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AN EXPERIMENTAL ANALYSIS OF THE EFFECTS OF d-AMPHETAMINE AND COCAINE ON THE ACQUISITION AND PERFORMANCE OF RESPONSE CHAINS IN MONKEYS

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In one component of a multiple schedule of food presentation, monkeys acquired a different four-response chain each session by responding sequentially on three keys in the presence of four geometric forms (learning). In the other component, the four-response chain was the same each session (performance). Both *d*-amphetamine and cocaine, at the higher doses, disrupted the behavior in the learning component; the overall response rate decreased, the overall accuracy was impaired (i.e., percent errors increased), and there was less within-session error reduction. The performance component was generally less sensitive than the learning component to the disruptive effects of both drugs on rate and accuracy. After prefeeding or during an extended session, the response rate decreased in both components, but accuracy was generally unaffected. When the four discriminative stimuli in both components were removed, the behavior was disrupted to a greater extent in the performance component. The disruptive effects of both drugs on behavior in the learning component were attenuated when the drugs were administered during the session after the response chain had been acquired. It was concluded that the greater sensitivity of the learning component to disruptive drug effects is related to the relatively weak stimulus control and/or the lower rate of reinforcement associated with that component.

Key words: repeated acquisition, multiple schedule, response chains, *d*-amphetamine, cocaine, prefeeding, stimulus control, key press, monkeys

Previous research has shown that repeated-acquisition baselines are sensitive to the effects of *d*-amphetamine and cocaine in rats (Schrot, Boren, Moerschbaecher, & Simoes Fontes, 1978) and pigeons (Moerschbaecher, Boren, Schrot, & Simoes Fontes, 1979; Thompson, 1973, 1977, 1978). In Thompson's experiments, pigeons acquired a different four-response chain each session by responding sequentially on three keys in the presence of four colors. 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). Similar disruptive drug effects were obtained in the Moerschbaecher et al. (1979) study, where pigeons acquired a different chain of conditional discriminations each session. In that study, the repeated-acquisition procedure constituted one component of a multiple schedule. In the other component, the chain of conditional discriminations remained the same from session to session. This performance component was generally less sensitive than the learning component to the disruptive effects of both drugs on rate and accuracy.

The first objective of the present research was to measure the effects of varying doses of *d*-amphetamine and cocaine on the acquisition and performance of response chains in monkeys. The learning and performance conditions were compared within each session by using a multiple schedule. The second objective was to conduct an experimental analysis of some of the possible "behavioral mechanisms" (cf. Laties & Weiss, 1969) for the drug effects obtained.

EXPERIMENT 1

This experiment measured the effects of varying doses of *d*-amphetamine and cocaine on the acquisition and performance of response chains.

METHOD

Subjects

Three adult female patas monkeys served. Each subject had previously been used in ex-

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periments involving either matching-to-sample or fixed-consecutive-number procedures. The subjects were maintained at about 85% of their free-feeding weights (range 3.2 to 5.5 kg) on a diet consisting of Noyes banana-flavored food pellets, Purina Monkey Chow, fruit, and vitamins. The pellets were either earned during the experimental session or, when necessary, provided after the session. Monkey Chow, fruit, and vitamins were given to each subject after the daily session. Water was continuously available.

Apparatus

Each subject was housed in a primate cage (Research Equipment Co., model LC-1001) measuring 66 cm by 74.9 cm by 93.9 cm. A removable response panel (BRS/LVE, model TIP-001), measuring 56 cm by 21.5 cm by 45 cm, was attached to the side of each subject's cage during the experimental session. Three response keys (BRS/LVE, press plate model PPC-012) were centered and aligned horizontally on the panel. The keys were spaced 11.5 cm apart, center to center, and 51.5 cm from the cage floor. Each key required a minimum force of 0.29 *N* for activation. An in-line projector (BRS/LVE, model IC 901-696), mounted behind each key, could project colors and geometric forms onto the key. A yellow pilot lamp (1.2 cm in diameter) was mounted 22.5 cm to the right and 17 cm up from the center of the right-hand key. A press on this lamp (.34 *N* minimum force) closed a switch on which it was mounted. A food pellet aperture (5.5 cm in diameter) was located 15.5 cm to the right and 8 cm down from the center of the right-hand key. The response panels were connected to solid-state scheduling and recording equipment located in an adjacent room.

Procedure

Preliminary training. During magazine training, the yellow lamp over the food pellet aperture was illuminated. When the subject pressed this lamp, a 500-mg food pellet was delivered. After several reinforcers were presented in this way, the illumination of the yellow lamp was made dependent on the completion of a four-response chain. One of four geometric forms (horizontal line, triangle, vertical line, circle) was projected onto a red background on all three response keys. The subject's task was to learn a four-response chain by pressing the correct key in the presence of each form, e.g., horizontal line—Left correct; triangle—Right correct; vertical line—Center correct; circle—Right correct. When the chain was completed, the keylights turned off and the yellow lamp over the food pellet aperture was illuminated. A press on the yellow lamp then produced a food pellet and reset the chain. When the subject pressed 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 stimuli on the keys after the timeout were the same as before the timeout. The session was terminated after 100 reinforcer presentations.

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 there were restrictions on their ordering across sessions (see Thompson, 1973). An example of a typical set of six chains is as follows: Left-Right-Center-Right (LRCR), CLRL, LRLC, RCRL, CLCR, RCLC; the order of the associated forms was always the same: horizontal line, triangle, vertical line, circle (reinforcement).

