

*REINFORCEMENT SCHEDULES: THE ROLE OF
RESPONSES PRECEDING THE ONE THAT PRODUCES
THE REINFORCER¹*

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In a two-key pigeon chamber, variable-interval reinforcement was scheduled for a specified number of pecks, emitted either on a single key or in a particular sequence on the two keys. Although the distribution of pecks between the two keys was affected by whether pecks were required on one or on both keys, the total pecks emitted was not; the change from a one-key to a two-key requirement simply moved some pecks from one key to the other. Thus, each peck preceding the one that produced the reinforcer contributed independently to the subsequent rate of responding; the contribution of a particular peck in the sequence was determined by the time between its emission and the delivery of the reinforcer (delay of reinforcement), and was identified by the proportion of pecks moved from one key to the other when the response requirement at that point in the sequence was moved from one key to the other.

A single reinforcer may act upon many responses. Dews has expressed the point as follows: "The reinforced response is followed promptly by the reinforcing stimuli; the preceding unreinforced responses are also followed by the reinforcing stimuli, though not quite so promptly. Indeed, the whole pattern of . . . responding is followed by the reinforcing stimuli and so, in a sense, is reinforced" (Dews, 1966, p. 578). In other words, the effect of a reinforcer is determined not only by its relationship to the response that produces the reinforcer but also by its relationship to other, earlier responses.

This view can be elaborated by reference to Fig. 1, which shows two sequences of responses terminated by the delivery of a reinforcer (RFT). Both sequences begin with an early

response, *b*, followed later by another response, *a*, that produces the reinforcer. In Sequence II, several other responses, *c* through *h*, are also emitted. Both sequences represent instances of partial reinforcement (*e.g.*, Kimble, 1961, pp. 286-292): in Sequence I, one of two responses is reinforced, whereas in Sequence II, one of eight responses is reinforced. One example of the paradox of partial reinforcement is that more responses may follow reinforcement at the end of Sequence II than at the end of Sequence I, even though a smaller proportion of the total responses is reinforced in Sequence II.

It is misleading, however, to say that only Response *a* is reinforced in Sequences I and II; there is no reason to assume that the effect of a reinforcer is restricted to the response that produces it. In Sequence I, Response *a* is reinforced, but subsequent responding may also depend on the temporal relationship between Response *b* and the reinforcer. The same conditions hold for Responses *a* and *b* in Sequence II, with the difference that several other responses, *c* through *h*, are also followed after various periods of time by the reinforcer. The delay from response to reinforcer is greater for some responses than for others, but it is appropriate to assume that the reinforcer nevertheless acts upon each of these responses. To put it simply, more responses are reinforced in Sequence II than in Sequence I. It

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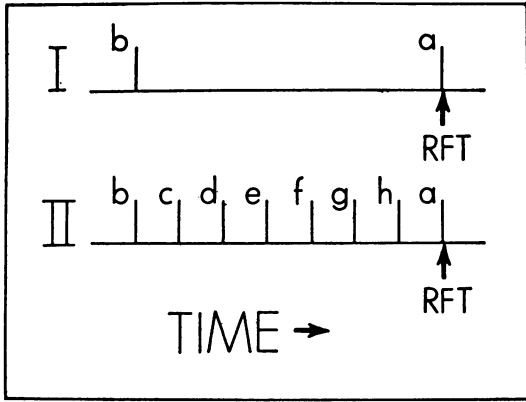


Fig. 1. Two sequences of responses terminated by the delivery of a reinforcer (RFT). In Sequence I, the reinforcer acts upon fewer responses than in Sequence II. Discussion in text.

should not be surprising, then, if reinforcement at the end of Sequence II generates more subsequent responding than reinforcement at the end of Sequence I.

According to this view, each response that precedes the delivery of a reinforcer independently contributes an increment to subsequent responding; this increment is a function of the time between the emission of the response and the delivery of the reinforcer (*cf.* Neuringer, 1969, p. 382: "... the time between a response and reinforcement controls the probability of that response, whether other responses intervene or not."). It should be possible, therefore, to analyze the responding generated by a particular schedule of reinforcement into components: some fraction may depend upon the response that produces the reinforcer (*e.g.*, Response *a* in Fig. 1), and another may depend on preceding responses and their temporal separation from the reinforcer (*e.g.*, Response *b* in Fig. 1). Such an analysis of the responding generated by a particular reinforcement schedule, however, encounters a difficulty: all of the responses are typically members of the same operant class. When reinforcement generates many responses, how can those that depend on the particular response that produces the reinforcer be distinguished from those that depend on the just-preceding response or on still earlier responses?

The present experiments attempt to identify the source of responses by tagging them with a distinctive feature: a different location. The procedure is illustrated in Fig. 2, which

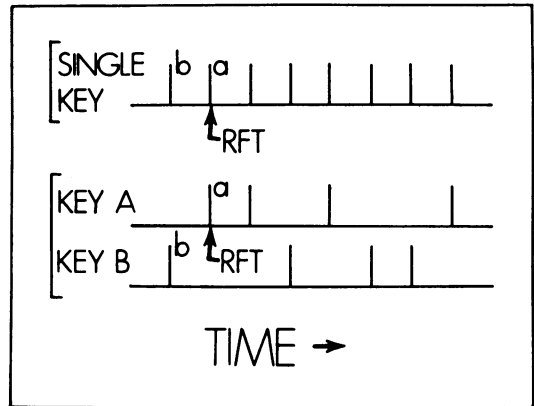


Fig. 2. Illustration of general procedure. The delivery of a reinforcer (RFT) follows a sequence of two pecks, *a* and *b*, either on a single key or on two keys (Key A and Key B). If some of the pecks that follow reinforcement in the single-key instance depend on the relationship between Peck *b* and the reinforcer, then some of these pecks will be emitted on Key B instead of on Key A when Peck *b* is emitted on Key B in the two-key instance. Discussion in text.

represents a pigeon's pecks either on a single key or on two keys (Key A and Key B). In the single-key instance, two successive pecks, *b* and *a*, are followed by the delivery of a reinforcer (RFT), and several additional pecks are then emitted. All of the subsequent pecks may depend solely upon the relationship of the reinforcer to Peck *a*, which produced it; on the other hand, some may be emitted because the preceding peck, *b*, also is followed by the delivery of the reinforcer, albeit after a delay. In the single-key instance, however, it is not possible to distinguish between those subsequent pecks that depend on the relationship between Peck *a* and the reinforcer, and those that depend on the relationship between Peck *b* and the reinforcer.

The two-key instance in Fig. 2 shows what may happen if, instead of being emitted on the same key as Peck *a* (Key A), Peck *b* is emitted on a different key (Key B). Of the pecks that follow Peck *a*'s production of the reinforcer, some are emitted on Key A and some are shifted to Key B. This possible outcome is consistent with the data from the present experiments and with the view that each of the responses preceding the one that produces the reinforcer independently contributes to subsequent responding. Two other possible outcomes, not illustrated in Fig. 2, are incompatible with this view: pecks may follow

reinforced Peck *a* on Key A just as in the single-key instance, without pecks on Key B, indicating that the subsequent pecks depend solely on the relationship between Peck *a* and the reinforcer; or pecks may follow reinforced Peck *a* on Key A just as in the single-key instance but with the total number of pecks augmented by additional pecks on Key B, indicating that the reinforcer has a common effect when it acts on one or more responses in a single class (Pecks *a* and *b* on the single key) and adds a further increment to responding when it follows responses in two or more different classes (Peck *a* on Key A and Peck *b* on Key B). Neither of these alternative formulations is consistent with the data from the present experiments, which examine several variations on the single-key and two-key procedures illustrated in Fig. 2.

