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EFFECTS OF d-AMPHETAMINE AND COCAINE ON STRAINED RATIO BEHAVIOR IN A REPEATED-ACQUISITION TASK

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Pigeons acquired a different four-response chain each session by responding sequentially on three keys in the presence of four colors. When the fixed-ratio requirement for food presentation was five completions of the chain, *d*-amphetamine and cocaine disrupted the behavior. As the dose of each drug was increased, the overall response rate decreased, the overall accuracy was impaired (i.e., percent errors increased), and there was less within-session error reduction (acquisition). In contrast, when the fixed-ratio requirement was either 20 or 50 completions of the chain, certain doses of both drugs produced large increases in the overall response rate by eliminating the extended pausing (ratio strain) that was characteristic of the control sessions. These rate-increasing effects were accompanied by error-decreasing effects, both during acquisition and after the response chain had been acquired. Taken together, the results show that the effects of *d*-amphetamine and cocaine on behavior in a repeated-acquisition task can be modulated by manipulating the value of the fixed-ratio schedule maintaining the behavior.

Key words: repeated acquisition, response chains, fixed-ratio schedule, ratio strain, *d*-amphetamine, cocaine, key peck, pigeons

Morse and Herrnstein (1956) reported an experiment in which a pigeon's performance under a large fixed-ratio schedule (FR 160) served as a baseline for studying drug effects. Under baseline conditions, most of the responses in each ratio were emitted at a high rate (5 responses per sec) just before reinforcement. However, the high rate was typically preceded by some responses at a lower rate and/or a long period of pausing. The ratio performance was therefore characterized as being "strained." After the administration of methamphetamine (.5 mg), the amount of pausing was greatly reduced, thereby increasing the overall rate of responding. A similar effect was obtained with a higher dose (2 mg) despite the fact that the local rate of responding just before reinforcement was decreased. The effects of varying doses of *d*-amphetamine on the responding of chimpanzees under an FR 100 schedule (Byrd, 1973) are consistent with and extend the generality of the Morse and Herrnstein findings.

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Another study of drug effects on strained ratio performance was reported by Dews (1958). The responding of pigeons was maintained by food presentation under a modified FR 900 schedule. Methamphetamine (.1 to 1 mg) was found to produce large increases in the overall rate of responding, as in the Morse and Herrnstein experiment. Such rate-increasing effects were not found, however, when responding was maintained under an FR 50 schedule; the overall response rate only decreased with increasing doses of methamphetamine. More recently, McMillan (1969) obtained similar results with *d*-amphetamine in pigeons. This drug increased the low overall response rate under an FR 250 schedule at doses that either did not affect or decreased the high rate under an FR 30 schedule.

In each of the studies described above, a single response key was used. The present research focused on the question of whether similar results would be obtained with more complex operant behavior. A repeated-acquisition baseline was established in which pigeons acquired a different response chain each session by responding sequentially on three keys in the presence of four colors. In previous research using this baseline (e.g., Thompson, 1973, 1977, 1978), the behavior was maintained under an FR 5 schedule, and *d*-amphetamine

and cocaine decreased the overall rate of responding and increased the percent errors with increasing doses. The present research examined the possibility that different drug effects would be found if the behavior was maintained under larger FR schedules. To provide a direct comparison, the drugs were also tested under the FR 5 schedule.

METHOD

Subjects

Two adult male White Carneaux pigeons were maintained at approximately 80% of their free-feeding body weights by food presented during the sessions and by postsession supplemental feeding. The 80% values were 550 g and 560 g for Pigeon 788 and Pigeon 3157, respectively. Water and grit were always available in the home cages. Each subject had an extensive history of repeated acquisition of four-response chains under fixed-ratio schedules ranging from FR 5 to FR 100; Pigeon 3157 had also served in Thompson's 1977 study.

Apparatus

The experimental space was a standard three-key pigeon chamber (BRS/LVE model SEC-002). Each translucent response key required a minimum force of .18 *N* for activation. Each key could be transilluminated by three Sylvania 24ESB indicator lamps, one with a red plastic end cap, one with a green cap, and the third with no cap. To provide a fourth color, "yellow" (actually yellow-orange) was produced by the red and green lights being on simultaneously. Events were scheduled by means of timers, steppers, and associated relay circuitry; recording was by counters, running-time meters, and a cumulative recorder. White noise was continuously present in the chamber to mask extraneous sounds.

