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YOKED VARIABLE-RATIO AND VARIABLE-INTERVAL RESPONDING IN PIGEONS[1]

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Pigeons' key pecks were maintained by variable-ratio or variable-interval schedules of food reinforcement. For pairs of pigeons in one group, variable-ratio reinforcement was arranged for one pigeon's pecks; for the second pigeon, reinforcement was arranged according to a variable-interval schedule yoked to the interreinforcement times produced by the first pigeon. For pairs of pigeons in another group, variable-interval reinforcement was arranged for one pigeon's pecks; for the second pigeon, reinforcement was arranged according to a variable-ratio schedule yoked to the interreinforcement responses produced by the first pigeon. For each pair, the yoking procedure was maintained for four or five consecutive sessions of 50 reinforcements each. In more than three-quarters of the pairs, variable-ratio response rates were higher than variable-interval rates within two sessions; in all cases, the rate difference developed within four sessions.

Key words: variable-interval schedule, variable-ratio schedule, yoked schedules, time per reinforcement, responses per reinforcement, shaping, undergraduate laboratory course, key pecks, pigeons

In a VI schedule, a response is selected for reinforcement on the basis of the time elapsed since some environmental event, such as the last delivery of a reinforcer; in a VR schedule, a response is selected on the basis of the number of responses that have been emitted. Thus, the rate of responding maintained by a VI schedule can change substantially without an appreciable effect on the time between reinforcements (provided that the rate is sufficiently high that the minimum interresponse time does not greatly exceed the minimum interreinforcement interval); as VI response rate changes, however, the number of responses per reinforcement must also change. In a VR schedule, on the other hand, a change in response rate has no effect on the number of responses per reinforcement, but directly affects the time between reinforcements (*cf.* Neuringer and Schneider, 1968). Over a range of values, interval schedules typically maintain lower response rates than ratio schedules (*e.g.*, Ferster and Skinner, 1957; Kintsch, 1965; Williams, 1968). The role of time per reinforcement and of responses per reinforcement in generating this difference in rate can be assessed by yoking: when a VR schedule is yoked to the responses per reinforcement produced by a VI performance, then the two schedules may differ in the times between reinforcements but not in the responses per reinforcement; when a VI schedule is yoked to the times between reinforcements in a VR performance, then the two schedules may differ in responses per reinforcement but not in the times between reinforcements. If the difference between VR and VI response rates occurs with both directions of yoking, then the difference can be attributed neither to time per reinforcement

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alone nor to responses per reinforcement alone; the basis for the difference must be sought in other properties of these schedules.

To assess the role of reinforcement rate in performances maintained by ratio schedules of reinforcement, Ferster and Skinner (1957, pp. 399-407; see also Killeen, 1969) arranged a yoked-box procedure. One pigeon's pecks were reinforced according to a variable-ratio (VR) schedule, and each reinforcer produced by this pigeon made the next peck of a paired pigeon in another chamber eligible for reinforcement. Thus, the second pigeon's pecks were maintained by a variable-interval (VI) schedule in which the successive interreinforcement intervals were matched to those produced by the first pigeon. Within each of two pairs of pigeons, rates of responding maintained by a VI 5-min schedule had first been roughly equated by adjustments of levels of deprivation; for one pigeon of each pair, the VI schedule was then changed to a VR schedule chosen to match the mean VI responses per reinforcement, and the VR interreinforcement times determined the yoked VI schedule for the other pigeon of the pair. For one pair, the response rate of the VR pigeon became consistently higher than that of the yoked VI pigeon within four sessions. For the second pair, with a shorter VI history before yoking, the responding of the VR pigeon was not well maintained, and differences between the VR and the yoked VI pigeon were evident mainly in the temporal patterning of responses, rather than in overall response rates.

The difference between VI and VR performance is well documented (*e.g.*, Thomas and Switalski, 1966; Zuriff, 1970), but except for some data with humans (Matthews, Shimoff, Catania, and Sagvolden, 1977), the existing literature provides little information about the rapidity with which this difference emerges in yoked schedules. The present research provides such data for pigeons while examining yoking in both directions and demonstrating the feasibility of such experiments in a large undergraduate laboratory course.