GENERAL METHOD

Subjects

Four adult male White Carneaux pigeons were maintained at about 80% of free-feeding body weight. Three were experimentally naive; the fourth (Pigeon 94) had been used in a variety of experimental procedures in an undergraduate laboratory course. Before commencing the present experiments, each of the pigeons was exposed for about two months to several variations on the schedules that are described below.

Apparatus

Daily 1-hr sessions were conducted in a standard two-key pigeon chamber (Ferster and Skinner, 1957). Two translucent Gerbrands keys were mounted 2.5 in. (6.4 cm) apart, center-to-center, at a height of 9 in. (23 cm) from the floor and were adjusted to operate at approximately equal forces of 15 g (0.14 N) each. When illuminated by ac Christmas lamps, the left key was amber and the right key was blue. Pecks on a given key produced feedback clicks only when that key was illuminated. Reinforcement consisted of the 3-sec operation of a standard Gerbrands mixed-grain feeder centered beneath the keys. During reinforcement, the feeder light was lit and all other lights in the chamber were turned off. Additional equipment in the chamber included a house-light for general illumination, a speaker that provided white masking noise, and a ventilat-

ing fan. Standard electromechanical scheduling and recording equipment was located in a separate room.

Procedure

In three experiments, reinforcement depended on a succession of pecks, either on a single key or in a particular sequence on two keys. In each experiment, this succession of pecks was reinforced according to a 60-sec variable-interval (VI 60-sec) schedule in which the 20 component intervals were selected according to the specifications of Catania and Reynolds (1968, Appendix II) and in which each interval was timed from the end of the preceding reinforcement.

EXPERIMENT 1: REINFORCEMENT SCHEDULING FOR TWO-RESPONSE SEQUENCES

When VI reinforcement is scheduled for a single peck, the probability that an interval will end and therefore that the next peck will be reinforced increases with time since the last peck (Anger, 1956; Ferster and Skinner, 1957). When VI reinforcement is scheduled for a succession of two pecks, however, the probability that the second of two pecks will be reinforced is not affected by the time between these two pecks. Thus, the contingencies are different when VI reinforcement is scheduled for single pecks (*e.g.*, Peck *a* in the single-key instance in Fig. 2) than when it is scheduled for a succession of two pecks (*e.g.*, Pecks *a* and *b* in either the single-key or the two-key instance in Fig. 2). The two methods of scheduling generate different distributions of terminal interresponse times or IRTs (where a terminal IRT is the time between the peck that produces the reinforcer and the just-preceding peck). A mathematical analysis of terminal IRTs in VI schedules has been provided by Revusky (1962). In an experimental analysis of analogous contingencies in fixed-interval (FI) schedules, Dews (1969) showed that both rate of responding and the distribution of terminal IRTs are affected by whether reinforcement is scheduled for a single response or for a succession of responses.

The general design of the present research requires control of the location, on one or another key, of particular pecks in the sequence of pecks that terminates in reinforcement. But,

because stipulating a sequence of locations implies that reinforcement will depend on a succession of pecks, the contingencies generated by stipulating the location of pecks are necessarily different from those generated by the reinforcement of single pecks. To compare these different contingencies, therefore, Exp. 1 scheduled VI reinforcement in four different ways: two single-key and two two-key procedures were examined.

METHOD

The order and the number of sessions of each procedure are shown in Table 1. In the single-key procedures, the VI schedule operated for pecks on the left key, designated Key A. During these procedures, the left key was blue and the right key was dark, pecks on the left key but not on the right key produced feedback clicks, and a peck on the left key could not be reinforced if the last peck was on the right key. In the two-key procedures, the VI schedule operated for pecks on the left key that followed a peck on the right key, designated Key B. During these procedures, the left key was blue and the right key was amber, and pecks on either key produced feedback clicks.

In the first single-key procedure, VI (A), the VI schedule operated for a single peck on Key A. Thus, the procedure was a standard VI schedule, except for the provision that a Key-A peck could not be reinforced if the last peck was on Key B (changeover delay of 0 sec, COD 0-sec, or changeover ratio of two responses, COR 2, because at least two Key-A pecks were

required for reinforcement, but with no temporal limitations, once a Key-B peck had been emitted: *cf.* Catania, 1966; Herrnstein, 1961). Key-B pecks, however, were infrequent, and the distribution of terminal IRTs was therefore typical of VI reinforcement.

In the first two-key procedure, VI (BA), the VI schedule operated for Key-A pecks that followed Key-B pecks. The eligibility of a Key-A peck for reinforcement was not affected by whether the preceding Key-B peck was emitted before or after the end of an interval. Thus, although reinforcement was always preceded by a Key-B and then a Key-A peck, the distribution of terminal IRTs was complexly determined: at the end of some intervals, reinforcement was available for a succession of two pecks, on Key B and Key A, but at the end of other intervals, when a Key-B peck had just been emitted, reinforcement was available for a single subsequent peck on Key A.

In the two remaining procedures, the VI schedule operated for two pecks in succession, either on a single key (AA) or in a specified sequence on the two keys (BA). In Table 1, these schedules are designated, respectively, as *tand VI AA* and *tand VI BA*; the procedures are tandem schedules in which, at the completion of a variable interval, a particular sequence of pecks is reinforced. In the terminology of Ferster and Skinner (1957, p. 733), the schedule might be called *tand VI 60-sec FR 1*, where the first peck of the sequence of two pecks completes the VI component and the second peck completes the FR (fixed-ratio) component. But this designation may become

Table 1

Schedules, sessions, and rates of responding in several one-key and two-key procedures in Exp. 1. When reinforcement was scheduled for Key-A pecks only, Key A was blue and Key B was dark; when reinforcement was scheduled for pecks on both keys, Key A was blue and Key B was amber. The schedules are described in detail in the text. Data are arithmetic means across the last 5 sessions of each schedule. A—resp/min, Key A (left); B—resp/min, Key B (right); CO—changeovers/min, one direction.

Schedule	Sessions	Pigeons											
		260			261			262			94		
		A	B	CO	A	B	CO	A	B	CO	A	B	CO
VI (A)	13	69	0	0	53	3	2	43	0	0	50	10	9
VI (BA)	12	29	28	22	25	36	19	28	40	20	25	48	18
tand VI AA	18	81	0	0	62	2	2	57	0	0	51	3	2
VI (BA)	16	33	28	23	25	29	15	24	38	18	20	36	16
tand VI AA	29	75	0	0	52	0	0	38	1	1	47	0	0
tand VI BA	15	25	27	18	26	30	13	19	39	15	22	29	15
tand VI AA	19	76	0	0	58	6	4	35	1	1	48	0	0
tand VI BA	17	21	31	18	28	31	16	22	38	21	24	35	18

inaccurate when the keys for which each component operates are specified. In *tand VI AA*, for example, if a Key-A peck terminates the VI component but is followed by a Key-B peck, two additional Key-A pecks are then required in succession (AA) rather than the single peck of FR 1, even though the VI component has already been completed (note that a changeover ratio, COR 2, is therefore implicit in this schedule). Thus, both tandem schedules are specified in terms of the exact sequence of two pecks that must precede the delivery of the reinforcer; this nomenclature also has the advantage of emphasizing the parallel contingencies in the two schedules.