Procedure

Repeated-acquisition baseline. All three response keys were illuminated at the same time by one of four colors, either yellow, green, red, or white. The pigeon's task was to acquire a four-response chain by pecking the correct key in the presence of each color, e.g., keys yellow —Left correct; keys green—Right correct; keys red—Center correct; keys white—Right correct; reinforcement. The same chain (in this case, Left-Right-Center-Right or LRCR) was repeated throughout a given session. When the pigeon pecked an incorrect key (e.g., the left or right key when the center key was correct), the error was followed by a 5-sec timeout. During the timeout, the keys were dark and responses were ineffective. An error did not reset the chain; i.e., the keylights after the timeout were the same color as before the timeout.

To establish a steady state of repeated acquisition, the four-response chain was changed from session to session. The chains were carefully selected to be equivalent in several ways and their ordering was restricted across sessions (see Thompson, 1973). An example of a typical set of six chains is as follows: LRCR, CLRL, LRLC, RCRL, CLCR, RCLC; the order of the associated colors was always the same: yellow, green, red, white.

As in previous research using repeated-acquisition baselines (e.g., Thompson & Moerschbaecher, 1979), the data for each session were analyzed in terms of (a) the overall response rate (total responses/min, excluding timeouts) and (b) the overall accuracy or percent errors [(errors/total responses) × 100]. In addition to these measures based on session totals, within-session changes in responding were monitored by a cumulative recorder. For example, acquisition of a response chain was indicated by within-session error reduction.

Schedule of reinforcement. Each four-response chain was initially maintained by food presentation under an FR 5 schedule; i.e., every fifth completion of the chain was followed by 5-sec access to mixed grain. Presentation of the grain magazine was accompanied by the offset of the keylights and the onset of the magazine light. All other completions of the four-response chain produced a .5-sec flash of the magazine light, which was accompanied by the offset of the keylights. Each daily session under the FR 5 schedule was terminated after 40 food reinforcements or 4 hr, whichever occurred first. A "blackout" (all lights off) of variable duration preceded and followed each session.

After several sessions under FR 5, the schedule was increased to FR 20 for Pigeon 788 and FR 50 for Pigeon 3157. The schedule values were selected on the basis of preliminary research in which the ratio size was increased

and decreased to determine a value for each subject that would generate strained behavior that could be maintained for extended periods of time. The daily sessions under these relatively large FR schedules were terminated after 4 hr. After drug testing (see below) under FR 20 or FR 50, the baseline schedule was decreased to FR 5, and the drugs were retested.

Drug testing. Before the drug testing began, the behavior under a given baseline schedule was stabilized. The behavior was considered stable when the response rate and percent errors no longer showed systematic change from session to session. After baseline stabilization (65 sessions under FR 20, 95 sessions under FR 50, 15 to 20 sessions under FR 5), dose-effect data were obtained for *d*-amphetamine sulfate and cocaine hydrochloride. Dose-effect curves were determined twice for each drug, in the following order: *d*-amphetamine, cocaine, *d*-amphetamine, cocaine. The doses of each drug were tested in a mixed order. The drugs were dissolved in saline and injected intramuscularly 5 min presession. Drug sessions were separated by at least three days, during which time there were baseline sessions and a control session (saline alone injected intramuscularly 5 min presession). The volume of each injection was .1 ml/100 g body weight.

