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EFFECTS OF d-*AMPHETAMINE ON RESPONDING UNDER SECOND-ORDER SCHEDULES OF REINFORCEMENT WITH PAIRED AND NONPAIRED BRIEF STIMULI*

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Three pigeons were studied under a multiple schedule in which pecks in each component were reinforced according to a variable-interval 120-s second-order schedule with fixed-interval 60-s units. In the first component of the multiple schedule, the completion of a fixed interval produced either food or a 4-s change in key color plus houselight illumination. In the second component an identical schedule was in effect, but the stimulus was a 0.3-s change in key color. Both long and short brief stimuli were not paired with food presentations in Conditions 1 and 3 and were paired with food in Condition 2. There were no consistent differences in response patterns under paired and nonpaired brief-stimulus conditions when the stimulus was a 4-s change in key color accompanied by houselight illumination. However, pairing the 0.3-s key-color change with food presentations resulted in higher indices of curvature and lower response rates in the early segments of the fixed interval than when the stimulus was not paired with food presentations. Low doses of *d*-amphetamine (0.3 and 1 mg/kg) produced small and inconsistent increases in overall response rates, and higher doses (3 and 10 mg/kg) decreased overall response rates. *d*-Amphetamine altered response patterns within fixed intervals by decreasing the indices of curvature and increasing response rates in the early segments of the fixed interval. Response rates and patterns under paired and nonpaired brief-stimulus conditions were not differentially affected by *d*-amphetamine. Thus, evidence for the enhancement of the conditioned reinforcement effects of psychomotor stimulant drugs was not found with the second-order schedules used in the present study.

Key words: conditioned reinforcement, *d*-amphetamine, second-order schedules, multiple schedules, brief stimuli, key peck, pigeons

Conditioned reinforcers are stimuli that acquire reinforcing functions by being associated with unconditioned reinforcers (Mazur, 1990; Skinner, 1938). It has been suggested that drugs classified as stimulants may modulate the effects of conditioned reinforcers (e.g., Hill, 1970). Stimulants have been shown to increase response rates in extinction when responding results in the brief presentation of a stimulus that has been associated with an unconditioned reinforcer (e.g., Hill, 1970; Hoffman & Beninger, 1985; Mason & Robbins, 1979; Robbins, 1978; Robbins & Koob, 1978). For example, Robbins and Koob delivered reinforcing brain stimulation to rats for pushing a panel in the presence of white noise (S+) and did not deliver brain stimulation for pushing in the presence of a houselight (S−). The rats were then divided into four groups, each given a different dose of pipradrol, and placed in a chamber with two levers. In the absence of brain stimulation, responses on one lever resulted in 1-s presentation of the S+, and responses on the other lever produced the S−. The rats acquired the lever-press response, and pipradrol produced a dose-dependent increase in response rate on the S+ lever and very little responding on the S− lever.

Most research investigating the relationship between conditioned reinforcement and stimulants has employed extinction procedures and between-group designs, techniques that have been shown to have some methodological weaknesses (see Hendry, 1969; Kelleher & Gollub, 1962; Wike, 1966). Other studies, however, have used brief-stimulus procedures such as second-order schedules of reinforcement (e.g., Goldberg, Kelleher, & Goldberg, 1981). Under a second-order schedule, re-

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sponding maintained by one schedule of reinforcement (the component or unit schedule) is treated as a unitary response that is reinforced according to another schedule of reinforcement. A brief stimulus presented at the completion of each component engenders response patterns within components similar to those seen with simple schedules of reinforcement (e.g., Gollub, 1977; Keenan, 1986; Kelleher, 1966a, 1966b; Marr, 1969; Stubbs, 1971). For example, Kelleher (1966b) maintained key pecking of pigeons by delivering food after the completion of 15 fixed-interval (FI) 4-min schedules. A 0.7-s change in key color followed the completion of each fixed interval and resulted in positively accelerated response patterns within the FI components (fixed ratio [FR] 15 [FI 4 min: S]). The similarity in response patterns following food and brief-stimulus presentations is often used as evidence for a conditioned reinforcement effect of the stimulus (e.g., Stubbs, 1971).

The use of second-order schedules in the study of conditioned reinforcement has a long and controversial history. Many investigators have emphasized the conditioned reinforcement effects of the brief stimulus in second-order schedules by showing that the stimulus must be paired with food in order for it to control response patterns that resemble those observed with food reinforcement (e.g., Byrd & Marr, 1969; de Lorge, 1967; Kelleher, 1966a). Others have emphasized the discriminative effects of the brief stimulus by showing that nonpaired stimuli can also control responding, and that the discriminative effects of the stimulus often mask its conditioned reinforcement effects (e.g., Cohen & Stubbs, 1976; Stubbs, 1971). Actually, many variables affect rates and patterns of responding within components of second-order schedules, including duration (Cohen, Hughes, & Stubbs, 1973) and type of brief stimulus (Stubbs & Cohen, 1972). These variables may interact to determine whether or not paired and nonpaired brief stimuli differentially affect behavior (Cohen & Calisto, 1981; Stubbs, Vautin, Reid, & Delehanty, 1978). For example, under a second-order schedule with fixed-interval components, Stubbs et al. (1978) found no differences between paired and nonpaired brief-stimulus presentations with a 2.5-s brief stimulus but did obtain differential effects with a 0.5-s stimulus change (i.e., greater FI curvature with a shorter paired brief stimulus than a shorter nonpaired stimulus).