METHOD

Subjects

Twenty-five adult, male, White Carneaux pigeons in Spring 1969 and 20 in Spring 1970 were maintained at about 80% of free-feeding body weights. Each pigeon was experimentally naive when introduced into the laboratory.

Apparatus

Five standard pigeon chambers included a 2.0-cm diameter key centered above a feeder (both R. Gerbrands Co.), a houselight, a masking-noise source, and a ventilating fan. The key was operated by a minimum force of about 0.14 N, and could be transilluminated by a white lamp. Reinforcement consisted of 4-sec access to grain in the feeder, during which the feeder was lit and the houselight and keylight were off. A window in the side of the chamber allowed visual observation of the pigeon; when the window was open for observation, room lights were turned off. Scheduling and recording were arranged by manual operation of pushbutton and matrix switches (Catania and Zimbardo, 1972) in conjunction with standard electromechanical equipment. The five chambers and their associated equipment racks were located around the perimeter of a single room.

Procedure

The experiments were conducted in the context of an undergraduate laboratory course in the experimental analysis of behavior. The number of laboratory sections per week varied with student enrollment: five afternoon sections, Monday through Friday, in Spring 1969, and four afternoon sections, Tuesday through Friday, in Spring 1970. Each section consisted of 10 to 15 students, assigned in pairs or trios to each experimental chamber. A general introduction to laboratory procedures was provided in the first week of laboratory meetings.

In the second week, a pigeon was placed in each chamber about 30 min before the start of each laboratory session. Each student group then conducted feeder training and shaping of their pigeon's key peck. In feeder training, the feeder was operated intermittently to a criterion of five successive reinforcer deliveries in which the pigeon's latency to start eating was 2 sec or less. Shaping followed immediately. For shaping, the students in each group were provided with pushbuttons arranged in series so that the feeder operated only when the pushbuttons were pressed simultaneously. The feeder operated, therefore, only if all students in a group judged the approximation to key pecking as appropriate for reinforcement. Shaping was typically completed within 30 or fewer reinforcements. The apparatus was arranged to reinforce each key peck, and after the first key peck occurred the pigeon was allowed to remain in the chamber to a satiation criterion of 5 min without a peck.

The third week provided an introduction to reinforcement schedules. Each student group worked with its pigeon of the previous week. First, low-rate responding was established with 25 reinforcements according to a differential-reinforcement-of-low-rate (DRL) schedule: a peck was reinforced if at least 2 sec (Spring 1969) or 3 sec (Spring 1970) had elapsed since the preceding peck (the first peck after a reinforcer delivery was not eligible for reinforcement). Then, high-rate responding was established with 25 reinforcements according to a fixed-ratio (FR) or variable-ratio (VR) schedule: each student group was allowed to select an FR or VR schedule over a range from five to 15 responses per reinforcement. (In the five-section Spring 1969 course, which began with 25 pigeons, the five pigeons with the lowest response rates at the end of this session were excluded from subsequent procedures.)

In the fourth week of each semester, the 20 pigeons were divided into four groups of five pigeons each, and each pigeon was used in each laboratory section. The 10 pigeons with the highest response rates over the last 10 reinforcements of the previous ratio session were assigned to VI schedules; the remaining 10 were assigned to VR schedules. Five (Spring 1969) or four (Spring 1970) 51-reinforcement sessions were then conducted for each pigeon. The VI schedules were timed from the end of the preceding reinforcement, and reinforcement durations were excluded from computations of both VI and VR response rates. Scheduling and recording did not begin until the first peck of each session, which was reinforced. At the end of each laboratory day, data were collected from each student group and were confirmed by comparison with cumulative records obtained during the session.

