

THE EFFECTS OF CHLORPROMAZINE AND IMIPRAMINE ON RATE AND STIMULUS CONTROL OF MATCHING TO SAMPLE

M. CHRISTOPHER NEWLAND AND M. JACKSON MARR

UNIVERSITY OF ROCHESTER SCHOOL OF MEDICINE AND DENTISTRY
AND GEORGIA INSTITUTE OF TECHNOLOGY

Pigeons were trained to perform simultaneous, two-color matching to sample under a multiple fixed-ratio fixed-interval schedule of food presentation. The sequence terminating with a peck on the matching key (a "match") was treated as a unit, analogous to a single key peck in conventional schedules. Except for intermittent reinforcement of matches, no consequent stimulus distinguished matches from mismatches (sequences terminating with pecks on the nonmatching key). The pattern of matches during nondrug sessions resembled that of simpler operants maintained by similar schedules. Matches increased in rate toward the end of both components; mismatch rates increased more slowly. Imipramine increased the rate of mismatches, disrupted schedule patterning, and lowered accuracy in a dose-dependent fashion. Chlorpromazine lowered the overall rate of matches but affected schedule patterns and accuracy less than imipramine. The types of errors during drug sessions were not systematically related to the types of errors that appeared during nondrug sessions. Stimulus control was evaluated for each of the four possible color configurations and was found to be by the entire configuration of colors, not simply by the color of the sample.

Key words: simultaneous matching to sample, configuration model, stimulus control, imipramine, chlorpromazine, fixed-interval schedules, fixed-ratio schedules, operant behavior, key peck, pigeons

Conditional-discrimination procedures are commonly used to study complex stimulus control. In this type of procedure the relationship of a stimulus to reinforcement depends upon the presence of another stimulus. Conditional discriminations differ from simple ones because in the latter the relationship between a particular stimulus and the availability of reinforcement does not change.

The imipramine experiment was submitted by the first author to the faculty of the Georgia Institute of Technology in partial fulfillment of the requirements for an MS degree and was presented at the 1980 meeting of the Southeastern Psychological Association in Washington, DC. The chlorpromazine experiment was presented at the 1984 meeting of the Association for Behavior Analysis in Nashville, Tennessee. The writing of the manuscript was partly supported by NIEHS Training Grant No. ES07026. We thank David Gentry, John Zirrax, and two anonymous reviewers, who commented on an earlier version of this paper. Reprints may be obtained from M. Christopher Newland, P.O. Box RBB, University of Rochester, School of Medicine and Dentistry, Rochester, New York 14642.

In matching-to-sample (MTS) procedures, which constitute a subset of conditional-discrimination procedures, the stimulus positively correlated with reinforcement, the S+, is that which shares some feature with a sample stimulus. When pigeons are subjects, a sample key can be illuminated, and a response on this key results in the illumination of two side, or comparison, keys. A response on the matching side key can then be reinforced under some schedule (Cumming & Berryman, 1965).

Although matching to sample may be arranged procedurally, it does not follow that behavior is under the control of a conditional discrimination. A simple case in point is the simultaneous MTS procedure, in which the sample remains lit while the comparison stimuli are presented. The response on a particular side key may be under the control of the sample key, in which case the discrimination is conditional. Alternatively, the entire configuration may form the discriminative stimulus

and thus the discrimination is simple. Such stimulus control could be detected by monitoring accuracy for each configuration and noting the patterns of errors that develop.

When whole MTS sequences are treated as operants, schedule contingencies operate on matches as they do on simpler operants. Both scalloped and break-run patterns of matching have been seen in fixed-interval schedules of MTS (Boren & Gollub, 1972; Clark & Sherman, 1970; Nelson, 1978). Nelson showed that interval schedules of matching to sample end in a moderate intermatch time, as do interval schedules of simple responses (Dews, 1969). When each match and each mismatch is followed by a distinctive stimulus, accuracy increases as the interval elapses (Boren & Gollub, 1972; Clark & Sherman, 1970); but when such a stimulus is not used, an increase in accuracy is not consistently found (Nelson, 1978).

