**CONJUNCTIVE SCHEDULES OF REINFORCEMENT I:
RATE-DEPENDENT EFFECTS OF PENTOBARBITAL
AND *d*-AMPHETAMINE¹**

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Key pecking of pigeons was maintained under conjunctive schedules of food presentation in which both a fixed-interval and a fixed-ratio schedule had to be completed before a peck produced food. For two pigeons, pecks on a single key completed both schedule requirements (fixed-interval 3-min, fixed-ratio 50 for one bird, fixed-interval 5-min, fixed-ratio 50 for the second). For two other pigeons, each requirement was scheduled on a separate key. On the two-key schedule, a peck after 5 min on the key scheduling the fixed-interval requirement produced food if at least 10 pecks had occurred on the ratio key (conjunctive fixed-interval 5-min, fixed-ratio 10). When each requirement was scheduled on a separate key, response rates on the fixed-ratio key were generally higher in the early portion of the interval and declined as the interval progressed; responding on the fixed-interval key, once initiated, typically remained at a constant rate throughout the interval. Responding under the single-key schedule was characterized by a high rate early in the interval; this then changed to a lower rate that continued until a peck produced food. For all pigeons, increases in response rates with pentobarbital and *d*-amphetamine were inversely related to the control rate of responding. When equivalent rates on each key of the two-key schedule were compared, both drugs increased rates on the fixed-ratio key less. Although the effects of both drugs were rate dependent, each drug differentially modified the pattern of responding under the single-key schedule.

A conjunctive schedule of reinforcement specifies the completion of at least two separate schedule requirements before a response can be reinforced (Ferster and Skinner, 1957). For example, in a conjunctive fixed-ratio, fixed-interval (*conj* FR FI) schedule of food presentation, food is delivered only after completion of the number of responses specified by the fixed-ratio *and* after a response terminates the designated interval. Typically, the conjunctive schedule does not spec-

ify when during the interval the ratio must be completed; if the ratio requirement is met before the interval has elapsed, a single response at the end of the interval produces food; if, however, the interval has elapsed before the ratio is completed, the terminal response of the ratio will produce food.

Herrnstein and Morse (1958) first described responding maintained by a single-key *conj* FR FI schedule of food presentation. In that experiment, pigeons were initially trained on an FI 15-min schedule and, subsequently, a ratio requirement was added. Under the conjunctive schedule, rates of responding were highest early in the interval and were followed by a lower rate that continued until a response produced food, a pattern of responding differing from the positively accelerated response rates typically engendered by FI schedules (Ferster and Skinner, 1957).

Under a wide variety of conditions, the manner in which a drug affects responding depends to a large extent upon the rate at which that behavior occurs in the absence of the drug (Kelleher and Morse, 1968). Typically, drug-induced changes in responding are in-

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versely related to the rate at which the response occurs in the drug's absence. Although the rate-dependent effects of amphetamines have been most thoroughly investigated (e.g., Dews, 1958; Smith, 1964), similar effects have also been obtained with barbiturates (Dews, 1964; McKearney, 1970; Waller and Morse, 1963). Many of these studies used FI schedules. The present experiment examined the effects of pentobarbital and *d*-amphetamine on responding maintained by single- and two-key *conj* FR FI schedules. On the two-key schedule, each requirement of the conjunctive was specified on a separate key. As is the case with FI schedules, the *conj* FR FI schedules generated different response rates during the interval. Unlike responding maintained by FI schedules, however, response rates under the conjunctive schedule decreased throughout the interval. It was possible, therefore, to assess the generality of rate-dependent drug effects on a pattern of responding where rates immediately before food are not necessarily highest. In the case of the two-key conjunctive schedule, it was also possible to compare the effects of pentobarbital and *d*-amphetamine on similar rates of responding maintained on two keys and examine the extent to which these rates were affected differentially.

METHOD

Subjects

Four adult male White Carneaux pigeons (P-9, P-10, P-203, and P-8348), obtained from the Palmetto Pigeon Plant, were maintained at approximately 80% of their free-feeding weights and had previously been exposed to various schedules of food presentation. None of the pigeons had previously received drugs.

Apparatus

The experimental chamber for P-9 and P-203 contained two plastic response keys 6 in. (15 cm) apart and mounted 9 in. (23 cm) from the floor. The chamber for P-10 and P-8348 contained a single response key located in the center of the front panel and mounted 9 in. (23 cm) from the floor. Each key (R. Gerbrands Co.) was transilluminated by two 7-W lamps (green for P-10 and P-8348, yellow for P-9 and P-203) and required a peck of at least 15 g (0.15N) force to interrupt an electrical contact that operated recording circuits.