After three daily sessions of repeated acquisition under the conditions described above, the fixed-ratio (FR) schedule was increased to FR 2; i.e., every other completion of the four-response chain was reinforced with food. After seven sessions under FR 2, the schedule was increased to FR 5. Under the FR 5 schedule, each completion of the four-response chain turned on the yellow lamp over the food pellet aperture and a press on the lamp reset the chain; every fifth completion of the chain produced a food pellet when the yellow lamp was pressed. There were 8 to 12 sessions of repeated acquisition under the FR 5 schedule.

Baseline conditions. A multiple schedule with learning and performance components served as the baseline. During the *learning* component, the repeated-acquisition procedure described under Preliminary Training was in effect. To reiterate briefly, the subject's task was to learn a different four-response chain each session by responding sequentially on three keys in the presence of four geometric

forms projected on a red background. During the *performance* component, the four geometric forms were projected on a green background and the four-response chain remained the same (LCLR) from session to session. In all other aspects (FR 5 schedule of food reinforcement, timeout duration of 5 sec, etc.), the performance component was identical to the learning component. Each daily session began in the learning component, which then alternated with the performance component after 10 reinforcements or 15 min, whichever occurred first. Each session was terminated after 100 reinforcements or 2 hr, whichever occurred first. The data for each session were analyzed in terms of (a) the overall response rate (total responses/min, excluding timeouts) in each component and (b) the overall accuracy or percent errors [(errors/total responses) × 100] in each component. In addition to these measures based on session totals, within-session changes in responding were monitored by a cumulative recorder. For example, acquisition of the response chain in the learning component was indicated by within-session error reduction.

Drug testing. Before the drug testing began, the multiple-schedule baseline was stabilized. The baseline was considered stable when the response rate and percent errors in each component no longer showed systematic change from session to session. After baseline stabilization (50 to 60 sessions), 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: cocaine, *d*-amphetamine, cocaine, *d*-amphetamine for Monkeys EV and B; the order of the two drugs was reversed for Monkey EL. 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 5 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 .05 ml/kg body weight.

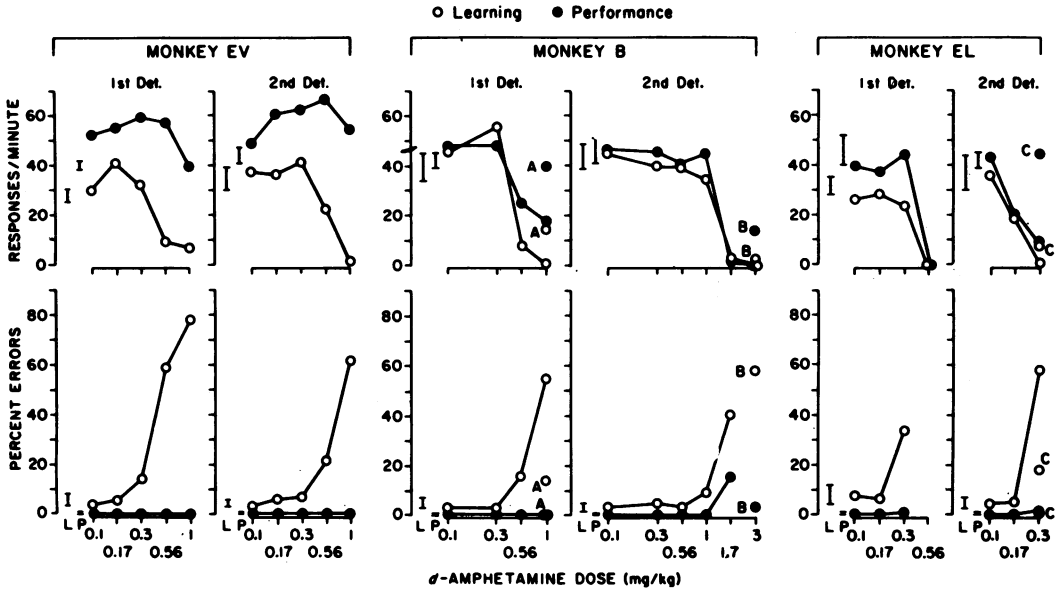

Fig. 1. Effects of varying doses of *d*-amphetamine (first and second determinations) on the overall response rate and percent errors in each component of the multiple schedule for each subject. The brackets indicate the control ranges for the learning (L) and performance (P) components. With Monkey B at 1 mg/kg of *d*-amphetamine (first determination), the session was terminated after 2 hr; the data points marked A show a second session, which was started 5 hr after the injection. At 3 mg/kg of *d*-amphetamine, Monkey B did not respond at all during the 2-hr session; the data points marked B show a second session, which was started 7 hr after the injection. With Monkey EL at .56 mg/kg of *d*-amphetamine, the data points for percent errors have been omitted because the overall response rate was virtually zero in both components. At .3 mg/kg of *d*-amphetamine (second determination), the session was terminated after 2 hr; the data points marked C show a second session, which was started 3 hr after the injection.

Results

Figure 1 shows the effects of varying doses of *d*-amphetamine (first and second determinations) on the overall response rate and percent errors in each component of the multiple schedule for each subject. The brackets indicate the control ranges for the learning (L) and performance (P) components; the ranges are based on the saline sessions (4 to 6) that were associated with each determination of a dose-effect curve. The 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 two determinations are presented separately because there were instances in which the baseline shifted somewhat across determinations (e.g., compare the control ranges for response rate in the learning component for Monkey EV). Moreover, in some cases, there were systematic differences between the first and second determinations of the dose-effect curves (e.g., Monkey B).