In general, studies involving drugs and second-order schedules have not analyzed performance in the context of conditioned reinforcement. Many of these studies wee designed to show that subjects will respond for experimenter- or self-administered drugs under schedules involving long sequences of behavior such as an FR 10 (FI 5 min: S) second-order schedule (e.g., Goldberg, 1973, 1976; Goldberg, Kelleher, & Morse, 1975; Katz, 1979; Kelleher, 1976; Kelleher & Goldberg, 1977; Spealman & Goldberg, 1982). In other studies, responding was maintained under second-order schedules of reinforcement, and presession injections of drugs were administered (Barrett, Katz, & Glowa, 1981; Barrett, Valentine, & Katz, 1981; Bond, Sanger, & Blackman, 1975; Goldberg, Morse, & Goldberg, 1976; Goldberg et al., 1981; Gonzalez & Goldberg, 1977; Katz, 1980; Marr, 1970; Winsauer, Thompson, & Moerschbaecher, 1985). It is difficult, however, to relate the findings of these studies to conditioned reinforcement, where the primary interest involves the question of whether stimulant drugs may enhance the effects of conditioned reinforcers. The most important test for conditioned reinforcement involves a comparison of performance with stimuli that are paired with unconditioned reinforcers and stimuli that are not paired. Studies that have examined the effects of presession treatment of stimulant drugs have used only paired brief stimuli. The purpose of the present experiment was to examine the effects of *d*-amphetamine on responding under a second-order schedule with both paired and nonpaired brief stimuli. If *d*-amphetamine modifies the effects of conditioned reinforcers, then differences between paired and nonpaired stimulus conditions should be evident in either overall response rates or response patterns within components of the second-order schedule.

In a partial replication of the experiment of Stubbs et al. (1978), pigeons' responses were reinforced in both components of a multiple schedule according to a variable-interval (VI) 120-s (FI 60 s: S) second-order schedule. In one component, the brief stimulus was a 4-s change in key color accompanied by houselight illumination. In the other component, the brief stimulus was a 0.3-s change in key color without the houselight. In the first and third con-

ditions, both brief-stimulus presentations were not paired with food delivery but were paired with food in the second condition. Under each condition the effects of *d*-amphetamine were examined. An analysis of the data during nondrug sessions revealed no consistent differences in response patterns under paired and nonpaired brief-stimulus conditions when the stimulus was a 4-s change in key color accompanied by houselight illumination. However, pairing the 0.3-s key-color change with food presentations resulted in higher indices of curvature and lower response rates in the early segments of the fixed interval than when the stimulus was not paired with food presentations. The present study, therefore, examined the effects of *d*-amphetamine under conditions in which pairing the brief stimulus with food differentially affected behavior (0.3-s brief stimulus) and under conditions in which pairing did not differentially affect behavior (4-s brief stimulus).

METHOD

Subjects

Three experimentally naive male White Carneau pigeons (Palmetto Pigeon Plant) were maintained at 80% of their free-feeding weights (454 to 504 g). Water was freely available in their home cages, where a 12:12 hr light/dark cycle was maintained (lights on at 6:00 a.m.).

Apparatus

One noncommercial and two modular (Coulbourn Instruments) pigeon chambers were used. In the modular chambers the key (2.5 cm diameter) was located in the center of the work panel, 6.0 cm from the ceiling, and was transilluminated green, orange, white, or blue by an IEE one-plane readout. A minimum force of 0.10 N operated the key, and a 28-V white houselight was located above the key. Mixed grain was presented through an aperture below the key and was illuminated red during each food cycle. The noncommercial chamber (see Cohen & Lentz, 1976) had a similar configuration except that the intelligence panel was 27 cm high by 36 cm wide, a Gerbrands key (1.9 cm diameter) was located to the left of center, 4.5 cm from the ceiling and 13 cm from the left side wall, and could be operated with a minimum force of 0.07 N. The 28-V houselight was centered 1.5 cm from the ceiling, the hopper opening was centered with the bottom lip 7.5 cm from the floor, and a Lehigh Valley Electronics pigeon feeder was used. White noise was present continuously in the experimental room to mask extraneous sounds. Contingencies were controlled by an IBM-PC® computer, Coulbourn Instruments Lab-Linc® Interface, and Pascal programming.

Procedure

Responding on a blue key was established by autoshaping and was maintained by a continuous reinforcement schedule for three sessions, a VI 5-s schedule for one session, a VI 10-s schedule for one session, one session each of an FI 10-, 20-, 30-, and 40-s schedule, and three sessions of an FI 60-s schedule. Under the FI schedule the first response after 60 s operated the food magazine and red feeder light for 4 s while the keylight remained blue. Sessions were conducted Monday through Friday.

Next, a multiple FI 60-s FI 60-s schedule was in effect for 12 sessions. Component 1 was signaled by a blue keylight and Component 2 by a green keylight. The completion of four FI 60-s schedules terminated a component and initiated a 10-s blackout, during which time the chamber was dark and responses had no scheduled effects. After the blackout, the next component (1 or 2) was randomly determined with the restriction that there were no more than three consecutive presentations of the same component. Sessions began randomly with either component and ended after the completion of 12 components.

Second-order schedule: nonpaired brief stimulus. The FI 60-s schedule within each component of the multiple schedule was changed to a VI 120-s (FI 60 s: S^N) second-order schedule. In the presence of a component key color of the multiple schedule, responses controlled by an FI 60-s schedule were reinforced according to a VI 120-s schedule. If an interval of the VI schedule had not elapsed, the completion of an FI produced a brief stimulus. If an interval of the VI schedule had elapsed, the completion of an FI produced the food hopper and the key color remained on. The brief stimulus differed in Components 1 and 2. For Birds 3460 and 3461, the brief stimulus in Component 1 was a 4-s change in key color from blue to white plus the illumination of the