Each student group in each laboratory section conducted consecutive sessions for four pigeons. The responses of the first pigeon were reinforced according to a VI 30-sec schedule. A repeating sequence of 20 irregularly ordered intervals was arranged according to the specifications of Catania and Reynolds (1968, Appendix II). The responses between successive reinforcements were recorded cumulatively, and were used to arrange a yoked VR schedule for the second pigeon. Thus, for this pair of pigeons, responses per reinforcement were held equal; times per reinforcement, however, were fixed by the VI schedule for the first pigeon, but varied with the rate of responding maintained by the yoked VR schedule for the second pigeon.

The responses of the third pigeon were reinforced according to a VR 25 schedule. The sequence of ratios consisted of five different irregular orderings of the ratios: 1, 1, 3, 5, 10, 20, 30, 40, 60, 80. The times between successive reinforcements were recorded cumulatively to the nearest second, and were used to arrange a yoked VI schedule for the fourth pigeon. Thus, for this pair of pigeons, times per reinforcement were held roughly equal; responses per reinforcement, however, were fixed by the VR schedule for the third pigeon, but varied with the rate of responding maintained by the yoked VI schedule for the fourth pigeon.

RESULTS

Table 1 summarizes the rates of responding maintained during the last session of yoking for each pair of pigeons. In each of the 20 pairs, independently of whether VI times per

Table 1

Rates of pigeons' key pecking (responses per minute) maintained by yoked variable-ratio (VR) and variable-interval (VI) schedules of food reinforcement during the last of five (March 1969) or four (March 1970) consecutive sessions of 51 reinforcements each. Details in text.

Pigeon Pair	*VR 25*	*Yoked VI*	*Pigeon Pair*	*VI 30-sec*	*Yoked VR*
March 1969					
55 - 51	99	45	52 - 61	40	104
60 - 57	85	61	58 - 65	63	111
56 - 59	92	74	64 - 67	38	94
63 - 66	125	67	74 - 68	33	126
77 - 75	93	37	76 - 70	30	79
March 1970					
341-336	73	34	331-326	49	70
339-337	125	64	332-327	29	54
343-338	81	39	333-328	59	73
344-342	71	41	329-334	42	79
345-340	66	24	335-330	30	150

reinforcement were yoked to VR performance or VR responses per reinforcement were yoked to VI performance, VR response rates were higher than VI response rates. In each case, this difference was in the opposite direction from that at the beginning of the first session of yoking, because the highest-rate pigeons from the schedules of the preceding week had been assigned to VI schedules.

In March 1969, when the procedure continued for five sessions, the distributions of response rates did not overlap: the lowest VR response rate (79 responses per minute for Pigeon 70) was higher than the highest VI response (74 responses per minute for Pigeon 59). In March 1970, when the procedure continued for only four sessions, the lowest VR response rate (54 responses per minute for Pigeon 327) was lower than the two highest VI response rates (64 responses per minute for Pigeon 337 and 59 responses per minute for Pigeon 333). On the average, VR response rates were about twice those for VI schedules for both directions of yoking; mean response rates were 91 responses per minute for VR 25, 49 responses per minute for yoked VI, 41 responses per minute for VI 30-sec, and 94 responses per minute for yoked VR. A more detailed comparison of the two directions of yoking seems inappropriate on the basis of the present data, because it is not clear whether exposure to the schedules should be equated on the basis of time or of number of reinforcements.

Sample cumulative records for each direction of yoking are shown for the third session from the laboratory of October 1968 in Figure 1. Arrows illustrate the correspondence between responses per reinforcement and time per reinforcement respectively for the two yoked pairs.

Differences between yoked VR and VI response rates have been obtained reliably over several semesters of the laboratory course, with occasional variations in the details of the procedure (in some semesters, for example, pigeons were assigned to VI or VR schedules without regard to their response rates in the preliminary schedules of the preceding week). The laboratories of October 1967 (three sessions) and February 1968 (four sessions) examined only the yoking of a VR schedule to the times per reinforcement in VI 30-sec schedules; higher VR than VI rates were obtained within each of 16 pairs of pigeons. The laboratories of October 1968 through March 1970 examined yoking in both directions. In 17 of 19 pairs with VR schedules yoked to responses per reinforcement in VI 30-sec schedules, and in 17 of 19 pairs with VI schedules yoked to times per reinforcement in VR 25 schedules, VR response rates were higher than VI response rates by the final session; the four exceptions all occurred in the October 1968 and October 1969 laboratories, when the number of laboratory sections limited yoking to three sessions. In more than 75% of the pairs from all semesters, VR response rates were higher than VI response rates by the second session of yoking; in other words, a single session of 50 reinforcements and perhaps 15 min was typically sufficient to produce the rate difference, even when the pigeons were matched with reversed baseline rates. With variations, the yoking procedures have continued as a reliable component of subsequent offerings of the laboratory course.