As indicated in Table 1, schedules involving a single key alternated with schedules involving two keys. Each schedule was maintained for about two weeks, with variations that depended on incidental features of laboratory routine (e.g., the work calendar of laboratory personnel). The second presentation of *tand VI AA* was maintained for a longer time because of an apparatus failure in one of the early sessions.

RESULTS

The effects of the two single-key schedules, VI (A) and *tand VI AA*, and of the two-key schedules VI (BA) and *tand VI BA*, are summarized in Fig. 3, which shows the several schedules in the order in which they were presented. Each bar represents mean data from four pigeons (data for the individual pigeons are shown in Table 1). The Key-B rate is plotted above the Key-A rate; thus, the height of each bar represents the overall rate of pecking for the two keys taken together.

The overall rate of pecking did not vary systematically across schedules. The largest difference, between the first presentation of VI (BA) and the second presentation of *tand VI AA*, was of about the same order of magnitude as the difference between the first two determinations on a single schedule, *tand VI AA*. Thus, the changes in schedule had no substantial effect on the total output of responses, either in the comparison between one-key and two-key schedules, or between the schedules in which different contingencies operated for terminal IRTs, i.e., VI (A) and VI (BA) versus the two tandem schedules. The constancy of total output was also well-represented in the

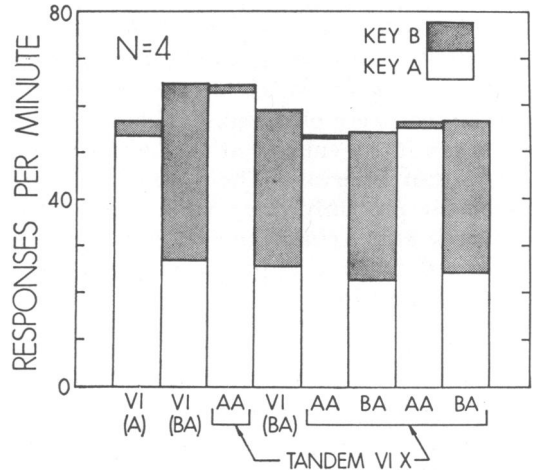


Fig. 3. Rates of responding for four pigeons on various single-key and two-key schedules. Each bar represents an arithmetic mean across the data from four pigeons, based on response rates over the last five sessions of each schedule. The Key-B rate is plotted above the Key-A rate; thus, the height of each bar represents the sum of the rates on the two keys. VI (A)—a peck on Key A is reinforced according to a variable-interval schedule; VI (BA)—the sequence of pecks, on Key B and then Key A, is reinforced according to a variable-interval schedule; *tand VI AA*—after completion of a variable interval, a sequence of two pecks on Key A is reinforced; *tand VI BA*—after completion of a variable interval, a sequence of two pecks, on Key B and then Key A, is reinforced. Details of schedules are described in the text.

individual data for two of the pigeons (Pigeons 261 and 94, Table 1). The two other pigeons deviated from this equality in opposite directions: Pigeon 260 consistently responded at a higher rate on Key A alone in the single-key schedules than on Keys A and B together in the two-key schedules, whereas Pigeon 262 responded at a lower rate on Key A alone in the single-key schedules than on Keys A and B together in the two-key schedules.

Although the schedules had no consistent effects on total output, they did affect the way in which responding was distributed across the two keys. In the single-key schedules, VI (A) and *tand VI AA*, most pecks were emitted on Key A. In the two-key schedules, VI (BA) and *tand VI BA*, the pecks were more evenly distributed between the two keys, with the somewhat larger proportion emitted on Key B in each schedule. The higher rate on Key B than Key A occurred for each pigeon in each of the four presentations of a two-key schedule, or in 16 of 16 cases.

Rates of responding, as examined in cumulative records, were roughly constant within sessions (*e.g.*, no warmup effects were evident). In the tandem schedules, brief pauses after reinforcement were observed, but once responding began it was emitted at a roughly constant rate within intervals. The pauses after reinforcement probably came about because the first peck after reinforcement could never be reinforced when a sequence of at least two pecks was required.

DISCUSSION

The finding that Key-B rates were higher than Key-A rates when the BA sequence was reinforced appears to be paradoxical, because reinforcement of the BA sequence meant that a Key-A peck was followed immediately by the reinforcer, whereas a Key-B peck was followed by the reinforcer only after a delay. The two-key schedules, however, also included contingencies that affected responses preceding the reinforced BA sequence. Consider the possible responses in the sequences of four pecks that can terminate in reinforcement: AABA, ABBA, BABA, and BBBA. Of these sequences, the BABA sequence will often be uncompleted, because the first two as well as the last two pecks are eligible for reinforcement and reinforcement will often be already available as the first two pecks are emitted. Thus, a disproportionate number of reinforcers will follow the sequences AABA, ABBA, and BBBA. In two of these three sequences, a Key-B peck precedes the reinforced BA sequence, and Key-B pecks will therefore be more often followed by the reinforcer in this position than Key-A pecks. (A Key-A peck appears in two of the three sequences in the next position back, but pecks in this position are necessarily followed by the reinforcer after longer delays than pecks in positions closer to the reinforcer, so that the effects of disproportionate Key-A and Key-B reinforcement at this position are not likely to be as great as in the position just before the reinforced BA sequence.) In any case, the somewhat higher rate recorded on Key B than on key A in the two-key schedules does not contradict the basic finding, which is that the total outputs maintained by the single-key schedules were approximately equal to those that were maintained by the two-key schedules.

EXPERIMENT 2: VARYING THE NUMBER OF RESPONSES IN THE SEQUENCE

The preceding experiment examined the effects of Key-B pecks in the position just before the terminal Key-A peck that produced the reinforcer. Experiment 2 systematically examined these effects as Key-B pecks were moved back to earlier positions preceding the terminal Key-A peck. As in Exp. 1, schedules were arranged either for a sequence of pecks on a single key (when only Key A was lit) or for a sequence of pecks on two keys (when both Key A and Key B were lit).

METHOD

The schedules are shown in order of presentation in Table 2, the first two conditions of which repeat the last two conditions of Table 1. Each schedule is described in terms of the sequence of pecks required at the completion of a VI component. Thus, *tand VI AA* and *tand VI BA* are designated, respectively, as $A + 1A$ and $B + 1A$. In general, the designation $A + nA$ means that the tandem schedule arranges VI reinforcement for $n + 1$ consecutive pecks on Key A, uninterrupted by pecks on Key B; the designation $B + nA$ means that the tandem schedule arranges VI reinforcement for a single peck on Key B followed by n consecutive pecks on Key A. In the single-key case, a Key-B peck cannot occur in any of the positions n steps back from the terminal Key-A peck; in the two-key case, a Key-B peck must occur in the position exactly n steps back from the terminal Key-A peck, but not in any position closer to the terminal Key-A peck.