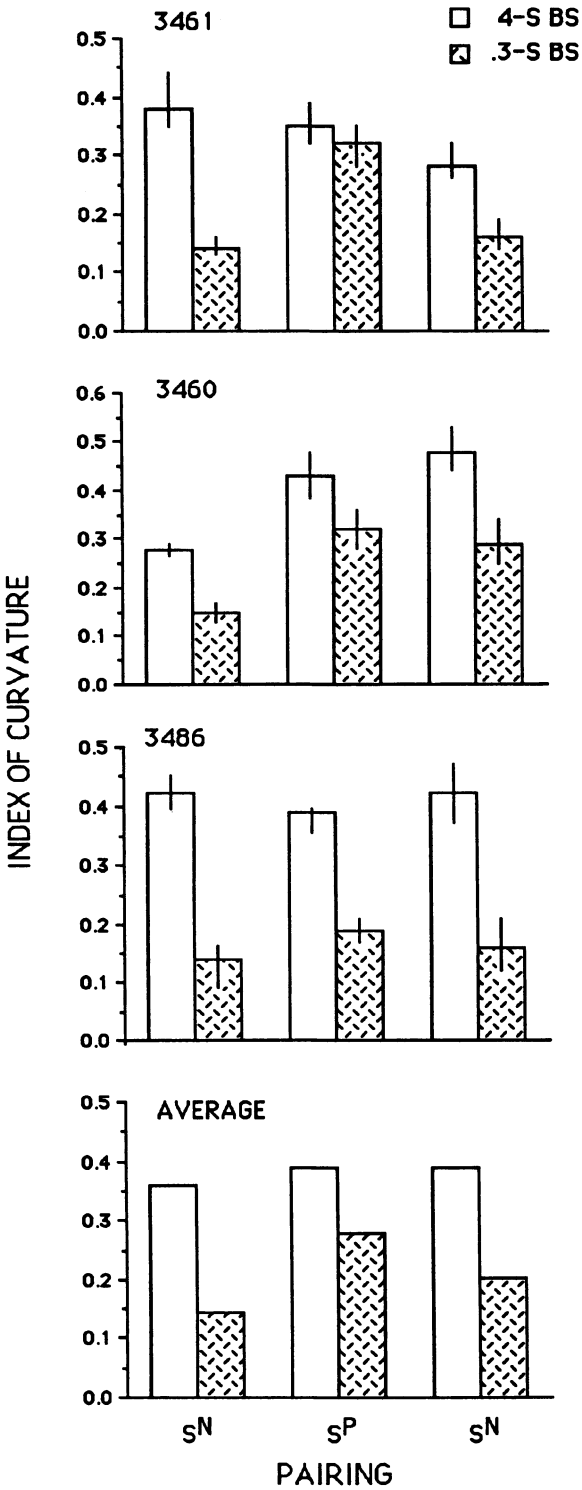

Fig. 1. Index of curvature within FI components of the second-order schedule for each subject, and the average for all 3 subjects. Data are means and ranges of the last five sessions during baseline (before the first drug injection)

houselight, and in Component 2 it was a 0.3-s change in key color from green to orange (no houselight). For Bird 3486, the 0.3-s orange brief stimulus occurred in the blue component, and the 4-s white keylight plus houselight occurred in the green component. Each component of the multiple schedule terminated after the completion of four FIs of the second-order schedule, and each session terminated after the completion of 16 components of the multiple schedule. The FI 60-s schedule contained a 30-s limited hold: If the FI was not completed within 30 s after it timed out, the FI was terminated by a 4-s blackout and the scheduling sequence continued. The VI 120-s schedule contained 20 intervals that were derived from the formula of Catania and Reynolds (1968, p. 380). An interval was randomly chosen following each food presentation and each 10-s blackout until the entire set of 20 intervals was exhausted, at which time random selection began anew. The same VI schedule was used in both Components 1 and 2. This nonpaired brief-stimulus condition was in effect for 57 to 60 sessions before responding became stable (no increasing or decreasing trends in index of curvature for at least five sessions) and the first injection was administered.

Paired brief stimulus. The brief stimulus in both components of the multiple schedule was now paired with food (i.e., VI 120 s [FI 60 s: S^P]); all other conditions were identical to the nonpaired stimulus condition. A preceding overlapping pairing operation was used (Stubbs & Cohen, 1972); the completion of each FI requirement scheduled to produce food turned on the brief stimulus 0.3 s before food delivery and remained on during the 4-s food cycle. This condition was in effect 31 to 38 sessions before *d*-amphetamine was administered in the same sequence as in the nonpaired condition.

Nonpaired brief stimulus. The first condition was replicated. Nineteen to 23 sessions were conducted before injections were administered.

Drug administration. *d*-Amphetamine (Sigma) was mixed in physiological saline and

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under Conditions 1 (nonpaired, S^N), 2 (paired, S^P), and 3 (nonpaired). For Birds 3461 and 3460, the 4-s brief stimulus was in Component 1 and the 0.3-s stimulus was in Component 2 of the multiple schedule. For Bird 3486, the 4-s brief stimulus was in Component 2 and the 0.3-s stimulus was in Component 1.

administered in the following doses: 0 (saline), 0.3, 1, 3, and 10 mg/kg body weight. Each subject completed two ascending dose series. *d*-Amphetamine was mixed with saline in a volume of 1 mL/mg and injected in the breast muscle 10 min before the session. An injection was given Tuesday and Friday of each week.

RESULTS

Responding under baseline conditions was characterized by a pause after a brief stimulus, followed by positively accelerated responding. The response patterns were similar to those previously reported under similar second-order schedules of reinforcement (Stubbs, 1971). Figure 1 shows the mean index of curvature and range for the last five sessions before the first injection was administered (baseline). The index of curvature is a statistic that describes the degree of response pattern under FI schedules (Fry, Kelleher, & Cook, 1960). The index was calculated from responses recorded in six 10-s periods of the FI 60-s components of the second-order schedule. A value of 0.0 indicates a constant response rate throughout the fixed interval, whereas larger numbers (reaching a value of 0.83 when the fixed interval is divided into sixths and all responding occurs in the last bin) indicate greater curvature. Figure 1 shows that the index of curvature was greater in the component with the 4-s white keylight plus houselight than in the component with the 0.3-s orange keylight, whether or not the longer brief stimulus occurred in Component 1 (Birds 3461 and 3460) or 2 (Bird 3486) of the multiple schedule. More importantly, consistent differences were not observed between the effects of a paired and nonpaired 4-s brief stimulus, but the index of curvature was greater with the paired compared to the nonpaired 0.3-s brief stimulus. This effect can be seen most clearly in Birds 3461 and 3460, for which the average index increased from the nonpaired to the paired condition, and there was no overlap in the 5-day ranges. Although the increase in curvature was less evident in Bird 3486, only one of the last five baseline sessions in Condition 1 overlapped with the range of indices in Condition 2. When the stimulus was no longer paired with food in Condition 3, the index decreased for Bird 3461 but remained high for birds 3460 and 3486.