DISCUSSION

Whether VR and VI schedules are matched with respect to responses per reinforcement or time per reinforcement, VR schedules generate higher response rates than VI schedules. Neither variable alone, therefore, can be the source of the different rates generated by the two types of schedules. Accounts of the rate difference have in any case usually been in terms of another property that differentiates VR schedules from VI schedules: the relation between interresponse times (IRTs) and probability of reinforcement (Anger, 1956, 1973; Kuch and Platt, 1976; Reynolds and McLeod, 1970; Shimp, 1970, 1973). In VR schedules, the probability that a response will be reinforced depends only on the value of the schedule; it does not vary with the time since the preceding response. In VI schedules, on the other hand, the probability of reinforcement increases with time since the preceding response. Thus, in VR schedules a relatively larger proportion of short IRTs and a relatively smaller proportion of long IRTs are reinforced than in VI schedules. This difference could provide the basis for lower VI than VR rates through the relatively greater differential reinforcement of long IRTs in VI than VR schedules.

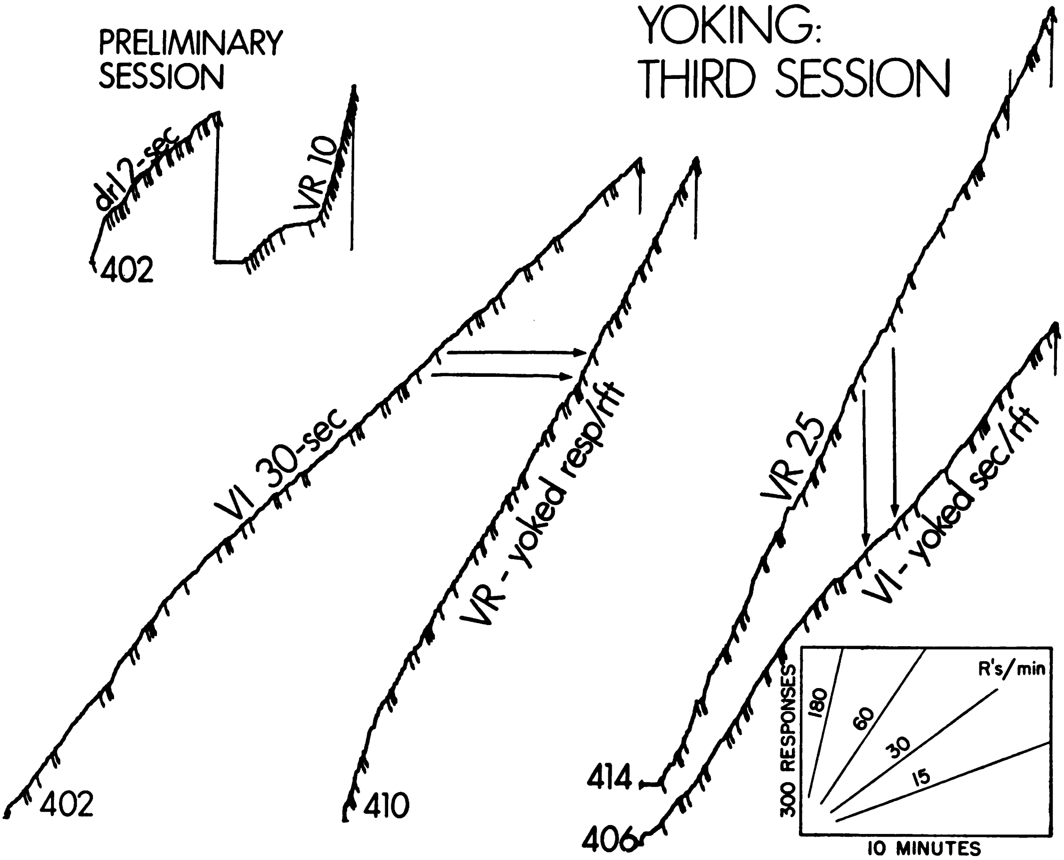

Fig. 1. Cumulative records of the third yoking session for two representative pairs of pigeons: the VI responses per reinforcement for Pigeon 402 provided a yoked VR schedule for Pigeon 410, and the VR time per reinforcement for Pigeon 414 provided a yoked VI schedule for Pigeon 406. In both pairs, VR response rate was substantially higher than VI response rate. Pen displacements represent reinforcer deliveries. Performances on preliminary differential-reinforcement-of-low-rate (DRL) and VR schedules are illustrated by the upper-left record for Pigeon 402. VI—variable interval; VR—variable ratio. (The records are from October 1968, when enrollment allowed only three laboratory sections and therefore only three sessions of yoking; complete sets of yoked records are no longer available for most semesters because students were allowed to take records for use in laboratory reports.)

The different probabilities of IRT reinforcement have implications for the distributions of reinforced IRTs in VR and VI schedules. In VR schedules, the distribution of reinforced IRTs is similar in form to the distribution of all IRTs, whereas in VI schedules, the distribution of reinforced IRTs is shifted in the direction of longer IRTs relative to the distribution of all IRTs. It is conceivable that organisms may be in some way directly sensitive to these different relations between IRT and reinforced-IRT distributions in VR and VI schedules. With