RESULTS

Figure 1 shows the effects of varying doses of *d*-amphetamine and cocaine on the response rate and percent errors under each FR schedule for Pigeon 3157. The brackets and points at C indicate the range and median for the control (saline) sessions that were associated with each drug. A drug was considered to have an effect on response rate or percent errors to the extent that the dose data fell outside of the control range. The points connected are those of the first determination. Under the FR 5 schedule, the response rate decreased monotonically below the control range and the percent errors tended to increase with increasing doses of both *d*-amphetamine and cocaine. In contrast, the dose-effect curves for rate were bitonic under the FR 50 schedule. The response rate under the FR 50 schedule was in-

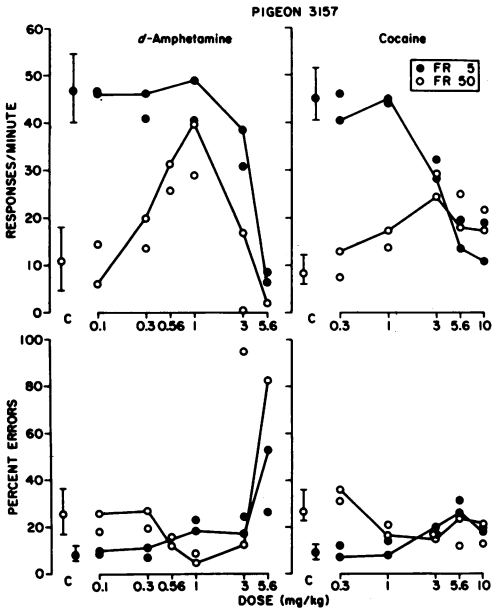

Fig. 1. Effects of varying doses of *d*-amphetamine and cocaine on the overall response rate and percent errors under the FR 5 and FR 50 schedules for Pigeon 3157. The brackets and points at C indicate the range and median for the control (saline) sessions that were associated with each drug. The points connected are those of the first determination.

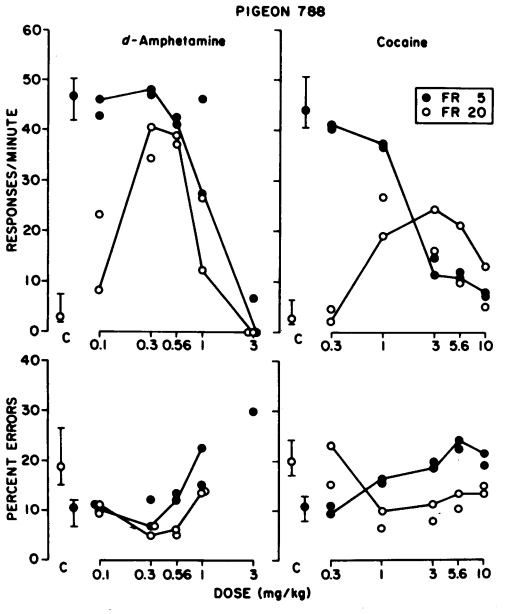

Fig. 2. Effects of varying doses of *d*-amphetamine and cocaine on the overall response rate and percent errors under the FR 5 and FR 20 schedules for Pigeon 788. The brackets and points at C indicate the range and median for the control (saline) sessions that were associated with each drug. The points connected are those of the first determination. At 3 mg/kg of *d*-amphetamine, three of the data points for percent errors have been omitted because the overall response rate was virtually zero.

creased substantially at intermediate doses of both drugs; the higher doses of cocaine produced smaller rate-increasing effects, and the highest dose of *d*-amphetamine in each determination decreased the rate. The errors under the FR 50 schedule were decreased in relative frequency at intermediate doses of both drugs; the higher doses of cocaine (first determination) had little if any error-decreasing effects, and the highest dose of *d*-amphetamine in each determination increased the percent errors.

That similar dose-effect data were obtained with Pigeon 788 is shown in Figure 2. In general, under the FR 5 schedule, increasing the dose of each drug decreased the response rate and increased the percent errors. Under the FR 20 schedule, however, most of the doses of each drug had rate-increasing effects and error-decreasing effects. The magnitude of these effects generally increased and then decreased with increasing doses. The only rate-decreasing effects under the FR 20 schedule occurred at the highest dose of *d*-amphetamine (3 mg/kg, both determinations).