Figure 2 shows the effects of *d*-amphetamine on index of curvature. As with baseline sessions (Figure 1), differences between the effects of paired and nonpaired brief stimuli were observed during preinjection sessions with the 0.3-s but not with the 4-s brief stimulus; the average index of curvature increased from Conditions 1 to 2 with the 0.3-s brief stimulus, and there was no overlap in the ranges of the 8 to 10 preinjection sessions for any bird. The average indices decreased from Conditions 2 to 3, but the ranges overlapped in all 3 subjects. *d*-Amphetamine decreased the index of curvature in both components of the multiple schedule and altered patterning to a more constant response rate. There were no consistent differences in the slopes of the dose-response functions for 4-s and 0.3-s paired and nonpaired brief stimuli, suggesting an equivalent effect of *d*-amphetamine on index of curvature.

Overall response rate was determined for each component of the multiple schedule by dividing total responses in each component by time spent in that component. Responses during food and brief-stimulus presentations were not included in these calculations. Figure 3 shows the effects of *d*-amphetamine on overall response rates. During baseline (five sessions before the first injection) and 10 preinjection sessions, there were no consistent differences in response rates between components with long or short or with paired and nonpaired brief stimuli. In Conditions 1 and 2, response rates were slightly higher after 0.3 and 1 mg/kg *d*-amphetamine and lower after 3 and 10 mg/kg *d*-amphetamine compared to the mean response rates during baseline and preinjection sessions. There was, however, very little increase in response rates in the second nonpaired condition following drug administration. Overall, rate increases were less visible when considering the range of response rates during preinjection sessions. More importantly, the functions for paired and nonpaired brief stimuli were very similar.

Figure 4 shows the effects of *d*-amphetamine on response rates in successive sixths of the fixed interval. Whereas the index of curvature (Figures 1 and 2) is a summary statistic showing the overall degree of response curvature within FI schedules, Figure 4 presents a more detailed analysis of actual response rates across segments of the fixed interval. Response rates during nondrug sessions were low during the first 10 s of the fixed interval and

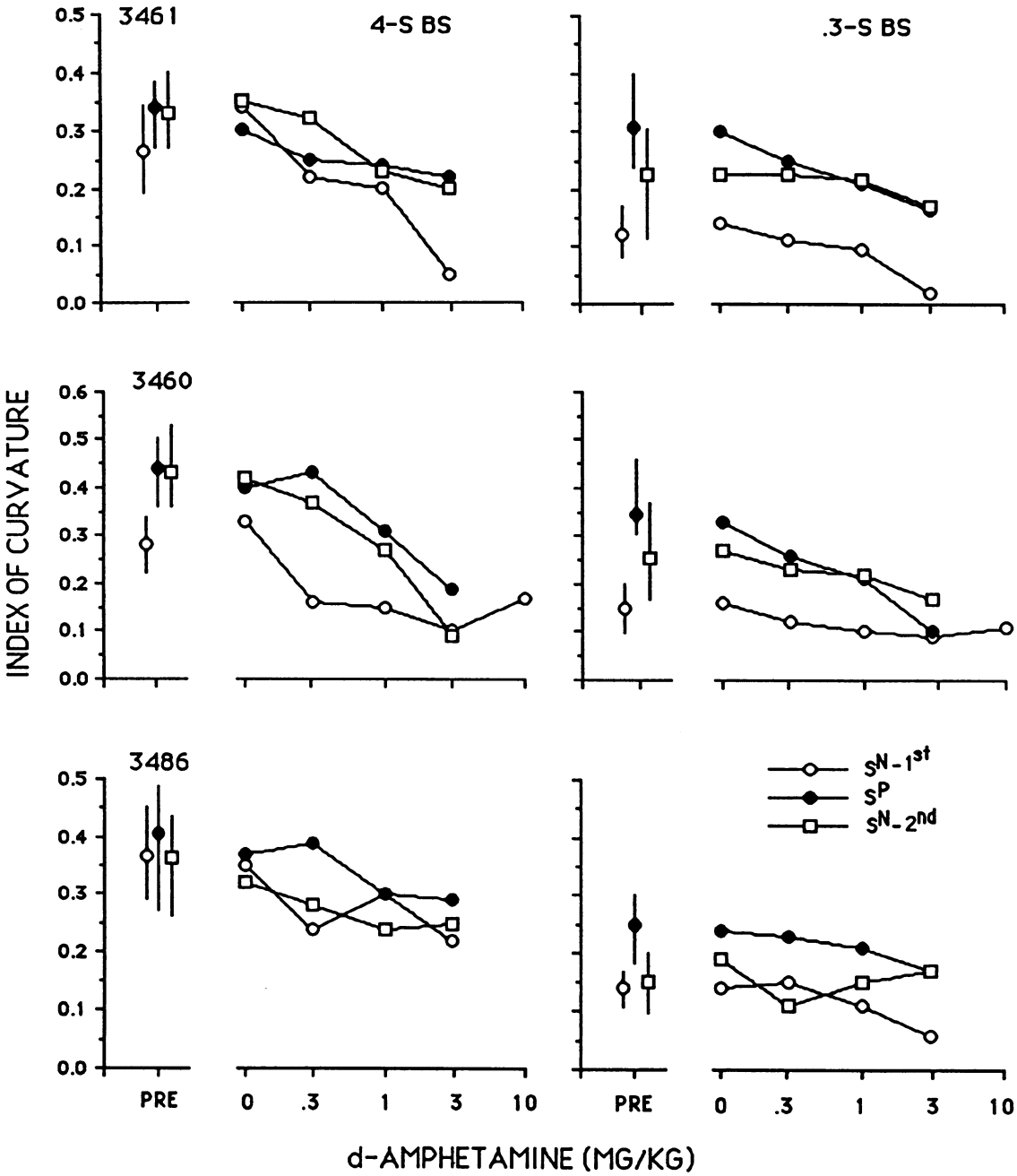

Fig. 2. Effects of *d*-amphetamine on index of curvature within FI components of the second-order schedule. PRE shows the mean and range index of sessions immediately before the 8 to 10 drug injection sessions for each bird. The left column contains data from components ending in the 4-s brief stimulus, and the right column contains data from components ending in the 0.3-s brief stimulus. Open circles represent the first nonpaired condition, closed circles represent the paired condition, and open squares represent the second nonpaired condition. Data are averages of two injections at each dose.