In general, Figure 1 shows that the dose-effect data for percent errors were more consistent across subjects than the data for response rate. With all three subjects, the percent errors in the learning component increased as the dose of *d*-amphetamine was increased. In contrast, except for an error-increasing effect at 1.7 mg/kg (Monkey B), accuracy in the performance component was generally unaffected by the drug. With Monkey EV, the response rate in the learning component increased and then decreased with increasing doses, whereas only rate-increasing effects occurred in the performance component. With Monkey B, the response rate in both components was increased at the lower doses of *d*-amphetamine (first determination) and was decreased at the higher doses. In the first determination, the rate-decreasing effects were greater in the learning component than in the performance component. With Monkey EL, increasing the dose of *d*-amphetamine decreased the response rate in both components.

When 1 mg/kg of *d*-amphetamine (first determination) was administered to Monkey B, the session was terminated after 2 hr. The data points marked A in Figure 1 show a second session (with the same four-response chain in the learning component), which was started 5 hr after the injection. As can be seen, there was still a rate-decreasing effect in the learning component even though the rate in the performance component had returned to control. At the same time, the percent errors in the performance component remained near zero, whereas there was still an error-increasing effect, albeit attenuated, in the learning component. At 3 mg/kg of *d*-amphetamine, Monkey B did not respond at all in either component of the multiple schedule during the 2-hr session. The data points marked B show a second session, which was started 7 hr after the injection. In both components, there was a rate-decreasing effect and an error-increasing effect; the magnitude of each effect, however, was greater in the learning component. With Monkey EL at .3 mg/kg of *d*-amphetamine (second determination), the session was terminated after 2 hr. The data points marked C show a second session (with the same four-response chain in the learning component), which was started 3 hr after the injection. As can be seen, the response rate and percent errors in the performance component were within the control ranges, whereas there was still a rate-decreasing effect and an error-increasing effect in the learning component.

Figure 2 shows the dose-effect data for cocaine. A comparison of Figure 2 with Figure 1 indicates that the effects of cocaine were generally similar to those of *d*-amphetamine. For example, with all three subjects, as the dose of cocaine was increased, the percent errors in the learning component tended to increase progressively, whereas accuracy in the performance component was relatively unaffected. There were, however, some apparent quantitative differences in effects between the two drugs within the range of doses tested. For example, the maximum rate-decreasing effects and error-increasing effects in the learning component were generally smaller with cocaine than with *d*-amphetamine.

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 record shows a representative saline session for Monkey B. The response pen stepped upward with each correct response

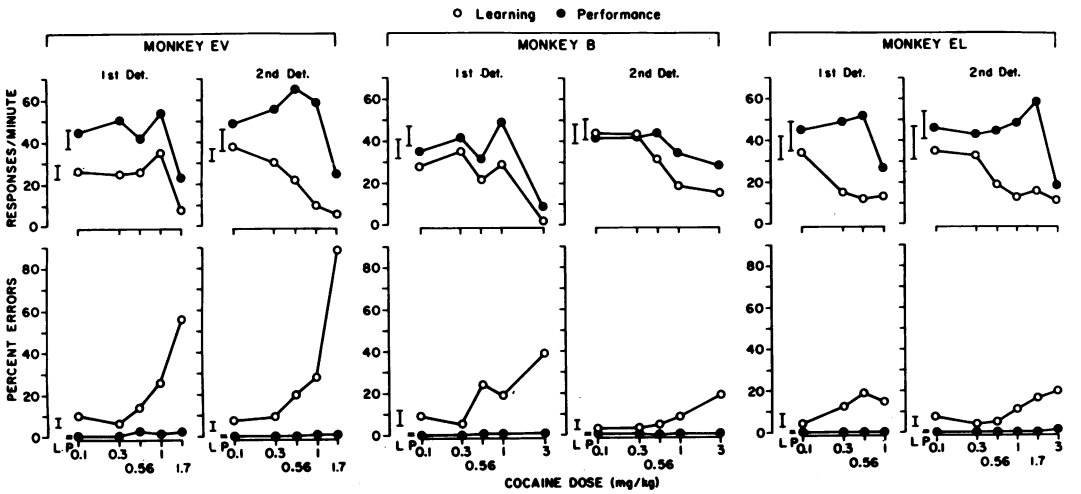

Fig. 2. Effects of varying doses of cocaine (first and second determinations) on the overall response rate and percent errors in each component of the multiple schedule for each subject. The brackets indicate the control ranges for the learning (L) and performance (P) components.