The results shown in Figures 1 and 2 are based on session totals (overall rate and overall accuracy). Although these data are informative, they do not provide evidence that acquisition (within-session error reduction) occurred under control conditions or that the drugs affected acquisition. Such evidence is illustrated in the cumulative records of Figure 3. The top left record shows a representative

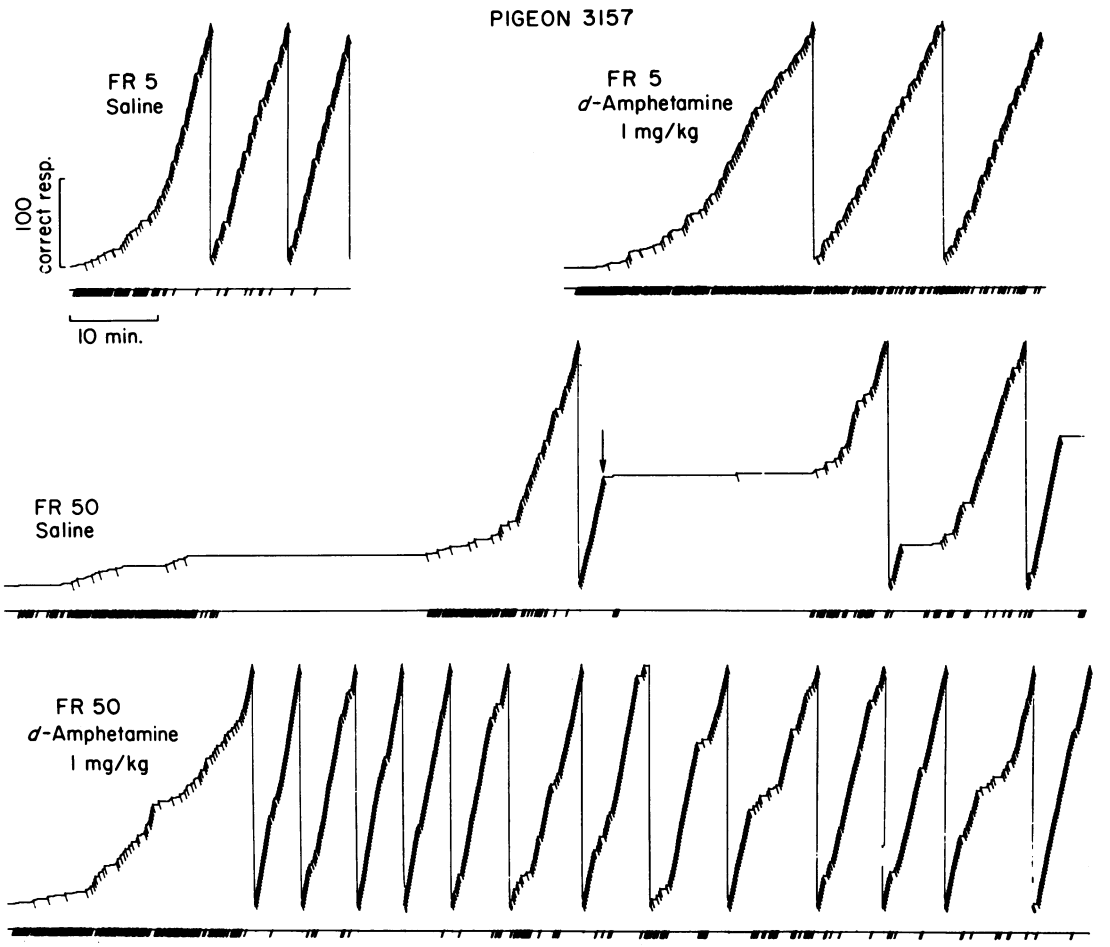

Fig. 3. Cumulative records showing the effects of 1 mg/kg of *d*-amphetamine on responding under the FR 5 and FR 50 schedules for Pigeon 3157. The response pen stepped upward with each correct response and was deflected downward each time the four-response chain was completed. Errors are indicated by the event pen (below each record), which was held down during each timeout.

saline session under the FR 5 schedule for Pigeon 3157. The response pen stepped upward with each correct response and was deflected downward each time the four-response chain was completed. Errors are indicated by the event pen, which was held down during each timeout. As can be seen in this saline record, errors decreased in frequency as the session progressed; i.e., acquisition occurred. After the first 10 min of the session, the correct responses were emitted at a high rate, and relatively few errors were made. The runs of correct responses were often preceded by brief pauses. The top right record shows that 1 mg/kg of *d*-amphetamine (second determination) had a large error-increasing effect under the FR 5 schedule. There was less acquisition (error reduction) during this session than during the saline session.