increased across successive 10-s bins. Responding in the 4-s brief-stimulus component was not differentially affected by pairing the brief stimulus with food presentations, whereas responding was differentially affected in the 0.3-s stimulus component; response rates with a 0.3-s nonpaired brief stimulus (Condition 1) were consistently higher in the early segments (10-s and 20-s bins) of the fixed interval than rates under a 0.3-s paired brief stimulus. Response

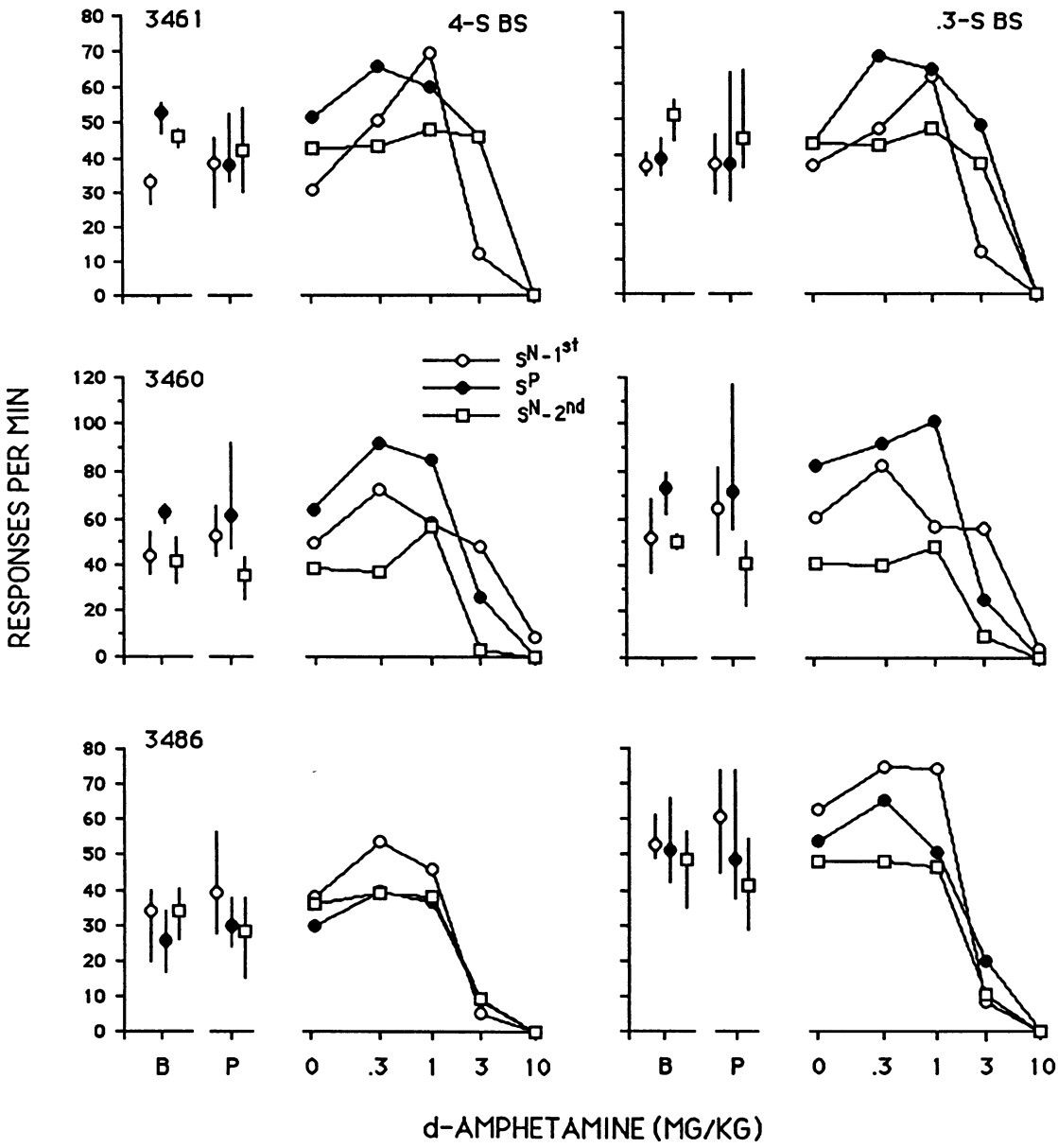

Fig. 3. Effects of *d*-amphetamine on overall response rate for each bird. B shows the mean and range of the last five sessions during baseline (before first injection) under Conditions 1 (first nonpaired, open circles), 2 (paired, closed circles), and 3 (second nonpaired, open squares). P (predrug) shows the mean and range of the 10 sessions immediately before drugs were administered. The left column contains data from components ending in the 4-s brief stimulus, and the right column contains data from components ending in the 0.3-s brief stimulus. Data are averages of two injections at each dose.

rates in the first 10 s of the fixed intervals increased for all 3 birds when the brief stimulus was no longer paired with food presentations in Condition 3. Response rates increased in both components of the multiple schedule under several doses of *d*-amphetamine, particularly 0.3 and 1 mg/kg. The largest, most consistent rate increases were observed during the early periods of the fixed interval, but there were several cases in which responding was enhanced throughout the interval. Consistent differences between paired and nonpaired brief-stimulus conditions were not observed after injection of *d*-amphetamine.

Different baseline response rates under both brief-stimulus durations and pairing opera-