the present yoked schedules, however, differences between VR and VI rates came about in most cases within one or two 50-reinforcement sessions. Given that the pairs were yoked so that VR pigeons began with lower rates than VI pigeons, differential reinforcement of IRTs or sensitivity to the different distributions of reinforced IRTs must have operated on the basis of a relatively small sample of reinforced IRTs, if these variables were the basis for the rate difference.

Delay-of-reinforcement effects may also be involved in the difference between VR and VI rates (Catania, 1971; Dews, 1962). The effect of each reinforcer in generating subsequent responses may depend not only on its relation to the response that produced it but also on its relation to earlier responses. The relatively higher probabilities of reinforcement for short IRTs in VR than in VI schedules imply shorter delays between these earlier responses and the reinforcer, and therefore larger contributions to subsequent responding (*i.e.,* higher rates), in VR than in VI schedules.

The available data, however, do not rule out another possibility, at a more molar level. Although the yoking procedures demonstrated that the difference between VR and VI performance cannot be attributed either to time per reinforcement alone or to responses per reinforcement alone, they did not eliminate the different correlations in VR and VI schedules between response rate and these two variables. On the average, times per reinforcement are inversely correlated with rate of responding in VR but not in VI schedules, whereas responses per reinforcement are directly correlated with rate of responding in VI but not in VR schedules. The correlation will necessarily be affected by the durations of the time intervals over which these variables are sampled, but the difficulty of defining such intervals does not justify excluding such correlations from consideration; distributions of reinforced IRTs are similarly complex and must be sampled over extended periods of time. Yoking with different parameter values of VR or VI schedules may be relevant to this question; response rates might separate more slowly with increasing VR or VI values. In addition, the role of the correlation between response rate and time per reinforcement could be assessed experimentally by maintaining the correlation while manipulating IRT reinforcement in VR and VI schedules (*e.g.,* by arranging yoked VR and VI schedules in each of which responses produced reinforcers only after unsignalled non-resetting delays). Relevant data do not seem available in the literature. Thus, the basis for the difference between VR and VI response rates remains an open question.

