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DISRUPTION OF TEMPORALLY ORGANIZED BEHAVIOR BY MORPHINE

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Four pigeons pecked keys in two different procedures commonly used in the study of timing, or temporal discrimination. Sessions consisted of 40 trials. During half of the trials, two keys were presented for 50 s. Left-key pecks were reinforced according to a variable-interval 67.86-s schedule during the first 25 s of the trial, and right-key pecks were not reinforced. During the second 25 s of the trial, right-key pecks were reinforced according to the same schedule, and left-key pecks were not reinforced. In the other half of the 40-trial session, the center key was presented. The majority of these trials arranged fixed-interval 25-s schedules. Occasionally a probe, or peak-interval, trial was presented. These trials were 100 s in duration and terminated without reinforcement. These two procedures were used to examine the effects of morphine on indexes of timing and on patterns of responding. Morphine altered behavior in a rate-dependent manner in both procedures. Low baseline (saline) response rates were increased following morphine administration, and high baseline rates were either unaffected or decreased slightly. Rate-dependent effects appeared as leftward shifts in the timing index for two-key trials and decreases in the index of curvature for fixed-interval trials. Despite large changes in response rates, no consistent shift of the peak time was observed during peak-interval trials. These results are discussed primarily in terms of rate dependency; that is, rates of responding following drug administration tend to be determined in large part by rates of responding under baseline conditions.

Key words: morphine, fixed-interval schedules, peak procedure, temporal discrimination, timing, key peck, pigeons

Since the earliest studies of the effects of drugs on operant behavior, time-based schedules of reinforcement have been used (Dews, 1955). The most commonly used is the fixed-interval (FI) schedule, which arranges reinforcement for the first response after a fixed period of time has elapsed. Drugs from several classes have rate-dependent effects on behavior under FI schedules, in which low baseline response rates early in the interval are increased and high rates late in the interval are either decreased or are less affected (Dews & Wenger, 1977; Kelleher & Morse, 1968). The reasons for this effect are not well understood, but a drug-induced disruption in temporal discrimination is a reasonable suggestion (McAuley & Leslie, 1986). Research on temporal discrimination, then, could aid in the understanding of rate-dependent effects on behavior maintained by FI schedules. Perhaps equally important, a recognition of the concept of rate dependency may temper explanations of drug effects on behavior under temporal discrimination, or timing, tasks in terms of constructs of timing theories (i.e., scalar expectancy theory; Church & Gibbon, 1982; Gibbon, 1977; Gibbon & Church, 1992).

In the current study, pigeons were exposed to two timing tasks during the same session, and the effects of morphine were tested. One of the tasks was the peak-interval (PI) or peak procedure (Roberts, 1981). In this procedure, most trials consist of an FI schedule. A number of trials each session, the PI trials, last for three to four times the duration of the FI and end without reinforcement. Response rates of well-trained pigeons typically start low and increase as time passes, roughly until the time when a peck would produce a reinforcer in an FI trial. Until this point, behavior resembles that produced by an FI schedule. Response rates then decrease to low levels for the remainder of the trial. The time when the highest, or peak, rate of responding occurs is used to index timing. In the other task, which we refer to here as the two-key procedure, two keys are presented simultaneously. During the first half of a trial, pecking the first key is reinforced according to a variable-interval (VI) schedule and peck-

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ing the second key is not reinforced. During the second half of the trial, the contingencies on the two keys are reversed. In this task, timing is indicated when pigeons switch from the left to the right key; well-trained pigeons switch near the midpoint of the trial (Bizo & White, 1994a, 1994b, 1995; Machado & Guilhardi, 2000).

The peak procedure was selected because of its similarity to the FI schedule. We reasoned that any drug that alters FI schedule performance in a rate-dependent fashion, including morphine (Heifetz & McMillan, 1971; Katz & Goldberg, 1986; McKearney, 1974; Odum, Haworth, & Schaal, 1998; Odum & Schaal, 1999, 2000; Rhodus, Elsmore, & Manning, 1974), should also alter performance on the PI trials, at least in the early portion of these trials. The two-key task, on the other hand, is seemingly not similar to the FI schedule. Reinforcement can occur at any time during the trial, and timing is indicated by switching between keys. We reasoned that this procedure would provide an indication of timing that was not subject to the same rate-dependent influences to which the peak procedure is subject.

Research on the effects of drugs on timing has focused primarily on psychomotor stimulants such as *d*-amphetamine, which are thought by some to increase the rate of a hypothetical pacemaker, thus producing leftward shifts in timing functions (Meck, 1981). Leftward shifts have been obtained using the peak procedure following administration of *d*-amphetamine in pigeons (Kraemer, Randall, Dose, & Brown, 1997) and methamphetamine in rats (Maricq, Roberts, & Church, 1981). Both studies also showed clear rate-dependent increases in responding. On the other hand, Bayley, Bentley, and Dawson (1998) did not observe shifts in the peak function in rats following administration of *d*-amphetamine, but did obtain large increases in rates of responding that were roughly rate dependent. Finally, in the only published study of drug effects on behavior under the two-key procedure of which we are aware (Chiang et al., 2000), *d*-amphetamine caused rats to switch levers earlier in the trial, consistent with some of the research using the peak procedure.

In the present study we tested morphine rather than *d*-amphetamine, primarily because we had previously obtained large, rate-dependent effects of morphine in pigeons responding on FI schedules, effects that were enhanced by food deprivation (Odum et al., 1998). Morphine has also produced dose-dependent increases in longer interresponse times in rats responding under a differential-reinforcement-of-low-rates schedule (Wenger & Wright, 1989), which also suggests that morphine may affect timing. More recently, Odum and Schaal (2000) studied the effects of morphine on pigeons pecking under a procedure originally devised by Stubbs, Vautin, Reid, and Delehanty (1978), in which two-key discrimination trials were occasionally presented during fixed intervals. If a short time had passed since the last reinforcer, pecking one key was reinforced. If a long time had passed since the last reinforcer, pecking the other key was reinforced. Morphine both disrupted the temporal pattern of behavior and produced a dose-dependent reduction in accuracy of the temporal discrimination. The present study examined, in particular, changes in indexes of temporal discrimination and their relation to rate-dependent effects of morphine.