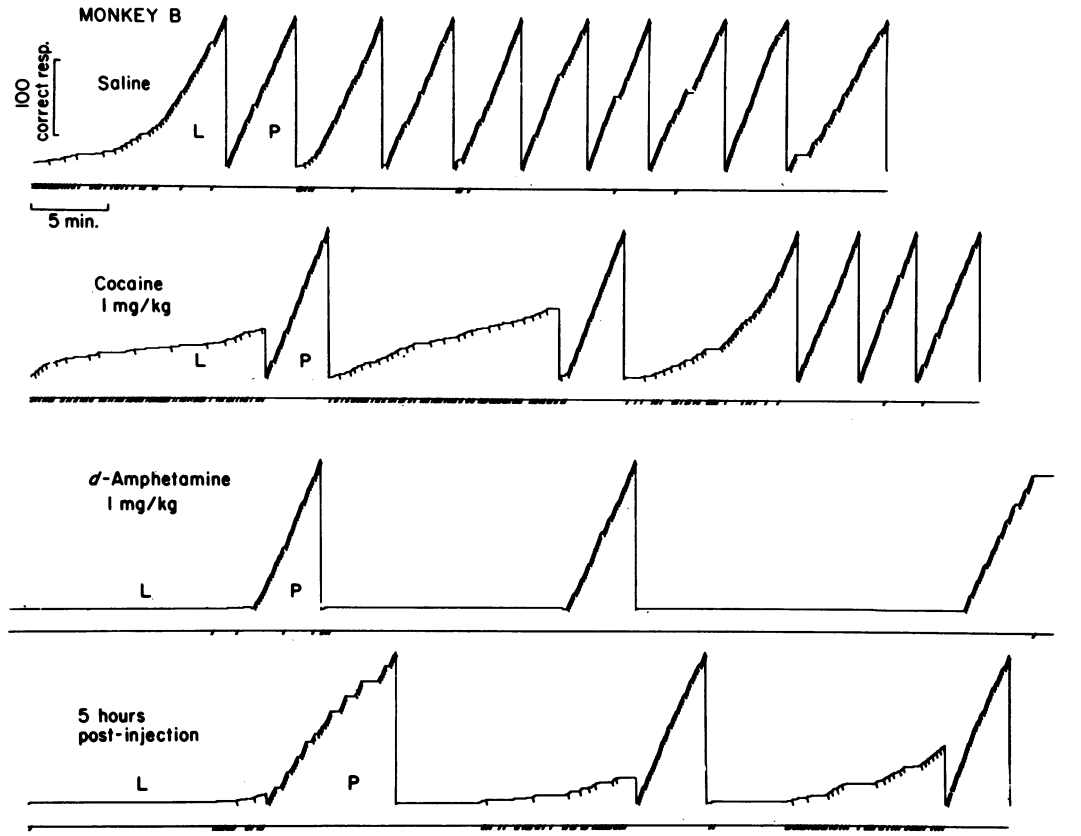

Fig. 3. Effects of cocaine and *d*-amphetamine, at the same dose, on the responding of Monkey B under a multiple schedule with learning (L) and performance (P) components. The response pen stepped upward with each correct response and was deflected downward each time the four-response sequence was completed. Errors are indicated by the event pen (below each record), which was held down during each timeout. A change in components of the multiple schedule reset the stepping pen. The bottom record shows a second session, which was started 5 hr after the injection of 1 mg/kg of *d*-amphetamine.

and was deflected downward each time the four-response sequence was completed. Errors are indicated by the lower event pen, which was held down during each timeout. A change in components of the multiple schedule reset the stepping pen. As can be seen in the saline record, within-session error reduction is evident during the learning component. Virtually no errors occurred in the performance component throughout the session. Compared to the saline session, 1 mg/kg of cocaine (first determination) decreased the rate of correct responding and increased the frequency of errors in the learning component during the first three cycles of the multiple schedule; i.e., acquisition of the response chain was clearly disrupted. In the performance component during the same period of time, the rate of correct responding was increased somewhat and the frequency of errors remained near zero. The same dose of *d*-amphetamine (first determination) virtually eliminated responding in the learning component during the first three cycles of the multiple schedule. In the performance component, there was little or no disruption of the rate of correct responding until the third cycle, in which some pausing occurred; the frequency of errors remained near zero. The differential effects of 1 mg/kg of *d*-amphetamine on learning and performance were still apparent 5 hr after the injection (see bottom record).

In summary, in all three subjects, the higher doses of *d*-amphetamine and cocaine disrupted the behavior in the learning component of the multiple schedule by decreasing the overall response rate and increasing the percent errors. The performance component was generally less sensitive to the disruptive effects of both drugs on rate and accuracy.

EXPERIMENT 2

The possibility that *d*-amphetamine and cocaine produced their disruptive effects because their "anorectic" action decreased the effectiveness of the food reinforcer seems unlikely since differential effects were obtained (greater disruption of acquisition than of performance). Nevertheless, in Experiment 2, this possibility was investigated by attempting to mimic the drug effects by a prefeeding manipulation. For comparison, a session (without prefeeding) was extended in order to produce a more gradual "satiation."

Method

Subjects

The subjects were the same three monkeys that served in Experiment 1.

Apparatus

The apparatus in Experiment 1 was used.

Procedure

Baseline conditions. The baseline conditions were the same as those in Experiment 1. There were at least seven baseline sessions between the end of Experiment 1 and the beginning of this experiment.

Prefeeding and extended sessions. In the prefeeding manipulation, 100 to 500 food pellets (500 mg each) were placed in the subject's food tray before the session. The session began as soon as the subject had consumed all of the pellets. The number of pellets prefed per session was varied in steps of 100 in an ascending order (100 pellets were available as reinforcers during each session). The prefeeding sessions were separated by at least five days, during which time there were baseline sessions. A few days after the last prefeeding session, an extended session was conducted in which more than 400 reinforcers were delivered.