As shown in Table 2, both the single-key and the two-key schedules were examined for values of n from 1 to 5. The value of n was then gradually increased in the two-key schedule only ($B + nA$), and both schedules were examined with n equal to 11. As in Exp. 1, each schedule was maintained for about two weeks, except that $A + 5A$ and $B + 5A$ were continued longer because of an apparatus failure in early sessions of each, $B + 6A$ through $B + 11A$ were continued for fewer sessions because their similarity led to small changes in performance, and $A + 11A$ was continued longer because of the preceding extended exposure to several consecutive $B + nA$ schedules.

Table 2

Schedules, sessions, and rates of responding in several one-key and two-key procedures in Exp. 2. Details as in Table 1, the last two conditions of which are repeated in the first two rows below.

Schedule	Sessions	Pigeons											
		260			261			262			94		
		A	B	CO	A	B	CO	A	B	CO	A	B	CO
A + 1A	19	76	0	0	58	6	4	35	1	1	48	0	0
B + 1A	17	21	31	18	28	31	16	22	38	21	24	35	18
B + 2A	14	41	31	17	34	20	15	33	30	15	39	11	10
A + 2A	14	76	1	0	63	3	2	36	2	2	52	1	1
A + 3A	14	69	0	0	65	2	1	45	1	1	58	1	1
B + 3A	14	59	14	13	51	18	10	41	12	9	63	15	14
B + 4A	14	65	17	12	54	20	10	40	29	10	53	17	10
A + 4A	18	111	0	0	86	2	1	48	1	1	74	1	1
A + 5A	20	106	0	0	102	1	1	72	1	1	85	0	0
B + 5A	22	96	17	15	80	18	10	69	13	8	73	13	10
B + 6A	11	98	14	11	96	15	11	69	14	9	79	12	8
B + 7A	11	100	13	11	94	12	9	60	13	8	79	10	7
B + 8A	8	109	11	9	93	8	6	56	10	8	80	13	7
B + 9A	7	103	13	10	98	10	7	61	11	6	88	9	6
B + 10A	7	99	12	8	98	9	6	67	8	5	94	9	6
B + 11A	8	99	10	7	105	10	6	60	13	5	95	10	6
A + 11A	22	107	0	0	123	2	2	73	3	2	91	0	0

RESULTS

Figure 4 summarizes the effects of the single-key and two-key schedules. The schedules ranged from *tand VI A + 1A* and *tand VI B + 1A*, in which a sequence of two pecks completed the tandem requirement, to *tand VI A + 11A* and *tand VI B + 11A*, in which a sequence of 12 pecks completed the tandem requirement. Thus, in the successive two-key schedules, B + nA, the Key-B peck was moved to positions further back from the terminal Key-A peck that produced the reinforcer. The single-key schedules, A + nA, matched the IRT contingencies that were established as the number of pecks in the two-key sequence increased; in effect, the single-key schedules examined the changes in response rate produced by adding a fixed-ratio component in tandem to the VI schedule.

In both the single-key and the two-key instances, the addition of responses to the terminal component of the tandem schedules raised the overall rate of responding. The major effect took place in the range of requirements between about four pecks (A + 3A) and six pecks (A + 5A). The increase in rate is consistent with findings from tandem FI FR schedules (Ferster and Skinner, 1957, Ch. 8; Dews, 1969).

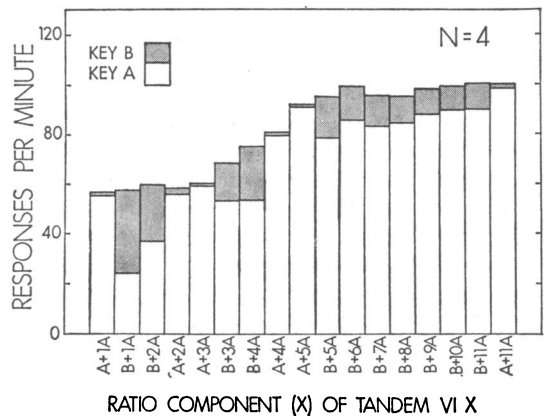


Fig. 4. Rates of responding for four pigeons on various single-key and two-key tandem schedules in which a variable-interval (VI) component was followed by the requirement of a specified sequence of pecks. In the single-key schedules, A + nA, a sequence of n+1 consecutive pecks on Key A was reinforced. In the two-key schedules, B + nA, a peck on Key B followed by n consecutive pecks on Key A was reinforced. Details are as in Fig. 3, the last two schedules of which are repeated as the first two schedules of this figure.

The total output, however, was not obviously affected by whether a single-key or a two-key schedule operated. Over the range of terminal requirements from two pecks (A + 1A and B + 1A) to 12 pecks (A + 11A and B + 11A), the sums of the rates on the two keys were about equal when the numbers of pecks

in the terminal requirements were equal, except for the differences that came about because the successive pairs were superimposed upon an increasing overall rate as the number of pecks in the terminal requirement increased. The major effect of changing from a single-key to a two-key requirement was to shift part of the total output of responses from Key A to Key B. In the two-key schedule, the proportion of pecks on Key B decreased as the Key-B peck was moved from a position one back from the terminal Key-A peck ($B + 1A$) to a position 11 back from the terminal Key-A peck ($B + 11A$).

Differences in the performances of individual pigeons, data for which are shown in Table 2, were unsystematic, and unrelated to the differences noted in Exp. 1. No consistent deviations from equality of overall single-key and two-key rates were noted for Pigeon 260. As the sequence of schedules progressed, Pigeon 261 began to respond at a higher rate on Key A alone in the single-key schedules than on Keys A and B together in the two-key schedules, whereas Pigeon 94 began to respond at a lower rate on Key A alone in the single-key schedules than on Keys A and B together in the two-key schedules. Pigeon 262, which began by responding at a lower rate on Key A alone, completed the sequence of schedules with roughly equal overall rates in the single-key and the two-key schedules.

As in Exp. 1, no substantial warm-up effects were evident in cumulative records, but pauses after reinforcement became somewhat longer as the number of pecks required in the terminal sequences of the tandem schedules increased.

DISCUSSION

These findings are consistent with the assumption that, in single-key schedules, the peck at each position back from the terminal reinforced peck makes an independent contribution to subsequent responding; in the present schedules, the proportion of pecks shifted from Key A to Key B at a given position provides an approximation of the magnitude of this contribution. The measure is an approximation because pecks preceding those specified in a particular sequence were not taken into account (*e.g.*, *cf.* the treatment of $A + 1A$ and $B + 1A$, or AA and BA , in Exp. 1, and note

that only one peck preceding the terminal Key-A peck is specified in $A + 1A$ and $B + 1A$, whereas 11 preceding pecks are specified in $A + 11A$ and $B + 11A$) and because the changes in the proportion of Key-B pecks were superimposed on different total outputs of responses.