METHOD

Subjects

Four adult male White Carneau pigeons were used as subjects. These pigeons had previous exposure to the present behavioral procedures and to the drug atropine. Eighty-eight sessions intervened between the last administration of atropine in the previous experiment and the first administration of morphine in this experiment. The pigeons were maintained at 80% initially, then 70% of their free-feeding body weights through postsession supplementary feeding. Pigeons were housed individually under a 12:12 hr light/dark cycle, with the light cycle starting at 7:00 a.m., and had free access to water and digestive grit. Sessions were conducted during the light part of the cycle.

Apparatus

Sessions were conducted in four experimental chambers (33 cm wide by 31 cm deep by 37.5 cm high) constructed of wood with aluminum front panels. The front panels consisted of three translucent response keys (2.1 cm diameter) arranged side by side 26 cm

from the floor. Colored lights served as discriminative stimuli and could be lit from behind each key. The response keys required a force of approximately 0.19 N to record a response. A 28-V 1.1-W lamp, 7 cm above the center response key, served as a houselight. Mixed grain was delivered through a rectangular aperture located 16 cm below the center response key using a solenoid-operated food hopper. The chambers were sound attenuated and were equipped with fans that provided ventilation. A white noise generator, located in the room containing the experimental chambers, was used to further mask extraneous noise. Experimental control and data collection occurred in an adjacent room on MS-DOS-based 80486 microcomputers using the Smart Cumulative Recorder® and Medstate Notation® (MED Associates, Inc. & Tatham, 1991).

Procedure

The pigeons had prior exposure to the basic procedure and therefore required no special training prior to the start of the experimental conditions. Each 50-min session began with a 10-min blackout. A session consisted of a multiple schedule of FI/PI trials and two-key trials. Trial types alternated between two-key and FI/PI trials, beginning with a two-key trial each session. Trials were separated by 10-s blackouts. There were 20 trials of the FI/PI type and 20 trials of the two-key type. Reinforcement, in all cases, consisted of 2.75-s access to grain.

Of the 20 FI/PI trials, 6 were PI 100 s and 14 were FI 25 s. The PI trials occurred semirandomly during the session, with three PI trials occurring during the first 10-trial block and three occurring in the second 10-trial block. At the beginning of an FI/PI trial, the center-key stimulus was lit from behind by a red lamp. If the FI 25-s schedule was in effect, grain was presented following the first peck after 25 s had elapsed. During the PI 100-s trials, the key remained lit for 100 s and the trial ended without a reinforcer.

Two-key trials were 50 s in duration. At the beginning of a 50-s trial, the two side response keys were lit green. Responses to the left key during the first 25 s of the trial were reinforced according to a VI 67.86-s schedule (Fleshler & Hoffman, 1962), and responses to the right key were not reinforced. Responses to the right key during the second 25 s of the trial were reinforced according to a second independent VI 67.86-s schedule, and responses to the left key were not reinforced. A VI 67.86-s schedule arranged an equal rate of reinforcement for the two-key procedure and the peak procedure (FI and PI trials combined). The schedule associated with the left key only timed during the first half of a trial, and the schedule associated with the right key only timed during the second half of the trial. Reinforcers that were scheduled but not delivered during a trial were held over until the next two-key trial.

The pigeons were exposed first to these procedures while being maintained at 80% of their free-feeding weights. Drug testing began for individual pigeons when overall response rates and trial response patterns were stable, based on visual inspection of the data. Following drug testing, the pigeons' body weights were decreased to 70% of their free-feeding weights. The transition between body weights required between 11 and 20 sessions to complete. Forty-five to 50 sessions were conducted at the new body weight prior to drug testing following the same procedures used previously.

Drug Administration

Morphine sulfate (obtained from the National Institute on Drug Abuse) was dissolved in saline for injection volumes of 1.0 ml/kg and was administered via intramuscular injection. At least three sessions intervened between injections. The effects of each dose and of saline vehicle were determined three times. Doses (saline, 1.0, 3.0, 5.6, and 10.0 mg/kg) were administered in ascending, descending, then ascending order.

Data Analysis

Overall response rates were computed separately for FI/PI trials, left two-key, and right two-key responding. All means and standard deviations are based on three determinations of each drug dose or saline administration except where otherwise noted. Means and standard deviations for control sessions are based on 15 data points (the day prior to each saline or drug administration).

Response patterns were examined by collecting data in 2.5-s bins for each trial type within a session. Responses within a bin were

aggregated across an entire session. Response rates presented in the figures were computed by averaging the response rates within each bin for each dose and pigeon.

In FI trials, indexes of curvature (Fry, Kelleher, & Cook, 1960) were determined. The index of curvature (I) was calculated for each session using the following formula:

$$I = [9R_{10} - 2(R_1 + R_2 + \ldots + R_8 + R_9)]/10R_{10},$$

where R_1 is the total number of responses in the first bin, R_2 is the total number of responses in the first and second bins, and so on, up through R_{10}, which is the total number of responses in all 10 bins.

Peak-interval response patterns, peak time, and 70% spread (defined below) were derived based on three determinations at each drug dose. At a dose of 5.6 mg/kg, however, responding was greatly suppressed during one session for P4244 and one session for P4571. This rate suppression prevented the derivation of indexes for peak time and peak spread during those sessions. In these cases, plots and indexes were based on the remaining two determinations. Peak time was determined by finding the bin containing the greatest number of pecks (e.g., if the greatest number of pecks occurred in the sixth bin, then the peak time would be 15 s). The peak spread was determined by finding the difference (in seconds) between the first time that response rates rose above 70% of the maximum response rate and the last time that response rates fell below 70% of the maximum response rate. A process of linear interpolation estimated the two 70% points of the peak spread. Linear interpolation was accomplished by converting responses into proportions of maximum responding and then determining proportionally the point at which 70% of that maximal rate was reached.

In two-key trials, the times at which 50% of responses occurred on the right key (T50) were assessed through a process of linear interpolation, just as 70% spread points for PI trials were derived. Difference limens were calculated to give an indication of the amount of variability around T50. Difference limens were determined by finding the points at which 25% (T25) and 75% (T75) of the responses had occurred on the right key, finding the distance between those points, and taking half of that value [limen = (T75 − T25)/2].

Data from each trial type were also analyzed in rate-dependency plots. Mean response rates following the administration of morphine within each bin were divided by mean response rates from the corresponding bin following saline administration and plotted on a logarithmic axis. This ratio was plotted as a function of the mean saline response rate of the corresponding bin, also plotted on a logarithmic axis. A linear regression line was fitted to each set of data using the method of least squares.