Results

Figure 4 shows the effects of varying amounts of prefeeding on the response rate and per-

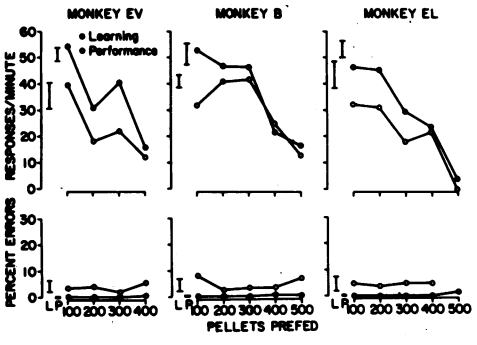

Fig. 4. Effects of varying amounts of prefeeding (single determination) on the overall response rate and percent errors in each component of the multiple schedule for each subject. The brackets indicate the control ranges for the learning (L) and performance (P) components; each control range is based on 4 or 5 baseline sessions. After Monkey EL was prefed 500 pellets, the overall response rate in the learning component was virtually zero; the data point for percent errors in that component has therefore been omitted.

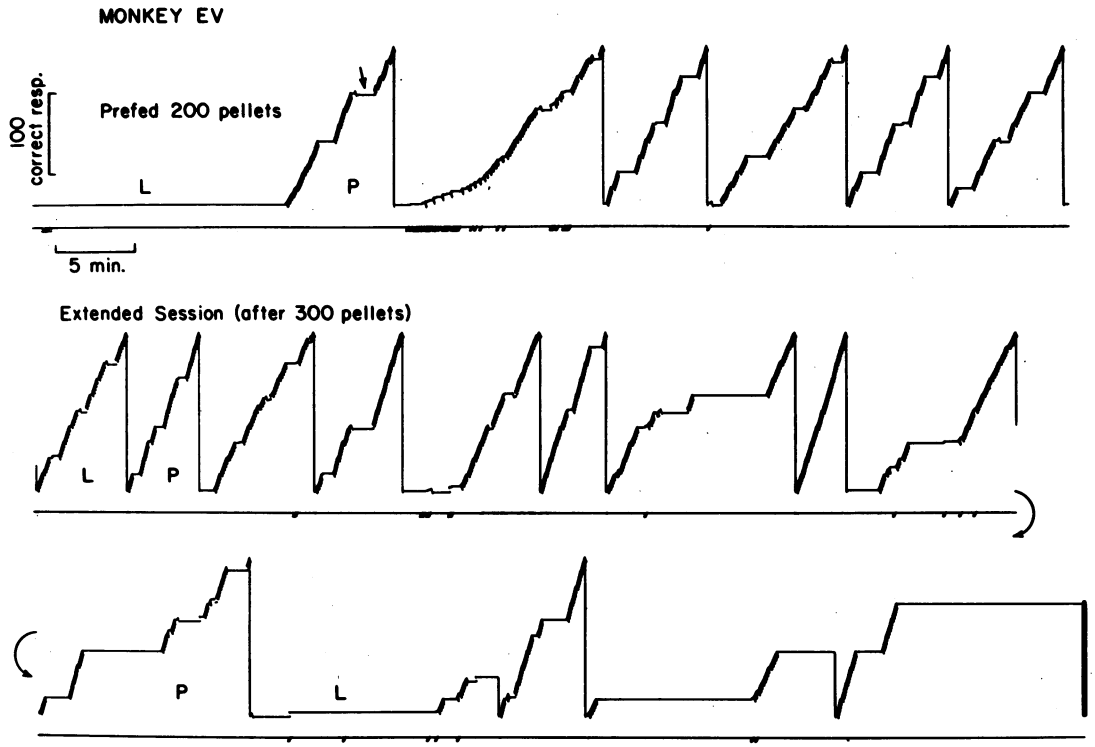

Fig. 5. Responding of Monkey EV under a multiple schedule with learning (L) and performance (P) components after the subject was prefed 200 pellets and during an extended session (without prefeeding). The arrow in the top record indicates a pause that occurred while the yellow lamp over the food pellet aperture was illuminated. During the extended session, more than 400 pellets were delivered; the data for the first 300 pellets have been omitted. The recording details are the same as in Figure 3.

cent errors in each component of the multiple schedule for all three subjects. The baseline session on the day before each prefeeding session was considered a control session; the brackets indicate the control ranges for the learning (L) and performance (P) components. Prefeeding was considered to have an effect on response rate or percent errors to the extent that the prefeeding data fell outside of the control range. As the amount of prefeeding was increased, the response rate tended to decrease progressively in both the learning and performance components, but accuracy was generally unaffected. The absence of an error-increasing effect in the learning component is in striking contrast to the disruptive drug effects obtained in Experiment 1 (Figures 1 and 2).

The nature of the rate-decreasing effect of prefeeding is illustrated in Figure 5 (top). The cumulative records for the control sessions in this experiment were similar to the saline record shown in Figure 3. After Monkey EV was prefed 200 pellets, virtually no responding occurred in the learning component during the first cycle of the multiple schedule. Correct responding occurred at a high rate in the performance component during the first cycle, although there were two noticeable periods of pausing. Note that during the second pause (see arrow), the stepping pen was displaced. This indicates that the yellow lamp over the food pellet aperture was illuminated. The four-response chain in the learning component was acquired during the second cycle. The pattern of acquisition was similar to that seen during control sessions (see Figure 3, top record, first cycle), except for the periods of pausing. During the rest of the prefeeding session, pausing occurred frequently in both components. Similar results were obtained during the extended session after 300 reinforcers had

been delivered, except that the pausing became more prolonged as the session progressed (see lower record in Figure 5).