In the two-key schedules, the proportion of pecks on Key B decreased as the Key-B peck was moved to positions further back from the terminal Key-A peck. One consequence of moving the Key-B peck back was that Key-B pecks made up a smaller proportion of the required pecks (*e.g.*, the proportion of pecks required on Key B was 0.5 in $B + 1A$, and 0.1 in $B + 9A$). In this experiment, the proportion of Key-B pecks emitted approximately matched the proportion of Key-B pecks required (Herrnstein, 1958, obtained a similar matching of emitted to required pecks in an experiment that examined a combination of ratio requirements on two keys). An account of the proportion of Key-B pecks, however, need not appeal to any matching tendency, because the Key-B pecks in the several two-key schedules were subjected to different delays of reinforcement.

As the Key-B peck was moved further back from the terminal Key-A peck, the mean time from a Key-B peck to reinforcement increased. The delay of reinforcement in a given $B + nA$ schedule can be calculated by taking the mean IRT (which is the reciprocal of the overall rate of responding) and multiplying it by n (which is equivalent to the number of IRTs separating the Key-B peck from the terminal Key-A peck). Thus, a delay-of-reinforcement function (*e.g.*, Dews, 1960; Chung, 1965; Chung and Herrnstein, 1967) could be estimated by plotting either the absolute rate of Key-B pecks or the proportion of Key-B pecks against the calculated time from a Key-B peck to reinforcement. With both Key-B measures, the functions tended roughly to decrease toward an asymptote with increasing delay of reinforcement, but are not presented here because the Key-B measures suffer from the limitations discussed above: the pecks preceding those specified in a particular sequence were not taken into account, and different total outputs of responses were produced by different $B + nA$ schedules. The implication is that, in the present context of schedules, delay-of-reinforcement functions would better be studied with tandem VI (B)

FI (A) schedules, or schedules in which the VI component operates for a single Key-B peck and the FI component operates for Key-A pecks. Such schedules would more directly control the minimum time between a Key-B peck and reinforcement than did the ratio requirement of the present schedules.

EXPERIMENT 3: VARYING THE PATTERN OF RESPONSES IN THE SEQUENCE

The previous experiments examined the effects of requiring a single Key-B peck at various positions preceding the terminal Key-A peck. Experiment 3 examined the effects of one or more Key-B pecks in the positions one back, two back, and three back from the terminal Key-A peck. In each tandem schedule, VI reinforcement was arranged for a sequence of four pecks; the schedules had the form *tand* VI XYZA, where X, Y, and Z independently represent either a Key-A peck or a Key-B peck. Eight different sequences of pecks were possible: one involved three Key-B pecks (BBBA), three involved two Key-B pecks (BBAA, BABA, and ABBA), three involved a single Key-B peck (BAAA, ABAA, and AABA), and one involved no Key-B pecks (AAAA). In this experiment, both keys remained lit throughout the single-key schedule, AAAA, as well as the two-key schedules.

METHOD

The order and sessions of each schedule are summarized in Table 3. The number of sessions was variable because greater decrements in reinforcements per session occurred in the

early sessions of each than in the schedules of Exp. 1 and 2. Once reinforcement had been scheduled at the end of a variable interval in a given tandem schedule, the next interval could not begin until the exact sequence of four pecks required by that schedule was reinforced. In transitions from one complex sequence of four pecks to another (*e.g.*, BBBA to BABA), several sessions sometimes elapsed before each pigeon's performance had changed so that the time from the end of an interval to reinforcement was short relative to the 60-sec mean value of the VI schedule. In such cases, the schedule was extended for several sessions so that the early sessions of low reinforcement rate did not count toward the approximate two-week duration ordinarily maintained for each schedule.

The time between the end of an interval and reinforcement was further affected by the way in which the apparatus was arranged (the schedules in Exp. 1 and 2 were arranged with different apparatus, and did not involve the following contingencies). After an interval had ended, Key-A and Key-B pecks were distributed to two banks of an electromechanical stepping switch, the first four positions of which corresponded to the sequence of four pecks. Once an appropriate peck stepped the switch from the first to the second position, three subsequent appropriate pecks advanced the switch to the fourth position, which operated the reinforcement circuitry: any inappropriate peck in the second, third, or fourth position, however, reset the switch to the first position and could not act as a first-position peck. Consider, for example, the sequence BAAA. When an interval ended, the stepping switch was in the

Table 3

Schedules, sessions, and rates of responding in several one-key and two-key procedures in Exp. 3. Details as in Table 1, except that Key B (right) was amber during all schedules.

Schedule	Sessions	Pigeons											
		260			261			262			94		
		A	B	CO	A	B	CO	A	B	CO	A	B	CO
BAAA	11	78	22	19	86	25	17	51	19	12	61	16	12
AABA	24	53	36	29	63	32	25	41	25	20	53	48	34
ABAA	12	58	31	26	76	24	23	48	22	18	68	40	31
BBAA	23	52	53	26	54	36	21	38	50	17	51	42	23
ABBA	15	26	58	21	36	42	19	29	51	25	44	55	22
BBBA	15	22	69	19	28	53	17	21	72	19	39	41	23
BABA	22	33	42	28	39	41	31	39	47	34	27	49	24
BAAA	28	72	24	19	50	28	15	67	23	16	54	48	20
AAAA	21	104	9	7	60	12	8	83	3	3	72	24	12

first position and remained there until a Key-B peck advanced it to the second position. Three consecutive Key-A pecks then advanced the switch to the fourth position and operated the reinforcement circuitry. If, however, a Key-B peck occurred in the second, third, or fourth positions, it reset the switch to the first position and thus could not simultaneously act to step the switch to the second position. At this point, three consecutive Key-A pecks could have no effect, even though they completed a BAAA sequence, because they could not advance the stepping switch beyond the first position. This particular BAAA sequence therefore could not be reinforced. In other words, once an interval ended, the appropriate sequence of four pecks sometimes was not reinforced until it had been emitted more than once, in instances when the sequence was emitted out of phase with the momentary position of the stepping switch.

The number of appropriate but out-of-phase and unreinforced sequences, and therefore the time from the end of an interval to the eventual reinforcement of that sequence, varied both with the particular sequence (*e.g.*, compare the contingencies for the sequences AAAA, BAAA, and BBBA) and with the pigeon's performance, which in turn varied over continued sessions of exposure to that sequence. In practice, the time from the end of an interval to reinforcement became short relative to the 60-sec mean value of the VI schedule with continued exposure. Thus, despite the limitation on reinforcement of out-of-phase sequences, it was nevertheless possible to compare the effects of various combinations of Key-A and Key-B pecks in the positions one back, two back, and three back from the terminal Key-A peck, because this method of scheduling maintained the essential feature of the procedure: no sequence of pecks other than the exact sequence specified by the schedule could precede the delivery of the reinforcer.

RESULTS

The preceding experiments specified the position of a single Key-B response in the sequence of pecks that terminated with reinforcement. The present experiment examined tandem schedules in which the VI component was followed by a requirement of four successive pecks, the last of which was always on

Key A; the number of Key-B pecks in the possible combinations were zero (AAAA), one (BAAA, ABAA, and AABA), two (BBAA, BABA, and ABBA), or three (BBBA). The data are summarized in Fig. 5, which shows that the overall rate of responding on the two keys taken together was approximately constant across the schedules. The major effect of the several schedules was to move different proportions of pecks from one key to the other.