RESULTS

Response rates changed in a dose-dependent manner following morphine administration at both levels of food deprivation and across each of the experimental conditions (Figure 1). Relative to control and saline conditions, response rates usually remained unchanged or increased following low to moderate doses of morphine and decreased following higher doses. Response rates in control and saline conditions did not differ systematically dependent on the level of food deprivation, but responding under the higher level of food deprivation (70% of free-feeding weight, or FFW) was often less sensitive to the rate-decreasing effects of morphine. For example, the highest doses of morphine (i.e., 5.6 and 10.0 mg/kg) suppressed all, or nearly all, key pecking in the 80% FFW condition. In the 70% FFW condition, only the highest drug dose (10.0 mg/kg) reliably suppressed all key pecking (data for this dose are not shown in the other figures). Because a broader range of doses could be tested under the 70% FFW condition, and because drug effects on the temporal distribution of behavior were more robust and reliable at the lower body weights, we have omitted the 80% FFW condition from the remainder of the data presentation.

In FI trials (Figure 2) following saline administration, response rates began at very low or zero levels and increased throughout the interval. Morphine increased rates of responding earlier in the interval compared to saline conditions. These changes were dose dependent, with higher doses producing larger increases in response rates early in the in-

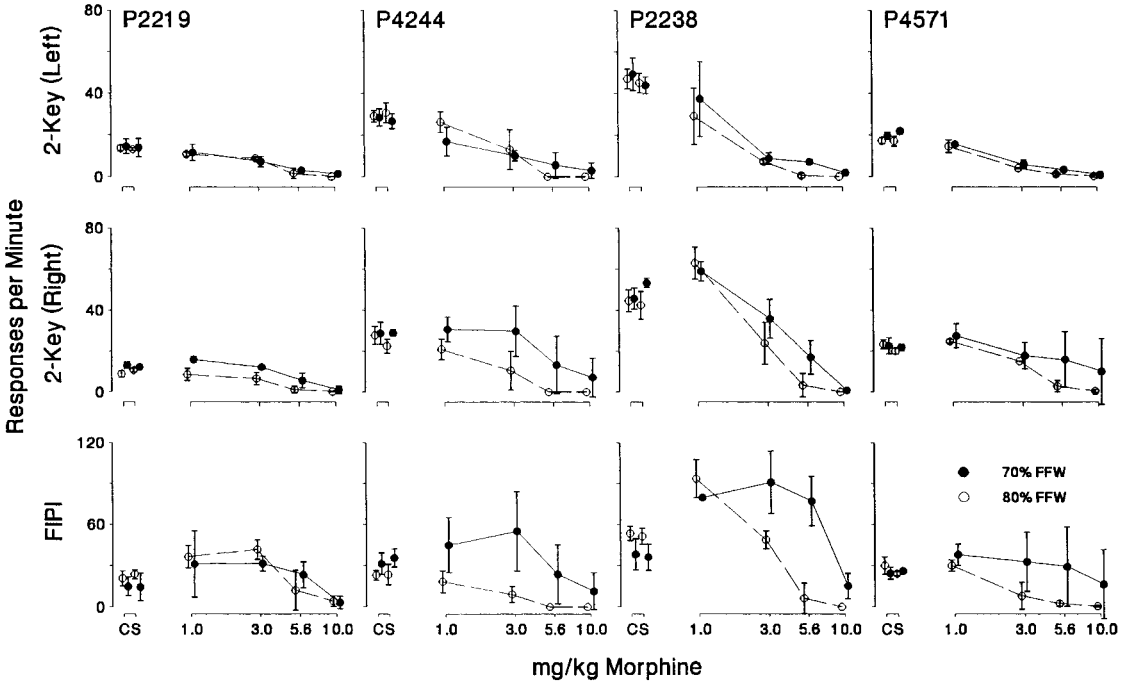

Fig. 1. Response rates as a function of dose for each pigeon responding on each procedure under both levels of food deprivation. Points represent means of three determinations of each dose. Error bars represent standard deviations.

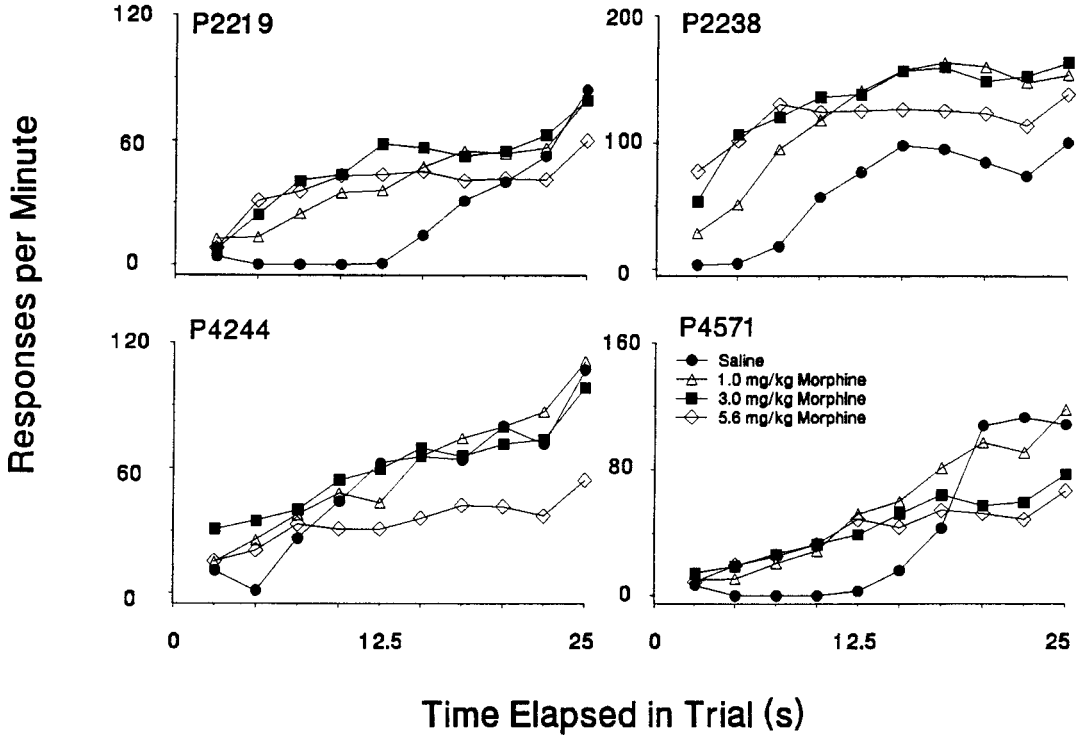

Fig. 2. Response rates in consecutive 2.5-s bins of FI 25-s trials for saline and drug conditions for each pigeon. Points represent means of three determinations of each dose.

