforcements were obtained for each cycle on the left. Was the rate of responding to obtain one of the secondary reinforcers influenced by the number of reinforcements programmed on the other? If so, the three left-key points at one reinforcement per cycle should differ from one another as should the two points at three reinforcements per cycle. Visual inspection of Fig. 3 indicates that they did not differ substantially. Thus, initial link responding on a given key appears to be largely independent of the number of reinforcements per cycle as-

sociated with the other key. As noted above, an analogous independence was not found by Herrnstein for rate of reinforcement.

Although the schedule of reinforcement associated with the second links was VI 15-sec throughout the experiment, there is a point of view from which the present procedure did not fully eliminate rate of reinforcement as a variable. Consider, for example, what happened in the sixth experimental condition, when 10 reinforcements were given during the second link on the left key while just one was given during the second link on the right key. On the left key, 10 reinforcements were obtained in the second link after cycling only once through the first link. On the average, this required 1 min to get through the first link and 2.5 min to produce the 10 reinforcements. Hence, the overall rate of reinforcement was 10 reinforcements per 3.5 min = 2.86 reinforcements per min. On the right key, where one reinforcement was produced during the second link, the overall rate of reinforcement was one reinforcement per 1.25 min = 0.80 reinforcements per min. In other words, rate of reinforcement calculated over total experimental time, instead of just over time during the second link, interacts with the number of reinforcements per cycle. Although this is a possible representation of the present experiment, it seems to be beside the point in regard to the potency of the secondary reinforcers. The secondary reinforcers in the present experiment were the stimuli associated with the second links, and in their presence only the number, not the rate, of reinforcement was varied. There seems to be no basis for taking rate of reinforcement over the total experimental time and assigning its consequences to a secondary reinforcer in the presence of which rate is fixed. Empirically, the difference between the nonproportional effect found here and the established proportionality for rate of reinforcement further suggests that number of primary reinforcements is a variable in its own right. Finally, it should be noted that number of reinforcements can vary while rate of reinforcement is constant only if duration is also allowed to vary. Thus, the present results could have been interpreted equally well as the effects of variations in the duration of the secondary reinforcer.

If rate of reinforcement in the terminal links was exclusively in control of initial link

responding, the data in Fig. 2 and 3 would be horizontal. Instead, a positive relation is indicated for each of the six subjects and for each of the two response keys. This indicates that number of reinforcements is a determinant of the strength of a secondary reinforcer. The present finding complements Herrnstein's (1964a) demonstration that rate of reinforcement in the terminal links controls initial-link responding when number of reinforcements is held constant. The two studies indicate, however, that the two variables, rate and number of reinforcements, do not affect responding in the same way: the function relating initial link responding to rate of reinforcement is a proportionality while that relating initial-link responding to number of reinforcements is nonproportional.

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