The proportion of Key-B pecks varied both with the proportion of Key-B pecks in the required sequence and the proximity of each Key-B peck to reinforcement. For example, a greater proportion of Key-B pecks was emitted in schedules with two Key-B pecks in the required sequence (BBAA, BABA, and ABBA) than in those with one Key-B peck in the sequence (BAAA, ABAA, and AABA), but within each of these groups of schedules the proportion of the Key-B pecks was higher in those with Key-B pecks closest to reinforcement (ABBA and AABA) than in those with Key-B pecks most distant from reinforcement (BBAA and BAAA). Thus, a change in the position of Key-B pecks affected the proportion of Key-B pecks emitted even when the proportion of Key-B pecks required in the sequence was held constant. This finding is illustrated in detail in Table 4, which shows the proportion of pecks obtained on Key B for each of the ter-

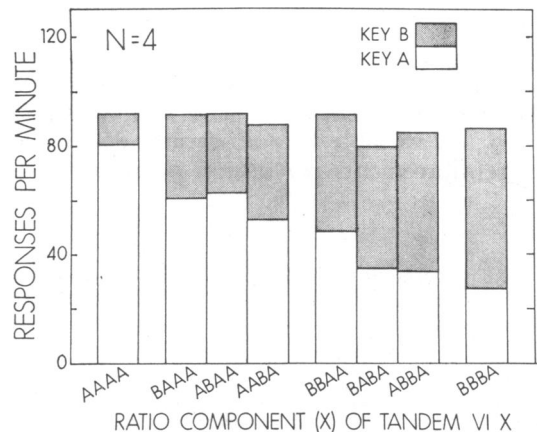


Fig. 5. Rates of responding for four pigeons on various tandem schedules in which a variable-interval (VI) component was followed by the requirement of a specified sequence of four pecks on Keys A and B. Each of the eight possible sequences that ended with a peck on Key A were examined. The data for the BAAA sequence represent a mean of two separate determinations (*cf.* Table 3). Details are as in Fig. 3.

minimal sequences. When the required sequence included a single Key-B peck, the proportion of pecks on Key-B increased monotonically as the pecks separating the Key-B peck from reinforcement decreased, except for the reversal in the second determination with the BAAA sequence for Pigeons 261 and 94. When the required sequence included two Key-B pecks, a similar relationship was obtained; in this case, the only exception was in the reversal of the BBAA and BABA sequences for Pigeon 262. The magnitude of this effect was also in some cases substantial, relative to the kinds of deviations that are usually taken into account in studies of matching relations between responses and reinforcers. For Pigeon 260, for example, the proportion of Key-B pecks increased from 0.22 to 0.40 in the change from the BAAA to the AABA sequence, and from 0.51 to 0.69 in the change from the BBAA to the ABBA sequence; in these two instances, in other words, a proportion of 0.18 or almost a fifth of the pigeon's pecks was shifted from one key to the other by a change in the position of Key-B pecks in the sequences, while the required proportion of Key-B pecks was held constant.

Table 4

Proportion of pecks on Key B (B/B+A) in the one-key and two-key procedures of Exp. 3. Data from the second determination with the terminal sequence BAAA are shown in parentheses.

Required Sequence	Proportion Specified	Proportion Obtained					Mean
		Pigeons					
		260	261	262	94		
AAAA	0.00	0.08	0.16	0.04	0.25	0.13	
BAAA	0.25 (0.25)	0.22 (0.25)	0.22 (0.36)	0.27 (0.26)	0.21 (0.47)	0.23 (0.33)	
ABAA	0.25	0.35	0.24	0.31	0.37	0.32	
AABA	0.25	0.40	0.34	0.38	0.47	0.40	
BBAA	0.50	0.51	0.40	0.57	0.45	0.47	
BABA	0.50	0.56	0.51	0.55	0.64	0.56	
ABBA	0.50	0.69	0.54	0.63	0.69	0.60	
BBBA	0.75	0.76	0.66	0.78	0.52	0.68	

Rate differences among individual pigeons, the data for which are presented in Table 3, were unsystematic and not obviously related to the individual differences in Exp. 1 and 2. The tendency, shown in the group data of Fig. 5, toward lower rates in the schedules that included two or three rather than zero or one Key-B pecks in the terminal sequence, was not consistently evident in the data for individual

pigeons. In the repetition of the schedule BAAA, the data from the initial exposure to that schedule were not closely recovered for Pigeons 261 and 94, perhaps because the initial exposure was for a relatively small number of sessions. In the final schedule, AAAA, Pigeons 260, 261, and 94 responded at a higher rate on Key-B than in the earlier single-key sessions, probably because both keys remained lit during this schedule. For Pigeon 94, in particular, about one-quarter of its pecks were emitted on Key B even after 21 sessions of the AAAA schedule; for Pigeon 94 and for the other pigeons, however, the total output on Keys A and B together was within the range of total outputs obtained with the preceding two-key schedules. The continued pecking on Key B for Pigeon 94 may represent an example of concurrent superstition (Catania and Cutts, 1963): preceding sessions of BAAA established a performance in which one or more Key-B pecks were followed by several successive Key-A pecks: this performance was often reinforced in the AAAA schedule if at least four pecks were emitted in the succession of Key-A pecks; thus, reinforcement may have continued for Key-B pecks in the positions four or more pecks back from the terminal Key-A peck.

Temporal patternings of responses within sessions, as examined in cumulative records, were similar to those observed in Exp. 1 and 2.

DISCUSSION

Despite instances of variability, the present data are consistent in suggesting that total outputs of responding on two keys are not affected by the way in which pecks are distributed between the two keys. Rates of responding may be altered by the terminal contingencies in schedules (as when rates increased with increasing ratio requirements in the tandem schedules: Exp. 2), but the present data indicate that these rates do not depend on whether the contingencies operate on a succession of pecks on a single key or on a specified sequence of pecks on two keys.

Although the specification of terminal contingencies for sequences of pecks on one or two keys did not affect total output, it did affect the proportions of pecks on the two keys. This finding limits interpretations in terms of tendencies to match proportions of Key-B pecks emitted to proportions of Key-B pecks required. It also implies that any ac-

count in terms of sequences of pecks as response-units (*cf.* the treatment of a related problem in Heise, Keller, Khavari, and Laughlin, 1969) must deal with the different effects of reinforcement on pecks at different positions in the sequence.

The argument that each peck in the sequence terminating with reinforcement makes an independent contribution to the subsequent rate of responding suggests that the performances in schedules involving a single Key-B peck should predict the performances in schedules involving two or more Key-B pecks. For example, the schedules BAAA, ABAA, and AABA provide data for a Key-B peck in the positions three back, two back, and one back from the terminal Key-A peck; thus, the sum of the Key-B rates in these three schedules might be expected to predict the Key-B rate in the schedule BBBA, which simply combines the Key-B requirements in each of the other schedules. This kind of summation, however, does not work, probably in large part because these schedules are restricted only to the last four pecks preceding reinforcement. As indicated in Exp. 2, pecks at least as far as 11 positions back from the terminal Key-A peck affect subsequent responding. Because the proportions of Key-A and Key-B pecks were different in each of the schedules of the present experiment, their representation in the unspecified earlier positions was likely to have been different in each schedule. In addition, the method of reinforcing the four-peck sequences created contingencies that presumably influenced whether Key-A or Key-B pecks were likely to be in the various earlier positions (*cf.* Procedure for Exp. 3, and the treatment of the BA sequence in Results for Exp. 1).