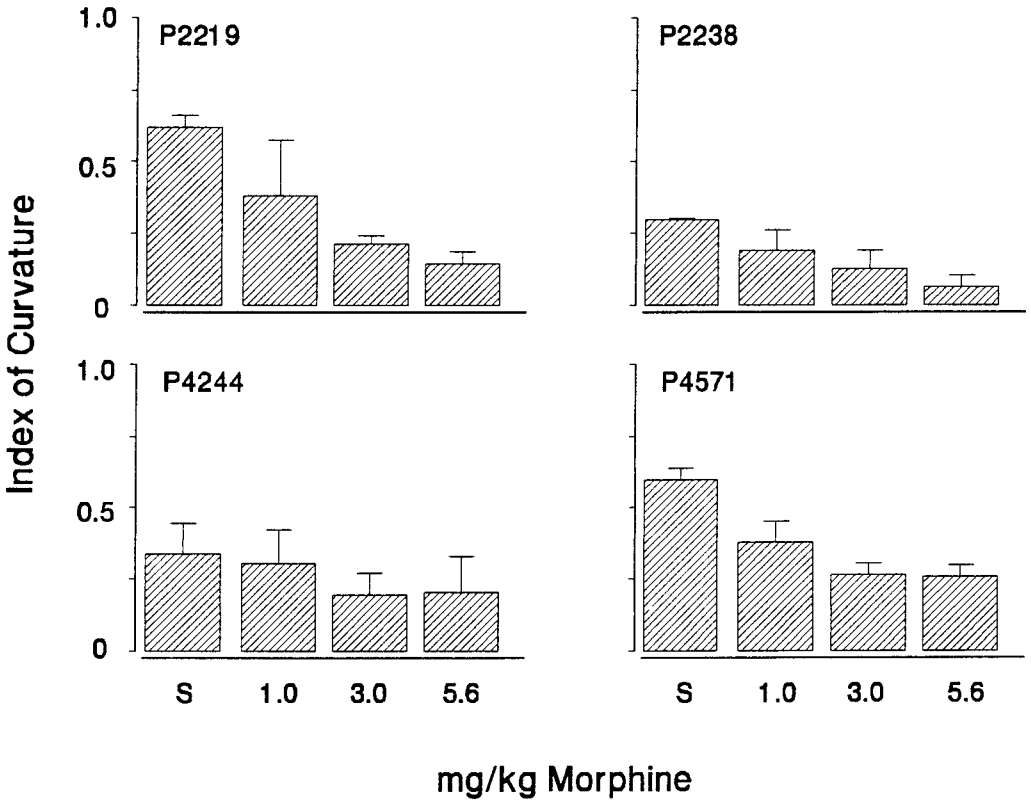

Fig. 3. Indexes of curvature in FI 25-s trials for saline and drug conditions for each pigeon. Large bars represent means. Error bars represent standard deviations.

terval than lower doses. The index of curvature under saline conditions ranged from 0.30 to 0.62, values that indicate the positively accelerated patterns of responding typical of FI schedules (Figure 3). Morphine decreased the index of curvature in all pigeons as a function of dose, reflecting primarily increases in response rates early in the interval.

In PI trials (Figure 4), following saline administration, response rates began at low or zero levels and increased through the interval roughly until the time at which a peck would produce a reinforcer in an FI trial (25 s into the trial). Response rates then decreased, eventually reaching low or zero levels, where they remained until the end of a trial. The effects of morphine on response rates during the early portion of PI trials were similar to those seen at the beginning of FI trials. That is, response rates increased earlier in the interval under drug conditions than under saline conditions. Following a rise to a peak rate, rates of responding began to decrease at about the same time following morphine as they did following saline administration, but rarely decreased to zero. Evidence of secondary rises or maintenance of moderate response rates was more prevalent following drug administration than following saline administration.

For PI trials (Figure 5), peak time was not consistently altered by morphine except for P2238, which showed dose-dependent decreases. There was a tendency for the variability around the peak, indicated by the 70% spread, to increase as a function of dose in each of the pigeons.

Responding in two-key trials is shown in Figure 6 as the percentage of right-key pecks. Following administration of saline, the percentage of responding allocated to the right key remained relatively low until the second half of the 50-s trial. Analysis of daily response patterns from trials with reinforcers and trials without reinforcers revealed no systematic differences between the two trial types, so all