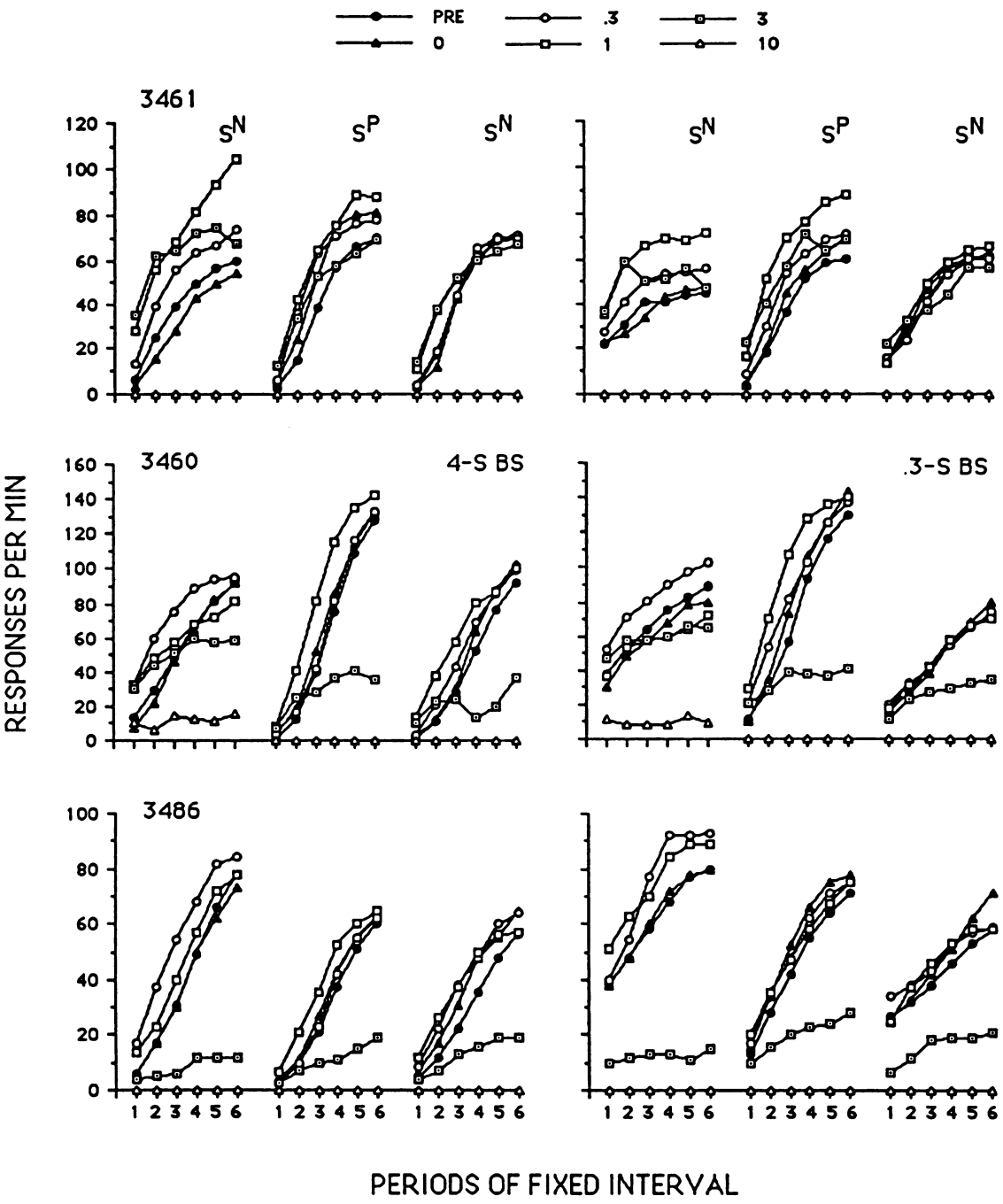

Fig. 4. Response rates during six 10-s segments of the FI 60-s component of the second-order schedule for each bird. Data are averages of two injections at each dose after 0, 0.3, 1, 3, and 10 mg/kg *d*-amphetamine. PRE (closed circles) shows the average rates of 10 sessions immediately preceding drug sessions. The left column contains data from components ending in the 4-s brief stimulus, and the right column contains data from components ending in the 0.3-s brief stimulus. The left-most S^N represents the first nonpaired condition, the right-most S^N represents the second nonpaired condition, and S^P represents the paired brief-stimulus condition.