The middle record in Figure 3 shows the first 2 hr of a saline session under the FR 50 schedule. This schedule generated higher error levels than the FR 5 schedule as well as long periods of pausing, an indication of ratio strain. Note the long run of correct responses without any errors just before the second reinforcement (at arrow). This would indicate that the response chain had been acquired. However, a considerable number of errors continued to occur during the rest of the session although the frequency of errors was lower than during the first part of the session. Most

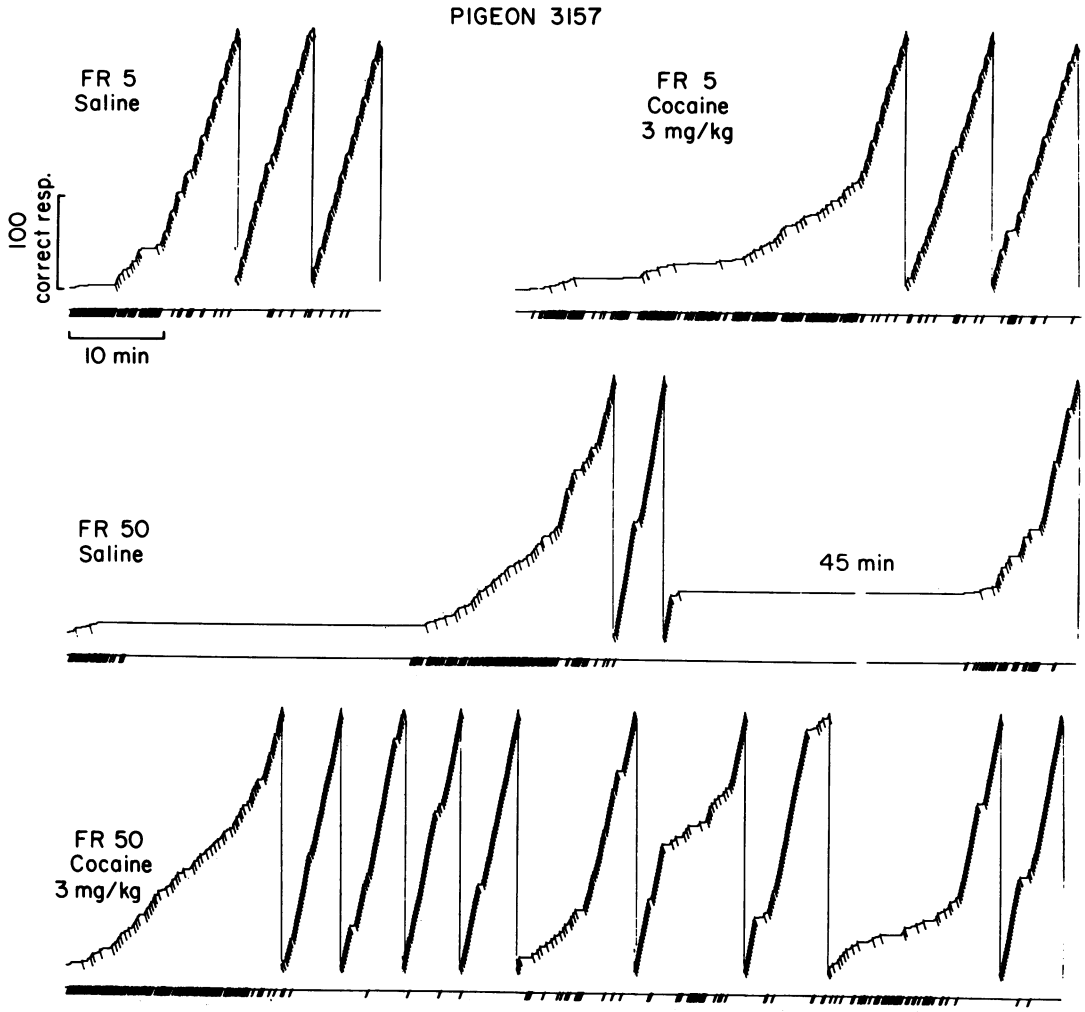

Fig. 4. Cumulative records showing the effects of 3 mg/kg of cocaine on responding under the FR 5 and FR 50 schedules for Pigeon 3157. A 45-min period of no responding has been omitted from the middle record at the point indicated. The recording details are the same as in Figure 3.