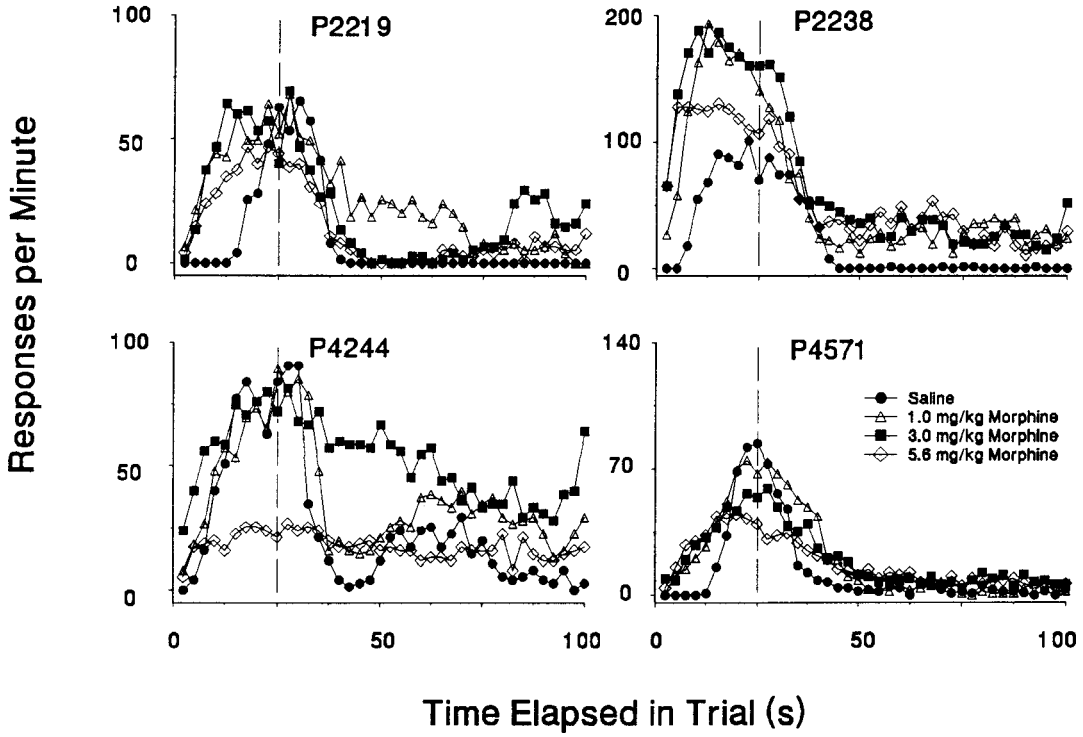

Fig. 4. Response rates in consecutive 2.5-s bins of PI trials for saline and drug conditions for each pigeon. Points represent means of three determinations of each dose. The dashed line indicates the point 25 s into a trial.

two-key trials were used in the present analysis. When morphine was administered, right-key responding increased earlier in the trial in a dose-dependent manner. At the highest dose (5.6 mg/kg), variability in responding was observed at the end of a trial, when some left-key responses were observed. These changes caused by morphine in the proportion of right-key responding are reflected in T50 (Figure 7), which is the time when 50% of responding was allocated to the right key. Increases in right-key pecking earlier in the trial resulted in dose-dependent decreases relative to saline in T50 for all pigeons. The variations around those functions, as indicated by the corresponding difference limens, were not reliably changed by morphine.

In the rate-dependency plots (Figures 8 and 9), points above the dashed line indicate rate increases and points below the line indicate rate decreases following morphine administration relative to rates following saline. Low baseline response rates early in FI trials (Figure 8, open triangles) increased following morphine administration, and high baseline rates were either unaffected or decreased slightly. This effect was consistent across all pigeons and did not differ systematically across doses. The same effect was present during PI trials (Figure 8, filled circles), except that the rate-increasing effect of morphine was quite variable during those segments of the trial when response rates were lower. This can be seen in the ''tail'' of data points starting near the dashed line representing control rates of responding and extending straight upwards at that lowest saline response rate. This tail of data points is responsible for the slope of the PI regression being less steep than that of the FI function.

Data from two-key trials were also analyzed using rate-dependency plots separately for left- and right-key responses (Figure 9, filled circles and open triangles, respectively). For both the left and right keys, low response rates following saline administration were increased following morphine administration. Overall, the right-key plots tended to fall higher on the *y* axis than did the left-key plots. In 8 of 12 comparisons between right-

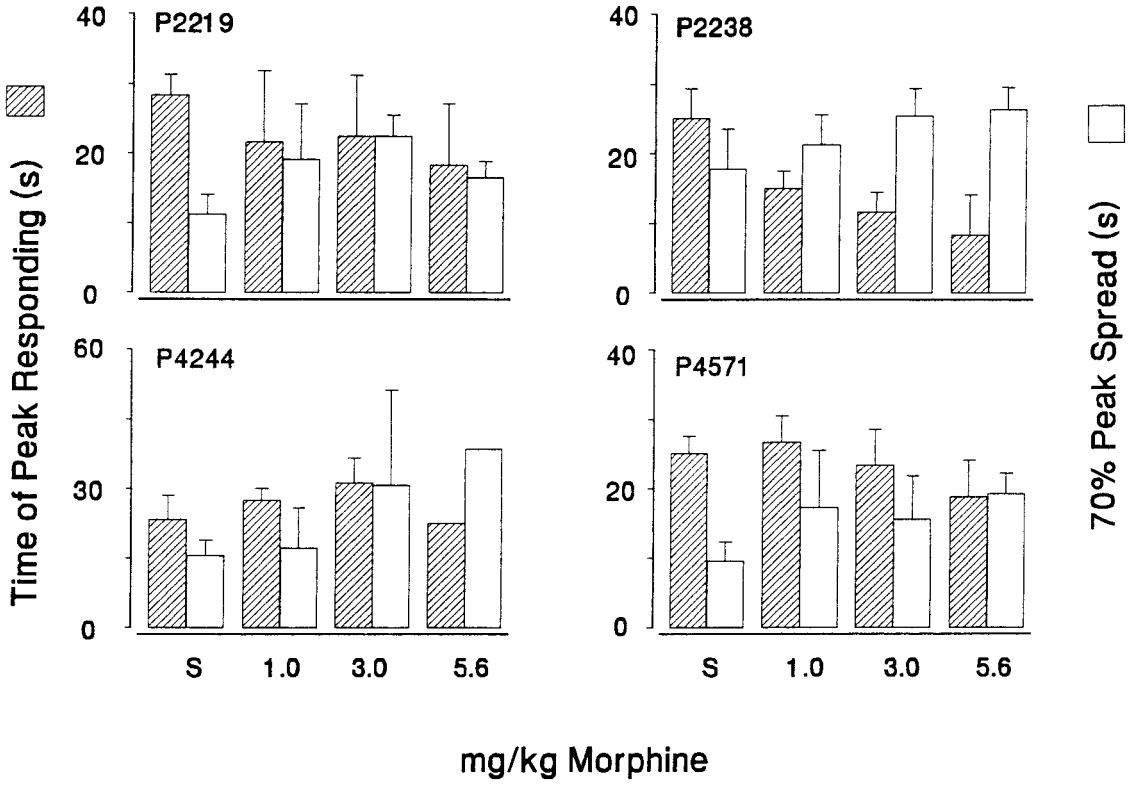

Fig. 5. Times of peak response rates and the 70% spread around that peak in PI trials for each pigeon. Filled bars represent mean times (in seconds) of peak rate of responding. Open bars represent the distance between the two points on the function at which 70% of the peak rate of responding occurs. Error bars represent standard deviations. No error bars are present for P4244 at the 5.6 mg/kg dose of morphine, because it is based on only two determinations and the indexes from those two determinations did not differ.

and left-key data, increases in low-rate responding were greater for right-key pecks than for left-key pecks. For both left and right keys, high rates of responding following saline administration remained unchanged or decreased following morphine administration. In 10 of 12 comparisons between right- and left-key data, decreases in high-rate responding were greater for left-key responding than for right-key responding. The rate decreases were clear and consistent at both the 3.0 and 5.6 mg/kg doses of morphine for the left key, but only for the 5.6 mg/kg dose of morphine for the right key. Both differential rate increases and decreases reflect the earlier switching from left to right keys (Figures 6 and 7). That is, response rates usually increased early in trials on right keys with corresponding decreases early in trials of response rates on the left key. These two changes contributed to an average earlier switch from left-key to right-key responding, as depicted in Figures 6 and 7.