The schedule of Exp. 3 affected not only contingencies for prior response sequences, but also rates of reinforcement. Throughout Exp. 1 and 2, the actual rates of reinforcement provided by the VI 60-sec component of the tandem schedules were typically within the range from about 50 to 55 reinforcements per hour (VI 72-sec to VI 65-sec). Within this range, the rate of reinforcement was lowest for those tandem schedules that required the greatest number of pecks in the ratio component, but there were no substantial differences in reinforcement rate between equivalent single-key and two-key schedules (*e.g.*, A + 11A and B + 11A). In Exp. 3, however,

reinforcement rates were sometimes as low as 15 reinforcements per hour in the early sessions of a given schedule; after several sessions of exposure, the rates that were maintained were ordinarily within the range from about 45 to 50 reinforcements per hour (VI 80-sec to VI 72-sec). These effects on reinforcement rate probably depended on the particular contingencies arranged by the apparatus in this experiment (see Method).

Reinforcement rates may have contributed to the differences among the overall rates of pecking for the several schedules of Exp. 3. But on the function relating VI response rate to VI reinforcement rate (Catania and Reynolds, 1968), a VI 60-sec schedule is located in the region of reinforcement rates at which a decrease of as much as one-third (*i.e.*, to VI 80-sec) would be expected to produce only relatively small decrements in the rate of responding. Thus, the contribution of reduced reinforcement rates to the overall rates of pecking in Exp. 3 is likely to have been small. It would not be plausible to argue, for example, that the overall rates of pecking in two-key schedules should have been higher, but depended upon an increment based on reinforcement of Key-B pecks that was cancelled by a decrement caused by reduced reinforcement rates; any decrements caused by reduced reinforcement rate could not have matched the large proportions of Key-B pecks in Exp. 3 if these had been increments to the rate maintained on Key A alone in a single-key schedule.

The argument that the overall rates of pecking in two-key schedules should have been higher than in single-key schedules, because two responses are reinforced instead of one, can also be based on the assumption that an increment in total output is cancelled by an effect of changeovers; it is possible that successive pecks on two keys consume more time than successive pecks on a single key, because of the time taken to move from one key to the other. This argument, however, can also be rejected. Experiment 3 provides several instances of pairs of schedules that require the same proportions of Key-A and Key-B pecks, but that generate different rates of changeover from one key to the other. In these comparisons, there is no systematic correlation between total output and changeover rate (*e.g.*, *cf.* ABBA and BABA, Pigeon 261,

and BBAA and BABA, Pigeon 262, Table 3); the finding is consistent with other data on two-key performances, which suggest that to some extent overall rates vary independently of the moment-to-moment patterning of responses in time (*e.g.*, Catania, 1963; Reynolds, 1963).

GENERAL DISCUSSION

The present findings imply that each peck preceding the peck that produces the reinforcer makes an independent contribution to the subsequent rate of responding. The reinforcer acts not only on the response that produces it, but also on other, earlier responses. The present experiments assessed the contribution of a response in a given position preceding reinforcement by changing its location from one key to another; the proportion of the total output of responses that also changed location was an index of the extent to which the total output depended on the reinforcement of that particular response. The change in location was, in effect, a manner of tagging those responses that had their origin in the relationship of a particular earlier response to the reinforcer.

The contribution of a given response to the total output diminished as the response was moved to positions further back from the reinforcer. Nevertheless, effects were demonstrable even for responses that were 11 positions back from the terminal reinforced response. These effects complicated the analysis of those schedules that specified only a short sequence of responses preceding reinforcement, because such schedules did not control the distribution of responses in the positions preceding those specified in the sequence.

Inadequacy of Chaining and Response-Unit Interpretations

The present account has not examined particular properties of response sequences on the two keys in detail, although the major sequential characteristics of performance can be derived from the response-rate and changeover data of Tables 1, 2, and 3. The reason is that a detailed analysis of the emitted sequences could not deal with the constant total outputs generated by different terminal sequences required on the two keys. Even if a plausible account of a particular succession of pecks

could be given in terms of response chaining or in terms of response units made up of several pecks, such an account could not specify the rate at which the pecks in the sequence would be emitted. In fact, if reinforcement of a succession of pecks on two keys (*e.g.*, the four pecks of the sequence ABBA) made that succession of pecks function as a unit, some account would have to be given of why that unit should be emitted at such a rate that the output equals that produced by the reinforcement of successions of four pecks on a single key. It may or may not be convincing to suggest that a succession of four pecks on a single key (*e.g.*, the sequence AAAA) functions as a unit. But in either case, the pigeon's performance on two keys does not consist of the unvarying and accurate repetition of the unit, and thus it is necessary to consider how the pecks that make up a unit combine with those pecks that are not part of the unit to generate a given total output (*e.g.*, if ABBA is the reinforced sequence, and the sequence ABBAABBBA is emitted, only the first four pecks can be counted as an instance of the unit established by reinforcing the ABBA sequence). Because of the difficulties with such accounts, the discussion that follows concentrates upon delayed reinforcement of each response in a sequence as a determinant of the total output of responses, and does not consider accounts in terms of chaining or in terms of higher-order response units.

The Role of Delayed Reinforcement

Responses in different positions preceding a reinforced response are acted upon by the reinforcer with different delays. The effects of delayed reinforcement have been amply demonstrated (*e.g.*, Ferster, 1953; Dews, 1960). Dews (1962) argued that the way in which responding is temporally distributed within a fixed interval is a consequence of the action of different delays of reinforcement on responses emitted at different times within preceding fixed intervals. Effects of delayed reinforcement have been demonstrated within concurrent schedules, in which delayed reinforcement may be explicitly scheduled (*e.g.*, Chung, 1965; Chung and Herrnstein, 1967) or in which one response may be maintained by a reinforcer later produced by a different response (*e.g.*, Herrnstein, 1961; Catania and Cutts, 1963). Delayed reinforcement presum-

ably also operates in stimulus-control procedures, in which delays are often incorporated to increase the temporal separation of responses in the presence of one stimulus and subsequent reinforced responses in the presence of another stimulus (*e.g.*, Ferster and Appel, 1961; Morse, 1955).

These demonstrations provide no evidence to suggest that the effect of delayed reinforcement on a response depends on whether the reinforcer follows the response with an explicitly scheduled delay, is produced by a subsequent response of the same or a different operant class, or occurs incidentally without any scheduled relationship to the response. The output generated by a response that is reinforced after a particular delay is not affected by whether other responses intervene between that response and the reinforcer (Neuringer, 1969). The implication is that a reinforcer that follows two responses will generate more subsequent responding than a reinforcer that follows a single response, because the reinforcer in the first case acts upon each of the two responses independently. When a reinforcer follows two responses, however, its effect will also depend on their separation in time (interresponse time or IRT), because that time will determine the delay with which the reinforcer acts on the first of the two responses.