Each response also operated a relay mounted behind the front wall of the chamber. Centered 2 in. (5 cm) above the floor of the front panel of each chamber was an opening through which mixed grain could be presented. When grain was available, the key-lights were darkened and the grain magazine was illuminated. White noise was continuously present in the sound-attenuating enclosures that housed each experimental chamber.

Procedure

Subject P-10 responded initially on an FI 5-min schedule during which the first response (key peck) after 5 min produced 4-sec access to food. After 23 sessions, the schedule was changed to *conj* FR 50 FI 5-min. On this schedule, a response produced food when both schedule requirements were completed; i.e., after 5 min elapsed and at least 50 responses had occurred. P-10 was exposed to this schedule for 74 sessions before drugs were administered. P-8348 was trained initially on an FR 50 schedule. After 51 sessions, an FI 3-min schedule was added to the FR 50 schedule (*conj* FR 50 FI 3-min); drugs were first administered after 35 sessions under the conjunctive schedule.

P-9 and P-203 were studied on a schedule where different response requirements were specified on each of two keys. Initially, at least one peck had to occur on the left (FR) key before food was produced following the first response on the right (FI) key after 5 min elapsed (*conj* FR 1 FI 5-min). Only pecks on the FI key produced food and then only after the schedule requirements were completed on the two keys. After 20 sessions on *conj* FR 1 FI 5-min, the ratio requirement on the left key was increased by nine responses and food was presented when a peck on the FI key occurred after 5 min had elapsed, given that at least 10 responses were previously made on the FR key. The two-key conjunctive schedule was in effect for 34 sessions before drugs were administered. Sessions terminated after 30 food presentations or 3 hr (2 hr for P-8348), whichever occurred first, and were conducted five days per week.

Pentobarbital sodium and *d*-amphetamine sulfate were dissolved in 0.9% sodium chloride solution and prepared so that the volume injected was always 1.0 ml/kg of body weight. All doses are expressed in terms of the total

salt. The birds were injected intramuscularly twice a week (Tuesday and Friday) immediately before the session. Saline injections were given on Thursdays and these sessions served as control days. Doses were given in an irregular order with at least two administrations of each dose. Pentobarbital was studied first, with control rates determined separately while each drug series was in effect.

RESULTS

Performances under single- and two-key conjunctive schedules. Figure 1 presents representative segments of cumulative response records showing the different temporal patterns of responding under the conjunctive schedules. The records are taken from the last 10 intervals of a typical control session. Under the two-key procedure, after an initial pause, responding on the FI key was usually maintained at a fairly constant rate while pecking on the FR key first increased and then decreased as the interval progressed. The cumulative records for P-9 show a few intervals where responding on both keys occurred only during the later portion of the interval or after the interval elapsed. On those occasions, responding usually alternated between the two keys.

The diagonal marks on the cumulative records for P-9 and P-203 denote completion of the FR requirement and indicate that the ratio was usually completed early in the interval. Typically, more than the required 10 responses occurred on the FR key.

The control by the single-key conjunctive schedule (P-10 and P-8348) was similar to that reported by Herrnstein and Morse (1958). Many intervals began with a pause followed by a high rate of responding and then by a transition to a lower rate. The lower rate was maintained until a peck produced food. The ratio was completed early in the interval and the transition to a lower response rate occurred closely with the completion of the ratio requirement. Response rates under the single-key procedure were considerably higher than those under the two-key procedure.

Effects of pentobarbital. Figure 2 summarizes the effects of different doses of pentobarbital on average overall rates of responding. For the pigeons responding on the two-key schedule, both control and drug rates on

the fixed-ratio key were consistently below those on the fixed-interval key. For both birds, there was a tendency for lower doses (1.0 to 3.0 mg/kg) to increase responding on both keys slightly with the highest dose (17.0 mg/kg) markedly reducing responding. With these exceptions, however, there was generally little change in overall response rates across the range of doses given.

The effects of pentobarbital on responding maintained by the single-key schedule (P-10 and P-8348) are also presented in Figure 2. Overall control rates for these pigeons were about two to three times greater than the highest rates for the two-key schedule birds. For P-10 there was little change in the rate of responding at 1.0 and 3.0 mg/kg; increasing doses decreased overall rates of responding. Response rates for P-8348 were unchanged at low doses of pentobarbital (1.0 to 3.0 mg/kg), increased at 5.6 and 10.0 mg/kg, and decreased at the highest dose (17.0 mg/kg).