DISCUSSION

Morphine altered temporally organized behavior arranged by both the two-key procedure and the FI/PI procedure. In the two-key procedure, the function relating the time in the trial to the relative rate of right-key pecks was shifted left, with corresponding reductions in T50. In the two-key procedure, then, morphine appeared to cause pigeons to overestimate elapsed time. During FI trials, response rates early in the interval were increased. Although the peak time was not consistently shifted in the PI trials, low response rates on either side of the peak were increased by morphine. The effects of morphine were largely rate dependent; low baseline rates were increased, and higher baseline

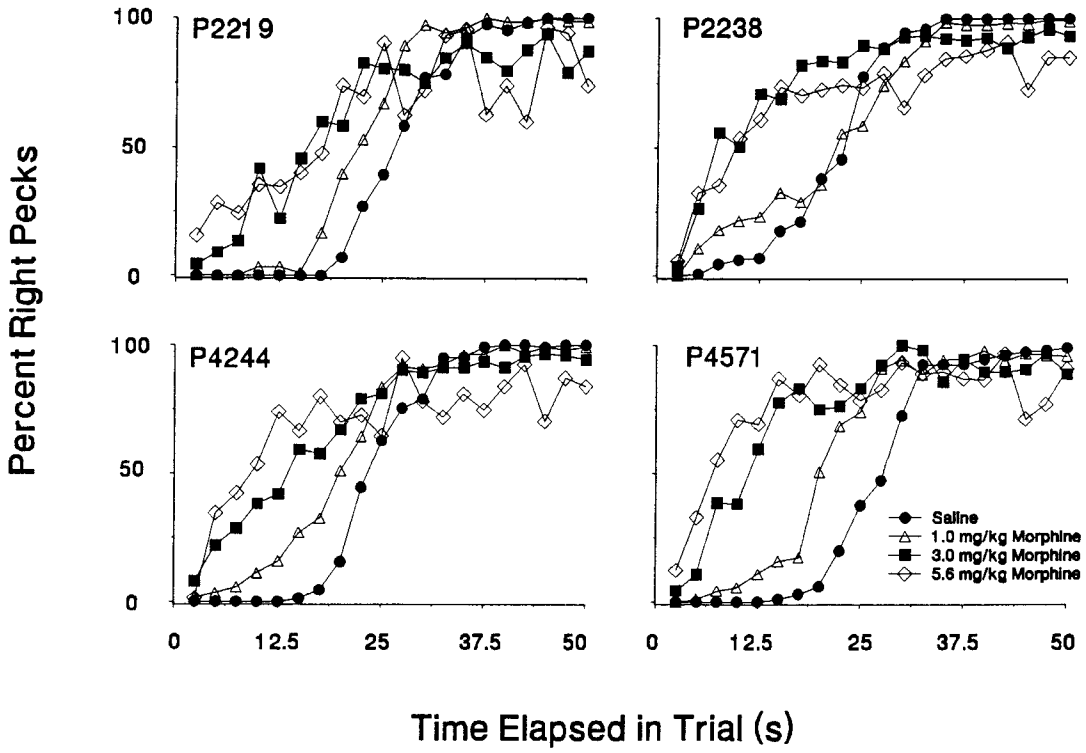

Fig. 6. Percentage of right-key pecks per 2.5-s bin of two-key trials for saline and drug conditions for each pigeon. Points represent means of three determinations of each dose.

rates were less affected or were reduced by low to moderate doses.

In evaluating these effects, it is necessary first to assess whether morphine had different effects on behavior under the two procedures. The indexes of timing in the two tasks were, apparently, differentially affected; T50 in the two-key task was shortened, reliably and robustly, but the time of peak responding in the PI trials was not consistently altered despite the large and reliable increases in low response rates in the FI/PI trials. If these findings were accepted as evidence that morphine altered performance differently in the two procedures, it would suggest that different behavioral processes (established as different by the differential effects of a third variable, morphine) are responsible for the temporal organization of behavior under the two tasks.

Two observations, however, suggest that morphine actually had the same effect on behavior in the two procedures. The first involves similarities in the requirements of the two tasks. In both tasks, pecking a single key (the center key in FI/PI trials, the right key in two-key trials) can be reinforced after 25 s of the trial has elapsed. In FI/PI trials, no other explicitly reinforced behavior is available during that period; in the two-key task pigeons can peck the left key for food. But the conditions remain similar; an FI 25-s schedule organizes center-key pecking in one task and an FI 25-s-like schedule organizes right-key pecking in the other. In both cases, morphine increased rates of these responses early in the trials. In the case of the two-key trials, increases in right-key pecking produced, necessarily, a leftward shift in T50. In the FI/PI trials, early-trial rate increases were not accompanied by leftward shifts in the time of peak responding but did produce changes in the index of curvature.