EXPERIMENT 3

In Experiment 1, the performance component was generally less sensitive than the learning component to the disruptive effects of both drugs on rate and accuracy. This finding is consistent with the widely held view that behavior under strong stimulus control is less readily disrupted by drugs than behavior under weak stimulus control (see reviews by Laties, 1975; Thompson, 1978). That the baseline error levels in the performance component were lower than those in the learning component indicates that the control by the discriminative stimuli (e.g., geometric forms) was stronger in the performance component, where the response chain was the same from session to session. In Experiment 3, this interpretation was tested by temporarily removing the four geometric forms that had been associated with each response chain. One would expect this tandem probe to disrupt behavior to a greater extent in the performance component than in the learning component if the discriminative stimuli that were removed had exerted stronger control over the behavior in the performance component. The stimulus control interpretation was further tested by another manipulation: *d*-amphetamine and cocaine were administered *during* the session after strong stimulus control had been established in the learning component in order to determine whether the disruptive drug effects would be attenuated.

Method

Subjects

The subjects were the same three monkeys that served in Experiment 1.

Apparatus

The apparatus in Experiment 1 was used.

Procedure

Baseline conditions. The baseline conditions were the same as those in Experiment 1. There were at least seven baseline sessions between the end of Experiment 2 and the beginning of this experiment.

Tandem probe. In the tandem probe, the four geometric forms that had been associated with each response chain were no longer present (the red and green lights still differentiated the learning and performance components). The session began under the tandem condition, which then alternated with the chain condition after two cycles of the multiple schedule.

Within-session drug administration. A few days after the tandem probe, the effects of within-session drug administration were assessed. After two cycles of the multiple schedule, the session was interrupted and either saline or drug was administered intramuscularly. Monkeys EV and B received .56 mg/kg of *d*-amphetamine sulfate and Monkey EL received 1 mg/kg of cocaine hydrochloride. About a week later, for comparison, saline and the same doses were administered intramuscularly 5 min presession. The drugs were dissolved in saline and the volume of each injection was .05 ml/kg body weight.

Results

The effects of the tandem probe on the responding of Monkey EV are shown in Figure 6, which compares the tandem and chain conditions within the same session. The tandem condition was in effect during the first two cycles of the multiple schedule (top record). As can be seen, the rate of correct responding was somewhat lower in the performance component than in the learning component. The tandem condition was then changed to the chain condition, wherein the geometric forms were present. Acquisition in terms of error reduction now occurred during the learning component, whereas the performance component was characterized by a high rate of correct responding and near-zero errors. When the tandem condition was then reinstated, the behavior was disrupted in both components. The disruption was somewhat greater in the performance component in terms of the rate of correct responding, thereby indicating that the discriminative stimuli that were removed had exerted stronger control over the behavior. Finally, when the chain condition was reinstated, relatively high rates of correct responding and low error levels again occurred in both components. Noteworthy in this regard is the high degree of retention of the stimulus control established

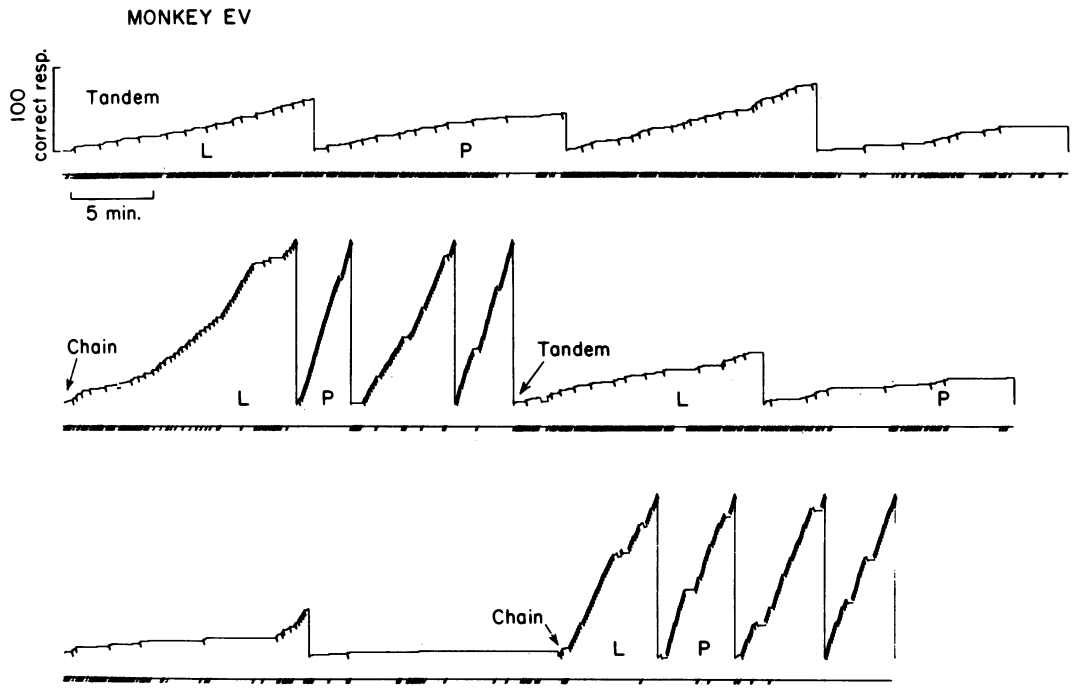

Fig. 6. Responding of Monkey EV under a multiple schedule with learning (L) and performance (P) components during a session in which the four geometric forms in both components were removed (tandem) and reinstated (chain). The recording details are the same as in Figure 3.

over an hour earlier in the learning component under the chain condition. The effects of the tandem probe in the other two subjects were similar to those shown for Monkey EV.