Analysis of the rate-dependent effects of pentobarbital was done as follows. For individual pigeons, responses were separately cumulated during each tenth of the FI component and average rates for these segments were obtained. For the two-key procedure, responses in tenths of the interval on the FR and FI keys were recorded separately. Responses occurring after the interval elapsed, as well as the response that produced food, were recorded separately and were not included in the analysis. Rates of responding at each dose of pentobarbital were then expressed as percentages of the control rates and the results of this analysis are presented in Figures 3 and 4. Points were not plotted if the control rates were less than 0.01 responses per second. Regression lines were fitted by the method of least squares.

The data resulting from the rate-dependent analysis were nearly identical for both pigeons on the two-key procedure. Figure 3 shows the effects of pentobarbital on local rates of responding for one pigeon (P-203) on the two-key schedule. With increasing doses of pentobarbital, changes in response rate on both keys were inversely related to the control rate of responding. The regression lines for the two keys were nearly parallel at each dose. Increasing doses of pentobarbital changed the slope of the regression lines, indicating that with larger doses, lower rates of

Fig. 1. Cumulative records of control performance under two-key (Pigeons 9 and 203) and single-key (Pigeons 10 and 8348) conjunctive schedules. The top record of each pair for P-9 and P-203 represents responding on the fixed-interval key, and the bottom record, responding on the fixed-ratio key. The diagonal mark on the cumulative record indicates completion of the ratio requirement. For P-10 and P-8348, completion of the ratio is marked by both a diagonal slash on the cumulative record and by the offset of the event pen; a diagonal slash without a corresponding displacement of the event pen denotes the elapse of the interval. The response pen reset after each presentation of food.

Fig. 2. Effects of pentobarbital on overall rates of responding under the conjunctive schedule. P-9 and P-203 responded on a two-key conjunctive schedule. Unfilled circles represent responding on the fixed-interval key; filled circles, responding on the fixed-ratio key. C: control rates (mean of nine nondrug sessions for each bird). The brackets represent the range of control rates.

responding were increased more and higher rates were decreased. Except for the lowest dose (1.0 mg/kg), equivalent rates on the FI key were increased slightly but consistently more than were rates on the FR key. This effect was most pronounced at the highest dose

(17.0 mg/kg). If the per cent increase in response rate with pentobarbital was a function solely of the control response rate, uninfluenced by other variables, all points, regardless of the key on which those rates occurred, would have fallen along one regression line.

Fig. 3. Effects of pentobarbital on responding during individual 30-sec portions of the two-key conjunctive schedule. Abscissa: control rates of responding on each key during individual 30-sec segments of the interval. Ordinate: drug rate of responding as a per cent of control rate. Abscissa and ordinate are logarithmic. Regression lines are fitted by method of least squares.

Fig. 4. Effects of pentobarbital on responding during successive 30-sec segments of the FI component of the single-key conjunctive schedule. Details as in Figure 3.

The effects of pentobarbital on local rates of responding maintained by the single-key conjunctive schedule are given for P-10 in Figure 4. These results are similar to those of the previous two pigeons, in that low rates were increased and high rates decreased. At 1.0 and 3.0 mg/kg, there was little effect, whereas doses of 5.6 and 10.0 mg/kg increased the slope of the regression line, indicating that lower rates were increased more and higher rates decreased more than at lower doses. Despite the fact that overall rates of responding increased for P-8348 at doses of 5.6 and 10.0 mg/kg (Figure 2), results of the analysis of the rate-dependent effects were largely identical to those obtained for P-10.

Effects of d-amphetamine. Figure 5 shows the effects of *d*-amphetamine on average overall rates of responding under both single- and two-key schedules. Except at the highest dose (3.0 mg/kg), where rates were decreased, *d*-amphetamine had little effect on responding on the FR key of the two-key schedule. Responding on the FI key was generally increased except at 3.0 mg/kg. For P-8348, responding on the single-key schedule, response rates were largely unaffected except at the highest dose; response rates for P-10 were increased slightly at 0.3 and 1.0 mg/kg.

Results from the analysis of the rate-dependent effects of *d*-amphetamine on responding under the two-key schedule are presented in

Fig. 5. Effects of *d*-amphetamine on overall rates of responding under the conjunctive schedules. Details as in Figure 2.