Delayed-Reinforcement versus Differential-Reinforcement Analyses of Schedules

This interpretation provides an alternative to the analysis of reinforcement schedules in terms of the differential reinforcement of IRTs. The rates of responding that are generated by reinforcement schedules have been attributed to the different probabilities with which different IRTs are reinforced in different schedules (*cf.* Anger, 1956; Millenson, 1964; Morse, 1966; Skinner, 1938, Ch. 7). In ratio schedules, the probability of reinforcement is independent of IRT. In interval schedules, the probability of reinforcement increases with IRT. Thus, the higher rates of responding (shorter IRTs) maintained in ratio than in interval schedules are usually attributed to the relatively less-probable reinforcement of long IRTs in ratio schedules.

But although IRT interpretations are consistent with the difference between ratio and

interval schedules, such interpretations account with difficulty for the tendency of IRTs to shorten even in the absence of differential reinforcement of short IRTs (*cf.* Millenson, 1966). In ratio schedules and to a lesser extent in interval schedules, IRTs shorten with continued exposure to a schedule, even though neither differentially reinforces short IRTs (Ferster and Skinner, 1957).

The tendency for IRTs to shorten in these schedules is consistent with other observations. Malott and Cumming (1964, 1966) found, with rats, that when a given range of short IRTs was reinforced with a low probability, whereas another range of longer IRTs was reinforced with a higher probability, the shorter IRTs nevertheless often predominated in the terminal performance. Blough (1966) manipulated the relative frequencies of different IRTs in pigeons by reinforcing only those IRTs that, over a preceding interval of time, had occurred least frequently relative to a theoretical exponential distribution of IRTs. He found that IRTs shorter than 0.8 sec, in contrast to longer IRTs, were not well controlled by this schedule. Difficulties in controlling short IRTs by differential reinforcement have also been noted by Staddon (1965) and Reynolds (1966).

Millenson (1966) suggested that short and long IRTs might be distinguished in terms of their "susceptibility to reinforcement": in other words, short IRTs are more easily affected by reinforcement than long IRTs. Such a notion seems consistent with the preceding observations and with other accounts of schedules of reinforcement (Anger, 1956; Catania and Reynolds, 1968). The present experiments suggest how an account in terms of the delayed reinforcement of responses in the sequence preceding the reinforcer can be brought to bear on the susceptibilities of different IRTs to reinforcement and can substitute for an account in terms of the differential reinforcement of IRTs.

Consider the comparison of two specific examples (*cf.* Fig. 1). In one case, a single 7-sec IRT is terminated by a reinforced response. In a second case, seven successive 1-sec IRTs are terminated by a reinforced response. The relative frequencies of reinforcement of the 7-sec and 1-sec IRTs illustrate the fact that, within interval schedules, the probability of reinforcement of an IRT is roughly pro-

portional to its duration; the probability of reinforcement of 7-sec IRTs is seven times as great as the probability of reinforcement of 1-sec IRTs. Nevertheless, over a considerable range of interval-schedule values, 1-sec IRTs would be likely to predominate over 7-sec IRTs with continued exposure of a responding organism to the schedule.

Consider now the effects of reinforcement. In the first case, when the terminal response of a single 7-sec IRT is reinforced, the total contribution of reinforcement to the subsequent rate of responding comes from its effect on the terminal response plus its effect with a delay of 7 sec on the response that initiated the IRT. In the second case, when the last response of the final 1-sec IRT is reinforced, reinforcement contributes to the subsequent rate of responding not only through its effect on the terminal response plus its effect with a delay of 7 sec on the response that initiated the first IRT, but also through its effect on the intermediate responses, with delays of 6, 5, 4, 3, 2, and 1 sec, respectively. It seems reasonable to assume that this additional contribution of reinforcement, with respect to a greater number of responses and after shorter delays than in the first case, would be reflected in subsequent responding. In other words, because a single reinforcer acts upon many responses and each contributes to subsequent responding, and because the reinforcer acts with shorter delays when IRTs are short (high rates) than when they are long (low rates), higher rates of responding follow reinforcement of short than of long IRTs.

The implications of this account for the development of performances under various reinforcement schedules has already been well-stated by Dews: ". . .the possibility should be considered that the high rates of responding engendered by fixed-ratio schedules (FR) may come about as follows: The higher the average rate of responding on an FR schedule, the closer, temporally, the initial response and all subsequent responses in the FR are to reinforcement, and, therefore, the greater the retroactive enhancing effect of that reinforcement. This will tend to increase the rate of responding, which in turn will tend to bring the responses closer to reinforcement, which will increase the rate further. Thus, there is, in effect, a positive feedback situation, in which random increases in rate will tend to be

self-enhancing. Similar interpretations can be given to other schedule performances that have been described; but their validation depends on specific quantitative information that is not now available" (Dews, 1962, p. 373).

Implications for the Vocabulary of Reinforcement.

Such an account does not appeal to the differential reinforcement of IRTs except in the sense that, in any schedule, reinforcers will act differently upon different IRTs. The susceptibility of short IRTs to reinforcement is simply a consequence of the short delay between the initiating response of the IRT and the reinforcer that follows the terminating response of the IRT. The account could be extended from one in terms of the delayed reinforcement of preceding responses when the last of a sequence of responses is reinforced to one in terms of the reinforcement of other behavior when a single response is reinforced at the end of a long IRT. The two accounts are complementary, but the former account has the advantage of not appealing to unrecorded behavior.

The present experiments provided an explicit alternative response, and demonstrated the relationship of this response to the reinforced response. The experiments suggested that each of the responses in the sequence preceding reinforcement made independent contributions to subsequent responding. By taking into account the time that separated each response from the reinforcer, the preceding discussion extended the analysis to the different rates of responding maintained by different schedules. Thus, the analysis also clarified what might otherwise seem to be an inconsistency of the present experiments: that total output was not affected by the locations of different pecks in the terminal components of the tandem schedules, but was affected by the number of pecks in those terminal components. A change of location from one key to the other did not affect the times from successive pecks to reinforcement, but a change in the number of pecks in a sequence affected these times by altering the probabilities with which different IRTs at different positions in the sequence were reinforced.

It has been argued elsewhere (Catania, 1969) that the usage of the term *reinforcement* for both operation and process has consequences

for the analysis of behavior. It is interesting to speculate on whether this usage has contributed to the failure to recognize the independent contributions to response rate of the responses preceding the one that produces the reinforcer. In descriptions of reinforcement schedules, it is said that a particular response is reinforced and that other responses are unreinforced. In terms of process, however, the present findings make it appropriate to say that all of the responses preceding the one that produces the reinforcer are reinforced. In analyses such as those of the present experiments, it is convenient to speak of both reinforcement as operation and reinforcement as process, and to allow the two terms to be distinguished by context. But if the ambiguity misleads, then it would be more useful to have a separate term for process. Perhaps it is time to recognize a term that has long been part of informal usage, and to distinguish operations from processes by saying that when we *reinforce* the last response of a sequence of responses we *strengthen* all of the responses in the sequence.

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