The effects of within-session drug administration on the responding of Monkey EV are shown in Figure 7. In the top two cumulative records, after two cycles of the multiple schedule, the session was interrupted and either saline or *d*-amphetamine (.56 mg/kg) was administered intramuscularly. By this point in the session, the four-response chain in the learning component had already been acquired, as indicated by near-zero errors (strong stimulus control). As can be seen, the only disruptive effect of the drug in the learning component was a small increase in errors; performance errors remained near zero. In contrast, when the same dose of *d*-amphetamine was administered 5 min before the session (bottom two records), its disruptive effects in the learning component were substantial. There was considerable pausing throughout the session, and, when responding did occur, errors were frequent. Again, there were no disruptive drug effects in the performance component. In short, these results show that the disruptive effects of *d*-amphetamine on behavior in the learning component were greatly attenuated when the behavior was under relatively strong stimulus control. Similar results were obtained with .56 mg/kg of *d*-amphetamine in Monkey B and with 1 mg/kg of cocaine in Monkey EL, although the effects of the presession injection on rate and accuracy were smaller than those obtained with Monkey EV (see Table 1).

GENERAL DISCUSSION

In Experiment 1, the higher doses of *d*-amphetamine and cocaine disrupted the behavior in the learning component of the multiple schedule; i.e., the overall response rate decreased, the percent errors increased, and there was less within-session error reduction. These effects, obtained with monkeys, are comparable to previously reported effects of *d*-amphetamine and cocaine on the responding of pigeons under similar conditions of repeated acquisition (Thompson, 1973, 1977, 1978). Experiment 1 also extends the generality of an-

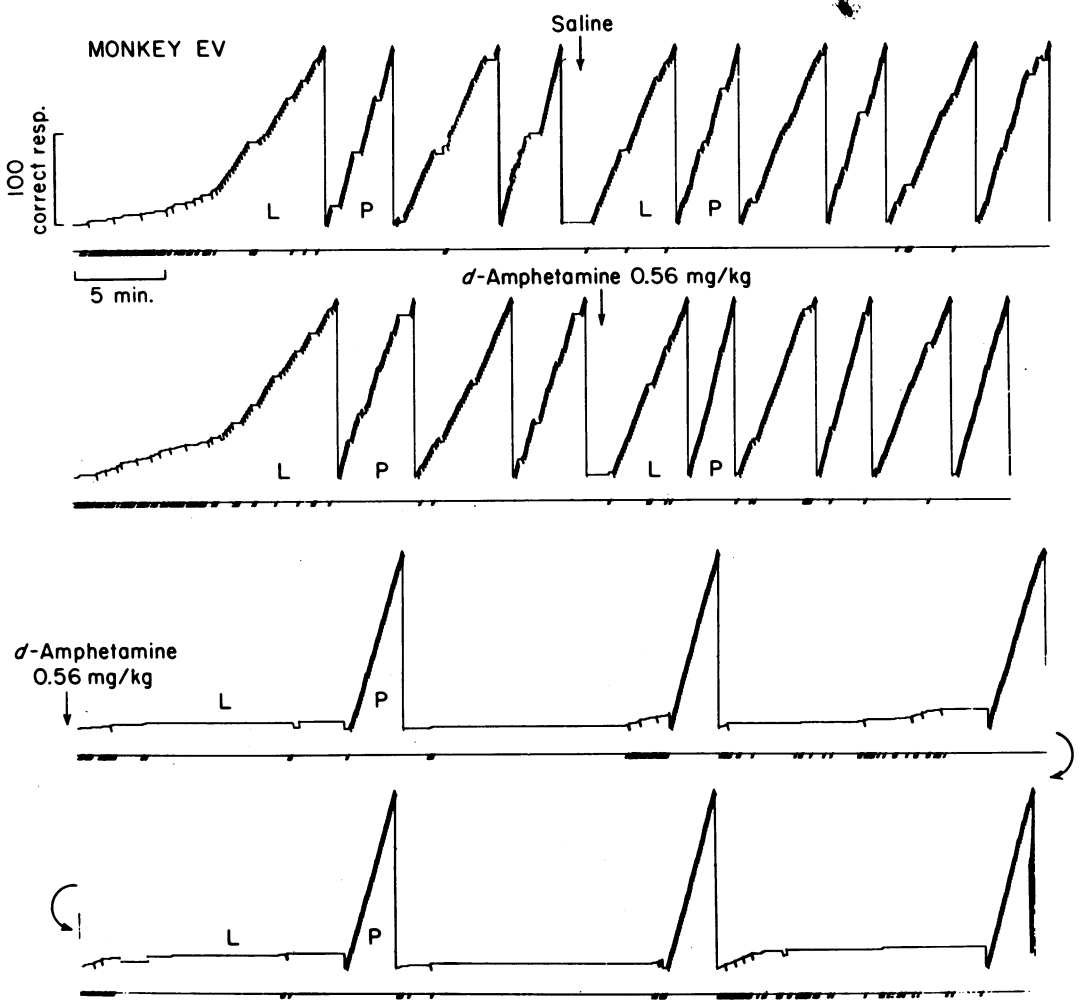

Fig. 7. Effects of within-session and presession injections of *d*-amphetamine (.56 mg/kg) on the responding of Monkey EV under a multiple schedule with learning (L) and performance (P) components. The recording details are the same as in Figure 3.