Figure 6 for P-203. As was the case with pentobarbital, *d*-amphetamine generally increased low rates of responding; high rates of responding were either unaffected or decreased. Response rates on the FR key were increased less than were comparable rates on the FI key. These results were similar for the second bird (P-9) on the two-key schedule.

Figure 7 shows the rate-dependent effects of *d*-amphetamine for P-10 on the single-key conjunctive schedule. As with pentobarbital, the effects of *d*-amphetamine depended on the

control rate of responding. Increasing doses also increased the slope of the regression line, with 3.0 mg/kg producing the largest increase in low rates of responding and the largest decrease in high rates of responding. These effects were comparable for both pigeons on the single-key schedule.

Cumulative response records depicting responding at selected doses of pentobarbital and *d*-amphetamine under both the two- and single-key schedules are presented in Figure 8. The effects of these two drugs on responding

P-203

Fig. 6. Effects of *d*-amphetamine on responding during successive 30-sec segments of the FI under the two-key conjunctive schedule. Details as in Figure 3.

under the two-key schedule (P-203) were very similar. Compared to control performance (Figure 1), both drugs decreased pause duration and increased the low terminal rates of responding on the FR key.

Under the single-key schedule (P-10), pentobarbital had little effect on the control pattern of responding (Figure 1); response rates were typically highest following an initial pause and then decreased as the interval progressed. During nondrug sessions, the number of responses contained in that portion of the interval where rates were highest was approximately 50, the number specified by the ratio requirement. Figure 8 shows that pentobarbital increased the number of responses that occurred before the change to a

lower rate of responding. With pentobarbital, there was also an increase in the number of times responding did not occur until after the interval elapsed; these postinterval rates were similar to those maintained by FR schedules and appeared largely unaffected by the drug. In contrast to pentobarbital, *d*-amphetamine produced a marked modification of the conjunctive pattern of responding maintained on the single key. Cumulative records in Figure 8 show a decrease in the pause as well as a pronounced reduction in the initial high rate of responding. With *d*-amphetamine, responding under the single-key schedule occurred either at a relatively constant rate or was slightly positively accelerated throughout the interval.

Fig. 7. Effects of *d*-amphetamine on responding during successive 30-sec segments of the FI under the single-key schedule. Details as in Figure 3.

DISCUSSION

The present experiment examined conjunctive performance maintained on one key and conjunctive performance in which each schedule was specified on a separate key. When responding stabilized under these procedures, the effects of pentobarbital and *d*-amphetamine were examined. Responding under both the single- and two-key conjunctive schedules was similar in many respects to that reported by Herrnstein and Morse (1958), who described conjunctive schedule performance as follows: "The initial pause sets the occasion for fixed-ratio behavior; a group of re-

sponses (whose size probably depends upon the value of the number requirement) sets the occasion for fixed-interval behavior" (p. 24). On the single-key schedule in the present study, there was typically an initial pause followed by a high rate of responding. At a point closely approximating the number of responses specified by the ratio, this initial high rate changed to a lower rate that continued until food was delivered. The initial high rate was characteristic of responding generated by ratio schedules, whereas the lower terminal rate resembled that typically found with FI schedules (Ferster and Skinner, 1957; Herrnstein and Morse, 1958). These results seem to support the view that

Fig. 8. Cumulative response records showing effects of selected doses of pentobarbital and *d*-amphetamine on responding under the single- and two-key conjunctive schedules. Details as in Figure 1.

the ratio requirement and the magnitude of the ratio are important and discriminable aspects of the conjunctive schedule that exert substantial control over both the rate and temporal pattern of responding.

The performance engendered by the two-key conjunctive schedule was similar to that maintained on a single key. Responding on the FR key was largely confined to the early portion of the interval and typically declined as the interval progressed; responding on the FI key, however, once initiated, remained at a constant rate throughout the interval. Under both the single- and the two-key conjunctive schedules then, differentiated patterns of responding emerged that consisted of different response rates during the interval. On the two-key schedule, these rates were controlled by separate keys and by the schedules on those keys. On the single key, different rates appear to have been jointly controlled by the individual requirements of the conjunctive schedule.