The second observation is the similarity in the rate-dependency plots. Such rate-dependent effects of morphine have been shown before (Odum et al., 1998). Slopes between plots were often similar, although relative differences in the extent of rate changes varied between schedule types in a manner similar to previous research examining rate-depen-

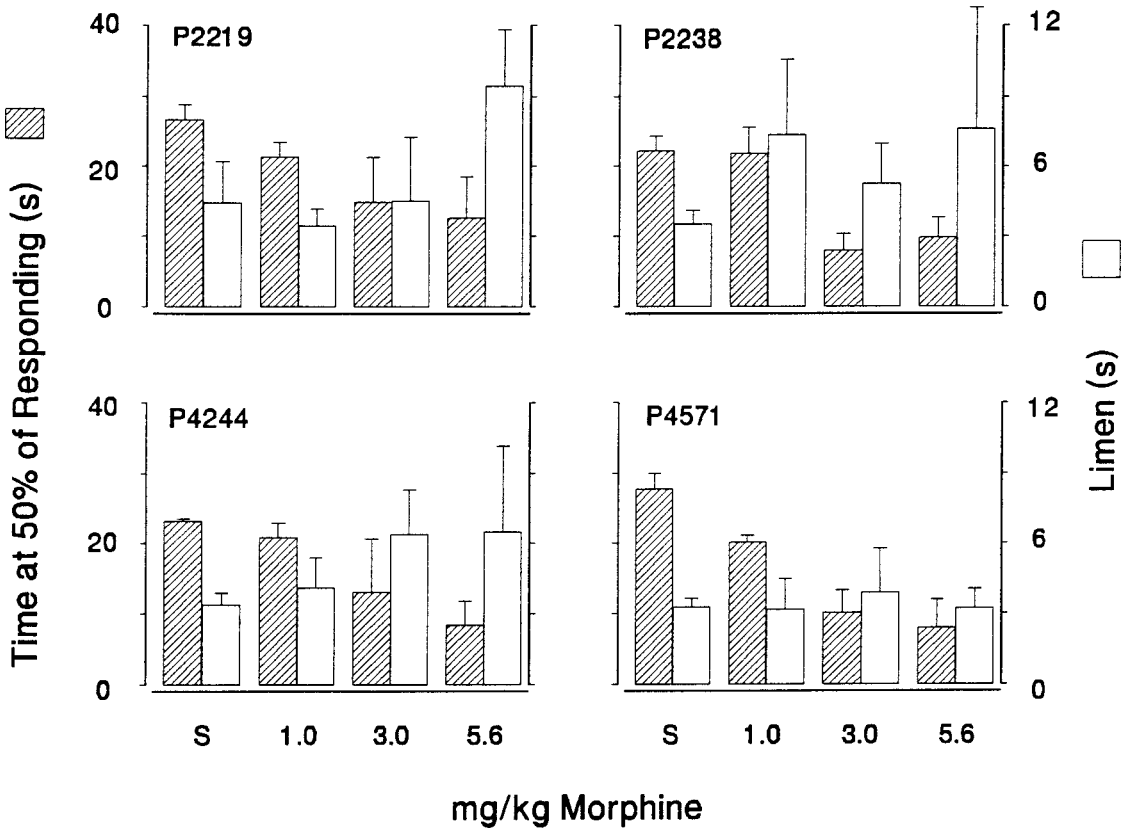

Fig. 7. Times of 50% right-key responding (T50) and difference limens in two-key trials for saline and drug conditions for each pigeon. Filled bars represent mean times (in seconds) of 50% right-key responding. Open bars represent mean difference limens (half the distance between 25% and 75% right-key responding). Error bars represent standard deviations.

dent effects on performance under schedules of different types and values (Thompson, Trombley, Luke, & Lott, 1970). An example of such a relative difference is that rates were much more likely to increase in the FI and PI schedules (Figure 8) than in the two-key procedure (Figure 9), so the FI and PI plots typically fall higher on the *y* axis. What is new (and surprising, perhaps) is that early-trial right-key rate increases occurred even though pigeons had to leave a source of reinforcement (the left key) to respond early on the right key. That explicit source of reinforcement may have been responsible for the graded effects of morphine (Figures 6 and 8) relative to the all-or-none effects of morphine on the FI/PI task (Figures 2, 4, and 8). Nevertheless, the similar effects revealed by the rate-dependency plots suggest that morphine had similar effects on behavior under the two tasks.

So despite our attempt to compare performance on timing tasks that yield different indexes of temporal discrimination, the similarities in the procedures and the effects of morphine suggest that performances were controlled by the same variables in the two tasks. The next question that must be addressed concerns the mechanisms by which morphine altered temporally organized behavior. The mostly rate-dependent effects suggest an explanation of the effects of morphine that does not focus on timing; that is, the effects of morphine were determined by baseline rates of responding. According to this view, timing played a role in establishing different baseline rates that were differentially affected by morphine, but morphine did

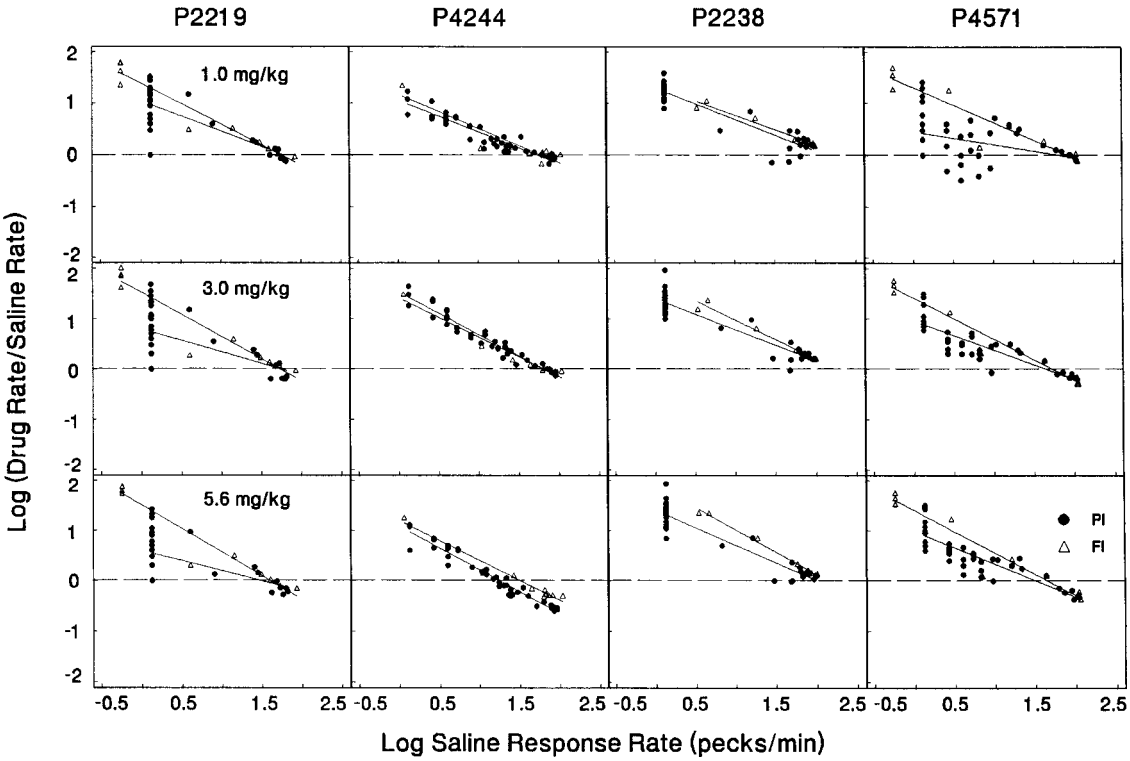

Fig. 8. Rate-dependency plots for fixed-interval and peak-interval trials for each pigeon. Dashed lines indicate saline response rates. Points falling above the dashed line indicate rate increases, and points falling below the dashed line represent rate decreases.

not alter rates by altering an underlying timing process.