A final point concerns the yoked-control procedure. As has been elaborated by Church (1964), a difference between two performances that have been equated with respect to some variable by yoking does not necessarily guarantee that the variable is without effect on those performances. Misleading results may come about, depending on how the variable is correlated with other variables that operate in the experiment. In the present experiments, however, the effects were obtained rapidly in each individual yoked pair and in both directions of yoking. Although it is conceivable that an argument could be formulated in which time per reinforcement or responses per reinforcement continued to have effects through correlations with other variables in spite of their yoking, it seems unlikely that such an argument could be made parsimoniously. Given the other plausible variables that are available, it is reasonable to conclude that the difference between VR and VI response rates does not depend directly on either time per reinforcement alone or responses per reinforcement alone.

REFERENCES

Anger, D. The dependence of interresponse times upon the relative reinforcement of different interresponse times. *Journal of Experimental Psychology,* 1956, **52,** 145-161.

Anger, D. The effect upon simple animal behavior of different frequencies of reinforcement. Part II: separate control of the reinforcement of different IRTs. *Journal of the Experimental Analysis of Behavior,* 1973, **20,** 301-312.

Catania, A. C. Reinforcement schedules: the role of responses preceding the one that produces the reinforcer. *Journal of the Experimental Analysis of Behavior,* 1971, **15,** 271-287.

Catania, A. C. and Reynolds, G. S. A quantitative analysis of the responding maintained by interval schedules of reinforcement. *Journal of the Experimental Analysis of Behavior,* 1968, **11,** 327-383.

Catania, A. C. and Zimbardo, G. G. Applications of matrix switching. *Journal of the Experimental Analysis of Behavior,* 1972, **17,** 23-24.

Church, R. M. Systematic effect of random error in the yoked control design. *Psychological Bulletin,* 1964, **62,** 122-131.

Dews, P. B. The effect of multiple S^{Δ} periods on responding on a fixed-interval schedule. *Journal of the Experimental Analysis of Behavior,* 1962, **5,** 369-374.

Ferster, C. B. and Skinner, B. F. *Schedules of reinforcement.* New York: Appleton-Century-Crofts, 1957.

Killeen, P. Reinforcement frequency and contingency as factors in fixed-ratio behavior. *Journal of the Experimental Analysis of Behavior,* 1969, **12,** 391-395.

Kintsch, W. Frequency distributions of interresponse times during VI and VR reinforcement. *Journal of the Experimental Analysis of Behavior,* 1965, **8,** 347-352.

Kuch, D. O. and Platt, J. R. Reinforcement rate and interresponse time differentiation. *Journal of the Experimental Analysis of Behavior,* 1976, **26,** 471-486.

Matthews, B. A., Shimoff, E., Catania, A. C., and Sagvolden, T. Uninstructed human responding: sensitivity to ratio and interval contingencies. *Journal of the Experimental Analysis of Behavior,* 1977, **27,** 453-467.

Neuringer, A. and Schneider, B. A. Separating the effects of interreinforcement time and number of interreinforcement responses. *Journal of the Experimental Analysis of Behavior,* 1968, **11,** 661-667.

Revusky, S. H. Mathematical analysis of the durations of reinforced inter-response times during variable interval reinforcement. *Psychometrika,* 1962, **27,** 307-314.

Reynolds, G. S. and McLeod, A. On the theory of interresponse time reinforcement. In G. H. Bower (Ed), *The psychology of learning and motivation, Vol. 4.* New York: Academic Press, 1970. Pp. 86-107.

Shimp, C. P. The concurrent reinforcement of two interresponse times: absolute rate of reinforcement. *Journal of the Experimental Analysis of Behavior,* 1970, **13,** 1-8.

Shimp, C. P. Synthetic variable-interval schedules of reinforcement. *Journal of the Experimental Analysis of Behavior,* 1973, **19,** 311-330.

Thomas, D. R. and Switalski, R. W. Comparison of stimulus generalization following variable-ratio and variable-interval training. *Journal of Experimental Psychology,* 1966, **71,** 236-240.

Williams, D. R. The structure of response rate. *Journal of the Experimental Analysis of Behavior,* 1968, **11,** 251-258.

Zuriff, G. E. A comparison of variable-ratio and variable-interval schedules of reinforcement. *Journal of the Experimental Analysis of Behavior,* 1970, **13,** 369-374.

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