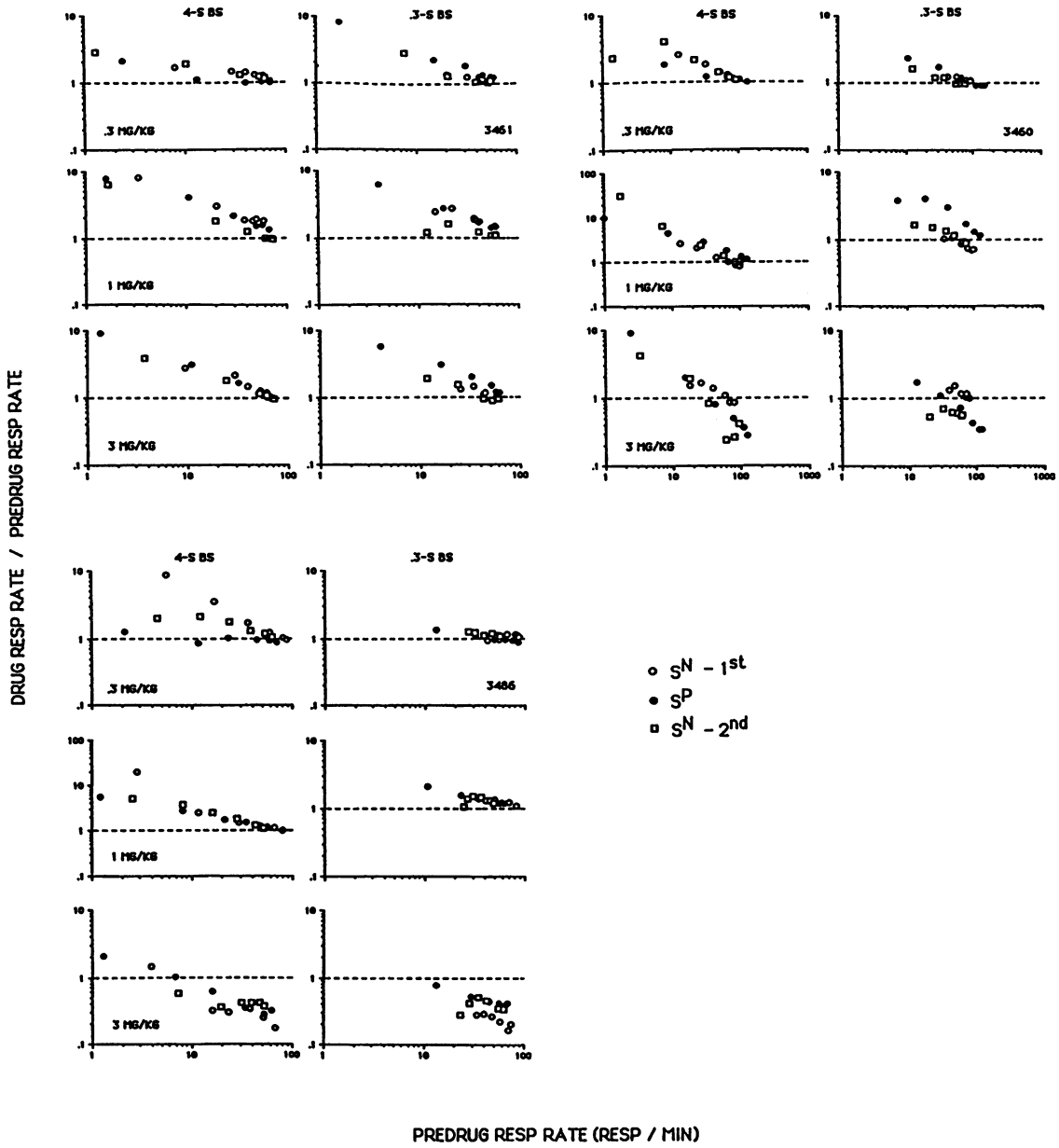

Fig. 5. Relationship between the ratio of response rate during a drug session to response rate during the session immediately preceding a drug session over six 10-s segments of the FI 60-s component of the second-order schedule for each bird. Data are for the 4-s and 0.3-s brief stimulus after 0.3, 1, and 3 mg/kg *d*-amphetamine under the first and second nonpaired conditions and the paired brief-stimulus condition. Data are averages of two injections at each dose.

tions illustrated in Figure 4 make a comparison of drug effects difficult across conditions. Thus, a rate-dependency analysis (Dews & Wenger, 1977) was performed and is presented in Figure 5. Predrug response rate during the six 10-s periods of the FI 60-s component of the second-order schedule is plotted as a function of the ratio of drug response rate to predrug response rate following 0.3, 1, and 3 mg/kg *d*-amphetamine. In general, the relationships were linear with a negative slope; response rates typically increased following

d-amphetamine when predrug response rates were low and were either unaffected or decreased when predrug rates were high. Most importantly, there were no consistent differences between the functions for paired and nonpaired brief stimuli. The best fitting straight line through the six points under each condition was determined by the method of least squares, and there were no consistent differences across conditions in the slopes and coefficients of determination.

DISCUSSION

Responding within components of the second-order schedule was generally characterized by a pause after the brief stimulus followed by positively accelerated responding, and this type of response pattern was observed under both the paired and nonpaired brief-stimulus conditions. In addition, the 4-s brief stimulus resulted in greater indices of curvature than the 0.3-s brief stimulus, consistent with previous research on second-order schedules (e.g., Cohen et al., 1973; Cohen & Stubbs, 1976; Stubbs, 1971; Stubbs et al., 1978).

There were no consistent differences in response patterns under paired and nonpaired brief-stimulus conditions when the stimulus was a 4-s change in key color accompanied by houselight illumination. However, pairing the 0.3-s change in key color with food presentations resulted in greater indices of curvature than when the stimulus was not paired with food presentations (Figures 1 and 2); considering five nondrug baseline sessions and from 8 to 10 preinjection sessions for each bird, the average index of curvature increased when the 0.3-s stimulus was changed from nonpaired to paired. There was no overlap in the range for 2 birds, and the index overlapped in only 1 of 13 sessions for Bird 3486. In addition to differences in the index of curvature, consistent differences in response rates across segments of the fixed interval were observed between paired and nonpaired brief-stimulus conditions with the 0.3-s but not with the 4-s stimulus (Figure 4); in the 0.3-s brief-stimulus component, response rates were relatively high in the early segments of the fixed interval under the first nonpaired condition and decreased when the brief stimulus was paired with food presentations. When the brief stimulus was no longer paired with food presentations, response rates in the first 10 s of the fixed interval increased for all 3 birds, although they did not increase to the same level as in the first nonpaired condition. These findings confirm the results of Stubbs et al. (1978), who reinforced pigeons' key pecks according to a variable-ratio 2 (FI 100 s: S) second-order schedule. With a brief stimulus consisting of a 2.5-s change in key color plus houselight illumination, no difference in response pattern was observed between paired and nonpaired brief stimuli. However, when the brief stimulus was a 0.5-s change in key color, a paired stimulus generated a greater degree of response acceleration than did a nonpaired stimulus.

One problem with the data in the present experiment is that once the index of curvature increased when the brief stimulus was paired with food presentations, it remained high for 2 of the 3 birds when the stimulus was no longer paired, suggesting a carryover effect from the food-pairing operation in Condition 2. Similarly, response rates in the early segments of the fixed interval were consistently lower in the second compared to the first nonpaired brief-stimulus condition. The sometimes irreversible or partially irreversible effects of pairing a brief stimulus with food is not uncommon in brief-stimulus procedures and has been reported elsewhere (Cohen, Calisto, & Lentz, 1979; Cohen & Lentz, 1976; Marr & Zeiler, 1974). Cohen and Lentz (1976), for example, showed that a nonpaired brief stimulus might maintain responding indefinitely under a fixed-ratio schedule of reinforcement if the brief stimulus had a history of being paired with food presentations. Interestingly, the subject that showed the largest conditioned reinforcement effect, Bird 3461, was studied in the same noncommercial operant chamber used in the studies by Cohen (1981), Cohen et al. (1979), and Cohen and Lentz (1976) on conditioned reinforcement. Perhaps the particularly strong and reversible brief-stimulus effects observed in this bird might be attributed to the configuration of that operant chamber.