Despite the similarities between the single- and two-key schedules, there were certain differences in performances maintained under each schedule. Perhaps most notable is that responding on the key scheduling the ratio requirement of the two-key conjunctive did not typically occur at a rate characteristic of ratio schedules. It is at present unclear whether this difference was due to the relatively small size of the ratio, to the control by the contingencies of the two-key schedule itself, or to the fact that only responses on the FI key produced food. These factors may also account for the higher rates of responding on the one-key procedure.

For the most part, the results from a comparison of single- and two-key conjunctive schedules are in basic accord with other analyses of control by this schedule (Herrnstein and Morse, 1958; Morse, 1966). Although the specific determinants of the different rates obtained under conjunctive schedules have not yet been fully analyzed, the fact that rates not immediately preceding food delivery are highest represents an interesting exception to the typical rate-increasing effects of food presentation (*cf.* Dews, 1970; Shull, 1970, 1971; Staddon, 1972). The completion of the ratio early in the interval and the lower terminal rates immediately preceding food presentation could result from a com-

bination of factors specific to the conjunctive schedule. One important feature responsible for the emergence of different rates during the interval appears to be the effects on subsequent responding of those intervals that elapse before the ratio is completed. A striking aspect of the data obtained by Herrnstein and Morse (1958) was the rate-decreasing effects of adding a ratio requirement to the FI schedule. On the conjunctive schedule, when rates decrease substantially and the interval elapses without completion of the ratio, food will be delivered only when the ratio is completed. In this way, according to Herrnstein and Morse (1958), the completion of the ratio becomes a discriminative stimulus. However, as the ratio schedule gains control over responding, the ratio will often be completed before the interval elapses; food will not be presented when the ratio is completed and responding will subsequently decrease. The low rates of responding that then prevail will immediately precede the delivery of food when the interval elapses. In this manner, different rates could develop during the interval that would depend specifically on the differential reinforcement of the completion of the ratio. The possibility that such complex sequences of responding emerge and are maintained in this manner by the conjunctive schedule is readily amenable to a direct experimental analysis involving the explicit use of discriminative stimuli and the selective modification of the requirements comprising the conjunctive schedule.

The effects of pentobarbital and *d*-amphetamine in these experiments support previous studies indicating that the behavioral effects of these drugs depend on the control rate of responding (Dews, 1964; McKearney, 1970). Low local rates, whether on the single- or the two-key conjunctive schedule, were increased more than were high rates. Rate-dependent effects of pentobarbital and *d*-amphetamine were obtained under conjunctive schedules, even though sequences of rates differed from those on FI schedules.

Although the present experiments show that increases in response rate were inversely related to the control rate, the data from the two-key procedure indicate that the rate increases on the FR key were somewhat less than would be predicted solely on the basis of the control rate alone. These results are similar

to those of McKearney (1970), who reported that the magnitude of the increase in rates with amobarbital depended on properties of the discriminative stimuli controlling responding. McKearney controlled differential rates throughout an FI 10-min schedule by scheduling presentations during odd-numbered minutes of a stimulus not present when food was delivered (S^A); during even-numbered minutes the stimuli (S^D) were identical to those present when food was delivered. When S^A was either a keylight color or a change from a dark to a brightly illuminated chamber, increases in responding with amobarbital were less than predicted on the basis of responding during S^D . The major differences between rate increases during S^D and S^A were in the y-intercept portion of the regression line; the slope was largely unchanged. Similarly, in the present study the essential difference between rate increases with pentobarbital on the FR and FI keys was also in the y-intercept, with the slope of the functions for the two keys being almost identical.

Despite the similar rate-dependent effects of pentobarbital and *d*-amphetamine, under the single-key conjunctive schedule, these drugs did differentially affect the pattern of responding and, therefore, the manner in which these rates were derived. Except for increasing the number of responses contained in that portion of the interval where rates were highest, pentobarbital produced little modification in the overall pattern of responding. In contrast, *d*-amphetamine substantially reduced the initial high rate of responding. The differential effects of these drugs in the context of the conjunctive schedule are similar to those found when responding is separately controlled by FR schedules. Except at high doses, pentobarbital does not typically decrease FR rates of responding (Rutledge and Kelleher, 1965; Waller and Morse, 1963), whereas at most doses, amphetamine does (Clark and Steele, 1966; Rutledge and Kelleher, 1965). The selective reduction by *d*-amphetamine of the high rate of responding occurring early in the conjunctive interval and the corresponding absence of decreases with pentobarbital lend additional support to the view that responding in that portion of the interval is controlled by the

ratio requirement of the conjunctive schedule.

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