A more careful examination of the rate-dependency plots for peak and two-key tasks (Figures 8 and 9) reveals two clear exceptions to the rate-dependency effect, however. In PI trials, a tail was obtained at the lowest response rates following saline administration, which means that not all low rates were equally increased by the drug. The data in Figure 8 show that the low response rates during the beginning of an interval were increased by morphine. Equivalent response rates occurring later, toward the end of the peak interval, were not increased as much. The second exception can be seen in the two-key rate-dependency plots (Figure 9). Low response rates on the right key were increased more robustly than low response rates on the left key. Earlier switches from the left to the right key largely prevented any increases in low-rate left-key responding, because there was typically only one switch per trial. Low response rates on the right key occurred at the beginning of an interval, prior to the switch between response keys; low response rates on the left key occurred following the switch, at the end of an interval. In both the peak and two-key procedures, low response rates toward the beginning of a trial were more subject to rate-increasing effects than similarly low rates toward the end of a trial. The effects of morphine, therefore, were both rate dependent and time dependent. They were time dependent insofar as the time in a trial appeared to have modulated the extent of the rate-increasing effects of morphine.

It is a well-established exception to rate dependency that low response rates under strong stimulus control are often resistant to the rate-increasing effects of drugs (Laties & Weiss, 1966; Odum & Schaal, 1999; for review, see Robbins, 1981). It may be that following the peak time in a peak trial and following the switch between keys in a two-key trial, temporal stimulus control is stronger than it is prior to those points. The time that reinforcement occurs in FI trials establishes a

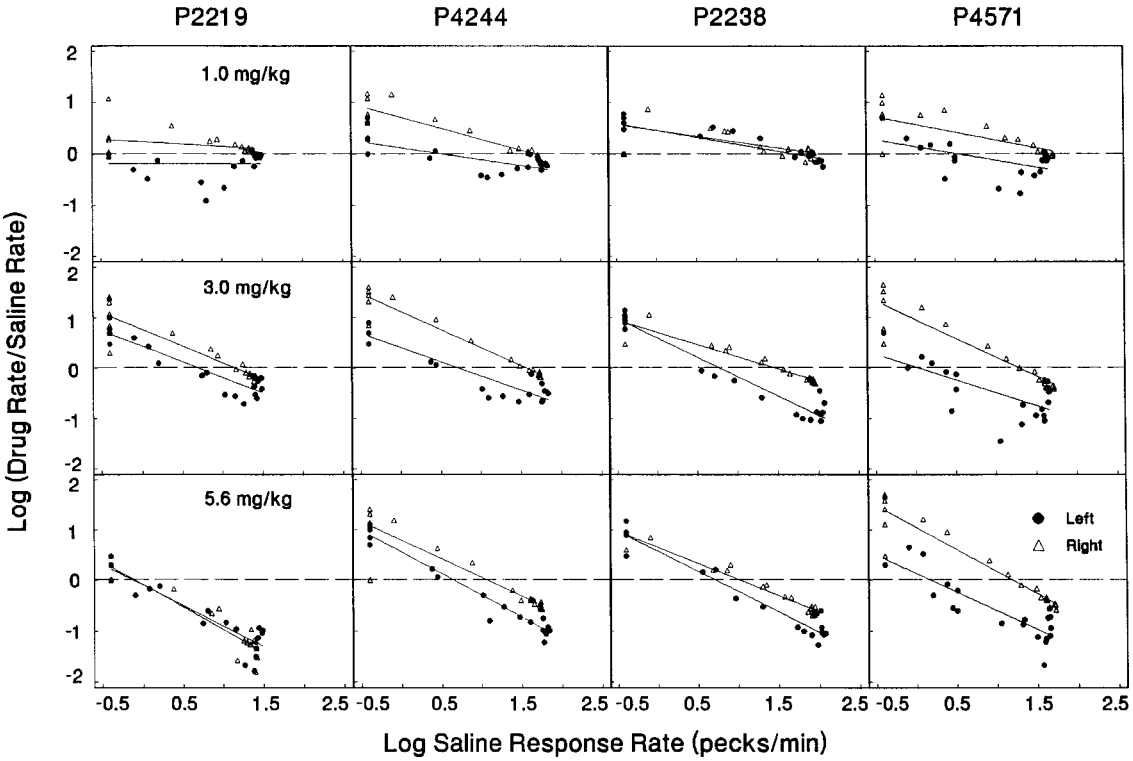

Fig. 9. Rate-dependency plots for two-key trials for each pigeon. Dashed lines indicate saline response rates. Points falling above the dashed line indicate rate increases, and points falling below the dashed line represent rate decreases.

strong stimulus context for responding to decrease late in PI trials. Similarly, in two-key trials, switches occurred from the left to the right key, and a switch back almost never occurred. Perhaps this behavior pattern helped to produce a temporal stimulus context strong enough to attenuate the rate-increasing effect of morphine on low baseline rates of responding.

Rates of responding under discriminative stimulus control (temporal or otherwise) can be altered without altering stimulus control. Such effects have been described previously in work conducted by Katz (1982, 1983), which demonstrated that drugs from a number of different pharmacological classes can produce clear alterations in response rates at doses below those that decrease stimulus control. Stimulus control, in the studies by Katz, tended to be robustly affected only at relatively high drug doses. He concluded, ''These studies, although implicating stimulus control as an important feature in determining the way the drug affected behavior, did not, however, demonstrate that the drug affected stimulus control'' (Katz, 1982, p. 622). Applied to the present findings, it is possible to view the effects of morphine as dependent on time as a stimulus, but these effects are not due to the changes in temporal stimulus control.

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