of the errors occurring after the response chain had been acquired were emitted during the early portion of the ratio run. The bottom record shows the first 2 hr of an FR 50 session that was preceded by the administration of 1 mg/kg of *d*-amphetamine (first determination). In comparison to the saline session under the FR 50 schedule, the amount of pausing was greatly reduced, thereby increasing the overall rate of responding. In terms of accuracy, there were fewer errors than in the saline session, both during the first excursion of the response pen while the chain was being acquired and during most of the subsequent excursions.

Figure 4 shows the within-session effects of 3 mg/kg of cocaine (first determination) under the FR 5 and FR 50 schedules for Pigeon 3157. The format and recording details are the same as in Figure 3. Under the FR 5 schedule, this dose of cocaine produced some pausing and had a large error-increasing effect during the first part of the session. In contrast, under the FR 50 schedule, the same dose produced a large increase in the overall rate of responding by eliminating the long pauses that were characteristic of the control sessions. This rate-increasing effect was accompanied by a small decrease in errors, both during the first excursion of the response pen and during most of the subsequent excursions. In summary, the within-session effects of 3 mg/kg of cocaine were generally similar to those of 1 mg/kg of *d*-amphetamine (Figure 3), although cocaine's effects appeared to last for a shorter period of time.

Returning to Figure 1, it can be seen that 3 mg/kg of *d*-amphetamine (first determination) decreased the percent errors somewhat under the FR 50 schedule. On the basis of this effect on overall accuracy, one might conclude that acquisition was facilitated, but such was not the case. The entire session is shown in Figure 5. In comparison to the saline sessions under the FR 50 schedule (e.g., see Figures 3 and 4), this dose of *d*-amphetamine increased the frequency of errors during the first excursion of the response pen; i.e., acquisition was disrupted. The decrease in percent errors for the entire drug session was due primarily to the long runs of correct responses with relatively few errors during the last part of the session (excursions 5 through 10). Similar within-session effects (not shown) also occurred at the higher doses of cocaine (5.6 and 10 mg/kg, both determinations) under the FR 50 schedule in Pigeon 3157. In general, the within-session drug effects shown in Figures 3, 4, and 5 were replicated with the other subject, although the particular doses were different.

DISCUSSION

Under the FR 5 schedule, *d*-amphetamine and cocaine disrupted the behavior. As the dose of each drug was increased, the overall rate of responding decreased, the overall accuracy was impaired (i.e., percent errors increased), and there was less within-session error reduction (acquisition). These results are con-