d-Amphetamine did not differentially affect overall response rates in paired and nonpaired brief-stimulus conditions (Figure 3). There were relatively small, and not always consistent, increases in overall response rates after low and intermediate doses (0.3 and 1 mg/kg) of *d*-amphetamine and substantial decreases at

higher doses (3 and 10 mg/kg). Much larger, more consistent increases in response rates have been reported in monkeys after cocaine administration under FI 5-min (FR 30: S^P) schedules (Goldberg et al., 1981; Gonzalez & Goldberg, 1977), and in monkeys and pigeons after *d*-amphetamine administration under FI 5-min (FR 30: S^P), FI 30-min (FR 10: S^P), FR 10 (FI 3 min: S^P), and FR 3 (FI 2 min: S^P) second-order schedules (Barrett, Katz, & Glowa, 1981; Bond et al., 1975; Gonzalez & Goldberg, 1977; Katz, 1980). The failure to get large and consistent increases in overall response rates in the present experiment might be attributed to differences in the type of second-order schedule. Previous studies used FI or FR components with FI or FR overall schedules of reinforcement, whereas a VI overall schedule was used in the present study. *d*-Amphetamine produced a small increase in rats' response rates under simple VI schedules of reinforcement (Bradshaw, Ruddle, & Szabadi, 1981), and cocaine produced only modest increases in monkeys' responding under a random-interval schedule of reinforcement (Howell, Byrd, & Marr, 1988).

d-Amphetamine decreased the index of curvature within the FI components of the second-order schedules (Figure 2) and increased response rates during the early segments of the fixed interval (Figure 4). Thus, the lower index of curvature was the result of a more uniform response rate across segments of the fixed interval compared to baseline sessions. Most importantly for the present analysis, *d*-amphetamine did not differentially affect response patterns under paired and nonpaired brief-stimulus conditions. Also, when the data were examined with a rate-dependency analysis, no consistent differences in response rates after *d*-amphetamine were evident across segments of the fixed interval under paired and nonpaired brief-stimulus conditions. The increase in response rates during early segments of the fixed interval and a more uniform response rate across segments of the fixed interval after *d*-amphetamine injection are consistent with previous research (Barrett, Katz, & Glowa, 1981; Bond et al., 1975; Katz, 1980).

Second-order schedules can be an effective technique to study conditioned reinforcement. A conditioned reinforcement effect was demonstrated in the present study when a 0.3-s change in key color served as the brief stimulus. However, enhancement of the conditioned reinforcement effect by *d*-amphetamine was not demonstrated; the changes in rates and patterns of responding after drug administration were similar under paired and nonpaired brief-stimulus conditions. Overall, these data differ from those of studies that have used extinction procedures and have demonstrated that stimulant drugs enhance the effectiveness of conditioned reinforcers (e.g., Hill, 1970; Hoffman & Beninger, 1985; Mason & Robbins, 1979; Robbins, 1978; Robbins & Koob, 1978).

Recently, Files, Branch, and Clody (1989) demonstrated that stimulants increased the reinforcing efficacy of food-paired stimuli with a procedure that combined second-order schedules and extinction. Pigeons' responses were reinforced according to a random-ratio (RR) 2 (VI 30 s: S^P) second-order schedule. Following 10 to 20 food presentations, a 20-min extinction period was initiated, although extinction was not signaled by any stimulus change. In this part of the session food was never presented. Rather, in some sessions responses produced a food-paired brief stimulus according to a VI 30-s schedule, and in other sessions responses had no scheduled consequences. Methylphenidate produced higher response rates in the extinction part of the session when responding produced a brief stimulus compared to when the stimulus was not presented. Cohen and Branch (1991) used a similar procedure in which the food and extinction phases of the session were signaled by different discriminative stimuli. *d*-Amphetamine increased response rates in the extinction part of the session more when responding produced food-paired brief stimuli compared to conditions when nonpaired brief stimuli or no brief stimuli were consequences of responding. In both the present study and that of Cohen and Branch, *d*-amphetamine did not differentially affect responding under paired and nonpaired brief-stimulus conditions in either VI 120-s (FI 60 s: S) or RR 2 (VI 30 s: S) schedules, respectively. However, when Cohen and Branch combined the second-order schedule with extinction, differential effects of *d*-amphetamine were observed in the extinction component. These findings are not unlike those of Cohen et al. (1979), who compared the effects of paired and nonpaired brief stimuli in multiple schedules of conditioned and unconditioned reinforcement: Responding

in the first component of a multiple schedule was maintained under an RR 2 (FI 40 s: S) second-order schedule, and responding in the second component produced only a 5-s brief stimulus according to an FR 9 schedule. Paired and nonpaired brief stimuli maintained similar response patterns under the second-order schedule, whereas only food-paired brief stimuli maintained responding in the extinction component. Thus, differential effects of pairing a brief stimulus with food or the enhancement of those effects by drugs may not be observed under some second-order schedules, but are more likely to be observed when the second-order schedule is combined with a period of extinction during which responding produces only a brief stimulus. Further research will determine whether enhancement of the conditioned reinforcing effects of brief stimuli by drugs can be obtained under second-order schedules without an extinction component with parameters other than those used in the present study or by Cohen and Branch (1991).

The present study was an attempt to determine whether *d*-amphetamine altered the effects of stimuli associated with unconditioned reinforcers. This work is related to research that has sought to determine how drugs modify the efficacy of unconditioned reinforcers (Glick, Weaver, & Meibach, 1981; Stein, 1969; Wise, Spindler, de Wit, & Gerber, 1978). Glick et al., for example, showed that amphetamine lowered the threshold of reinforcing electrical brain stimulation. Stein showed how drugs interact with neural mechanisms that mediate the reinforcing effects of unconditioned reinforcers. These authors have emphasized how drugs degrade or enhance the ability of unconditioned reinforcers to control behavior. An alternative explanation for changes in behavior following the administration of drugs is that drugs alter response topography such as that seen with a motor deficit or with the production of response stereotypy (e.g., Ettenberg, Koob, & Bloom, 1981; Heyman, 1983). Heyman proposed an application of Herrnstein's (1974) matching equation that separates the changes in reinforcement efficacy and response topography following drug administration. Heyman's data showed that the neuroleptic pimozide decreased motor capacity and reinforcement efficacy, whereas amphetamine increased reinforcement efficacy. Clearly, much research must be done to determine the behavioral mechanisms that are responsible for changes in responding following drug administration, whether those changes are due to alterations in the efficacy of unconditioned reinforcers or alterations in response topography. Several studies have demonstrated that stimulant drugs enhance the reinforcing effects of food-paired stimuli, but it is unclear what behavioral mechanisms are responsible for this effect.

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