Table 1

Overall response rate and percent errors in the learning component after within-session and presession drug administration. Monkeys EV and B received 0.56 mg/kg of *d*-amphetamine and Monkey EL received 1 mg/kg of cocaine.

		Within-session injection		*Presession injection*	
Monkey	*Session*	*Resp/ min*	*% Errors*	*Resp/ min*	*% Errors*
EV	Saline	42.2	1.3	36.3	4.8
	Drug	49.8	2.1	2.0	66.2
B	Saline	47.2	0.7	43.6	1.9
	Drug	46.8	0.7	35.8	7.4
EL	Saline	51.2	1.9	50.1	2.7
	Drug	42.2	2.6	22.4	9.4

other finding with pigeons (Moerschbaecher et al., 1979), namely, the performance component of the multiple schedule was generally less sensitive than the learning component to the disruptive effects of both drugs on rate and accuracy.

The rate-decreasing effects found in Experiment 1 are consistent with previous reports that *d*-amphetamine and cocaine decrease the rate of responding under FR schedules of food presentation in monkeys (Downs & Woods, 1975; Gonzalez & Goldberg, 1977; Johanson, 1978; Kelleher & Morse, 1964; Wilson & Schuster, 1975; Woods & Tessel, 1974). The present results are also consistent with the data of Gonzalez and Goldberg in showing that the

rate-decreasing effects of *d*-amphetamine lasted longer than those of cocaine. It is interesting that Gonzalez and Goldberg found rate-increasing effects at intermediate doses of both drugs when responding was maintained under a second-order fixed-interval schedule with FR components. Such effects were also found in the present study, which used a different type of second-order schedule (an FR 5 schedule with FR 4 components). In the Gonzalez and Goldberg study, the control response rates under the second-order schedule were relatively low when compared to the rates generated by a simple FR schedule, where *d*-amphetamine and cocaine produced a monotonic decrease in rate with increasing doses. Because the control response rates in the present study were comparable to those generated by the second-order schedule in the Gonzalez and Goldberg study, it is not surprising that certain doses of *d*-amphetamine and cocaine increased the rate of FR responding.

The error-increasing effects found in Experiment 1 complement the results obtained with other discrimination techniques, such as matching to sample (Glick & Jarvik, 1969), fixed consecutive number (Laties, 1972) and related procedures (Branch, 1974). With these techniques, it has been shown that accuracy decreases with increasing doses of *d*-amphetamine in monkeys and pigeons. The effect of cocaine on accuracy in such situations remains to be investigated.

Experiment 2 was designed to evaluate the possibility that *d*-amphetamine and cocaine produced their disruptive effects on rate and accuracy because their "anorectic" action decreased the effectiveness of the food reinforcer. An attempt was made to mimic the drug effects by a prefeeding manipulation. As the amount of prefeeding was increased from 100 to 500 pellets, the response rate tended to decrease progressively in both the learning and performance components of the multiple schedule, but accuracy was generally unaffected. Similar results were found during an extended session in which more than 400 pellets were delivered. These findings are consistent with the effect of "satiation" on matching-to-sample performance in pigeons. After prefeeding or during extended sessions, pausing occurred, but there was no decrement in matching-to-sample accuracy (Cumming, Berryman, & Nevin, 1965). On the basis of the results of Experiment 2, it would seem, therefore, that the "anorectic" interpretation may account for the rate-decreasing effects of the drugs but not for their error-increasing effects. However, this interpretation cannot readily explain why certain doses of *d*-amphetamine and cocaine decreased the response rate only in the learning component. It would be unreasonable to argue that the drugs had an "anorectic" effect in the learning component but did not have this effect a short time later in the performance component (cf. McMillan & Leander, 1976).

The finding that the performance component was generally less sensitive than the learning component to the disruptive effects of *d*-amphetamine and cocaine on rate and accuracy may be accounted for in terms of differential stimulus control. It has been shown in a variety of situations that behavior under strong stimulus control is less readily disrupted by drugs than behavior under weak stimulus control (see reviews by Laties, 1975; Thompson, 1978). The effects of the tandem probe in Experiment 3 indicated that the behavior in the performance component was, in fact, under stronger stimulus control than the behavior in the learning component. Experiment 3 also showed that the disruptive effects of *d*-amphetamine and cocaine on behavior in the learning component were attenuated when the drugs were administered during the session after the four-response chain had already been acquired, i.e., after strong stimulus control had been established.

Although the differential drug effects on learning and performance can be interpreted in terms of stimulus control, there is reason to believe that the baseline rate of reinforcement was an important determinant (Moerschbaecher et al., 1979). Components of a multiple schedule with different rates of reinforcement have been shown to be differentially sensitive to nonpharmacological variables. For example, Blackman (1968, Experiment II) found that, when response rates were equated, suppression of food-reinforced responding in the presence of a stimulus preceding unavoidable shock was greater in the component with the lower rate of reinforcement. During the baseline sessions in Experiment 1, the rate of reinforcement was lower in the learning component than in the performance component, and this may account for the greater sensitivity of the learning component to disruptive drug

effects. Any such interaction would be indirect since the conditions of stimulus control in part determined the rate of reinforcement; i.e., errors produced timeouts, which decreased the frequency of reinforcement per unit time. It seems reasonable to conclude that the greater sensitivity of the learning component is related to the relatively weak stimulus control and/or the lower rate of reinforcement associated with that component.

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