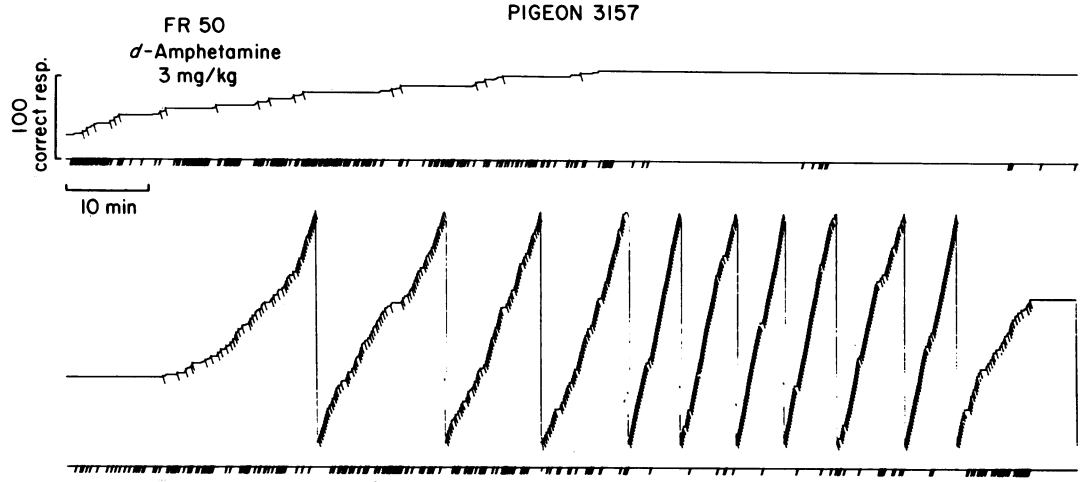

Fig. 5. Cumulative record showing the effects of 3 mg/kg of *d*-amphetamine (first determination) on responding under the FR 50 schedule for Pigeon 3157. The recording details are the same as in Figure 3.

sistent with the disruptive effects previously found with *d*-amphetamine and cocaine in studies where pigeons (Thompson, 1973, 1977, 1978) and monkeys (Thompson & Moerschbaecher, 1979) repeatedly acquired four-response chains under an FR 5 schedule. Similar disruptive effects were also obtained with these drugs in studies where pigeons (Moerschbaecher, Boren, Schrot, & Simoes Fontes, 1979) and monkeys (Thompson & Moerschbaecher, 1978) repeatedly acquired conditional discriminations under small variable-ratio schedules.

Under baseline conditions, the FR 20 and FR 50 schedules generated long periods of pausing as well as higher error levels than the FR 5 schedule. The extended pausing or ratio strain in the present three-key procedure was predictable on the basis of previous studies (e.g., Dews, 1958; Morse & Herrnstein, 1956) in which responding on a single key was maintained under large FR schedules. The higher error levels, however, could not have been predicted simply on this basis. Perhaps the most interesting aspect of the strained behavior was the finding that after the response chain had been acquired, as indicated by a long run of correct responses without any errors, a considerable number of errors occurred during the rest of the session. One interpretation of this finding is that, under conditions generating ratio strain, the timeout functioned as a reinforcer for errors (cf. Redd, Sidman, & Fletcher, 1974). This interpretation is supported by previous research (e.g., Azrin, 1961; Thompson, 1965) showing that pigeons will respond to produce timeouts from large FR schedules.

Under the FR 20 and FR 50 schedules, certain doses of both *d*-amphetamine and cocaine produced large increases in the overall rate of responding by eliminating the long pauses that were characteristic of the control sessions. These rate-increasing effects were accompanied by error-decreasing effects both during acquisition and after the response chain had been acquired. The rate-increasing effects were similar to those obtained in previous studies, where methamphetamine (Dews, 1958; Morse & Herrnstein, 1956) and *d*-amphetamine (McMillan, 1969) were administered to pigeons responding under large FR schedules on a single key. The generality of these previous findings is therefore extended by the present research, which involved more complex operant behavior as well as an additional drug (cocaine).

In more general terms, the present research shows that the effects of *d*-amphetamine and cocaine on behavior in a repeated-acquisition task can be modulated by manipulating the value of the FR schedule maintaining the behavior. The present data are also consistent with a rate-dependency interpretation. It is a well-documented finding that *d*-amphetamine and cocaine tend to decrease high rates of responding while increasing low rates (e.g., see review by Kelleher, 1977). Similarly, in the present study, when the overall control rate was relatively high (under FR 5), the drugs only decreased the overall rate, whereas when the overall control rate was relatively low (under the larger FR schedules), several doses of both drugs increased the overall rate.

That *d*-amphetamine can decrease errors in a repeated-acquisition task was previously reported by Harting and McMillan (1976). As in the present study, pigeons repeatedly acquired four-response chains. However, unlike the present study, the error-decreasing effects of *d*-amphetamine were found under an FR 5 schedule. The apparent discrepancy may be related to the fact that the control accuracy levels (percent errors) under the FR 5 schedule in the Harting and McMillan study were comparable to the levels under the FR 20 and FR 50 schedules in the present study. The effects of *d*-amphetamine and cocaine on accuracy may depend upon the control accuracy in the same way that the effects on rate may depend upon the control rate.

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