Matching to sample as an operant placed under a schedule of reinforcement can provide a useful baseline for evaluating drug-behavior interactions, regardless of the nature of the discrimination that emerges, because with such schedules, drug effects on both stimulus control and response rate can be evaluated simultaneously. The effects of drugs on the rates of matches and mismatches can be compared with their effects on simpler operants to determine the extent to which matches and mismatches resemble simpler operants (cf. Marr, 1979). The source of drug-induced changes in stimulus control can be investigated by comparing the errors that occur during drug and nondrug sessions. In addition, examination of the patterns of drug-induced errors can provide clues about the nature of stimulus control—that is, whether it is simple or conditional.

In the present experiment, chlorpromazine and imipramine were chosen for investigation because of their different effects on response rate. Chlorpromazine usually suppresses overall fixed-interval response rate, whereas imipramine increases fixed-interval rate in pigeons (Seiden & Dykstra, 1977). The effects of the two drugs on stimulus control are less clear and appear to depend strongly on the

nature of the baseline used. Vaillant (1964) compared these two drugs directly and reported that chlorpromazine disrupted stimulus control and lowered response rates, whereas imipramine increased response rates but left stimulus control intact. Thompson (1973, 1976) provided data that suggest a different conclusion. Imipramine altered both rate and accuracy during the repeated acquisition of a behavioral chain (Thompson, 1976), but chlorpromazine altered rate alone (Thompson, 1973). Some studies have reported that chlorpromazine disrupts differential control by external stimuli (Laties, 1972; Laties & Weiss, 1966; Thomas, 1966; Vaillant, 1964; Waller, 1961; West, Hernandez, & Appel, 1982), but others report little or no effect of chlorpromazine on stimulus control (Berryman, Jarvik, & Nevin, 1962; Dearing & Branch, 1981; Leander, 1981a; Wiltz, Boren, Moerschbaeher, Creed, & Schrot, 1974). A pair of studies by Thompson demonstrates the importance of the contingencies in these effects. In the repeated-acquisition procedure the presence of differential effects of chlorpromazine on total trial time and errors depended upon whether chain (Thompson, 1973) or tandem (Thompson, 1974) conditions were in effect.

In the present experiments the role of the stimulus configuration in maintaining MTS performance is examined. The effects of the two drugs on schedule performance and accuracy are evaluated at a global level. These global effects are then examined in relation to control response rates and finally with respect to the specific configurations of key colors. It will be shown that an adequate account of the behavior that develops must include the individual configurations of key colors.

METHOD

Subjects

Three male White Carneaux pigeons, P3, P7, and P72, maintained at approximately 80% of their free-feeding weights, served as subjects. These birds had served in previous operant conditioning experiments, but none had received drugs prior to this experiment.

Apparatus

A Grason-Stadler Model E31255AA-300 animal chamber was used as the operant chamber; it had three circular response keys placed horizontally across one wall and centered above the food magazine. A force of about 0.15 N operated the center key. A force of between 0.2 and 0.25 N operated the side keys. These forces were checked and adjusted weekly to ensure that they remained within the specified range. The keys and projection screen were cleaned weekly to remove accumulated white dust.

The keys were transilluminated by red or green light from Grason-Stadler projection units. The feeder was located below the middle key and was illuminated each time it was activated. A 1.5-W houselight was mounted behind a screen above and to the right of the right response key. A layer of adhesive tape was placed over the screen to dim the houselight. White noise was provided through a speaker and by a ventilation fan located at the back of the chamber. Programming and recording of events were controlled by electromechanical equipment located in the same room.

Training

The birds were first trained to peck each of the three keys and then were exposed to a discrete-trial, simultaneous, two-color (red and green) MTS procedure. A trial began with the noncontingent lighting of the center key with a red or a green light. A probability generator, set at .5, determined whether the center light was red or green. A peck on the center key transilluminated the side keys, one red and one green. The probability of the red comparison key appearing on the right side was .5. A peck on the lateral key that matched the center key was followed by 3-s access to mixed grain. A peck on the other key produced a 10-s blackout during which all chamber lights darkened. After a 25-s intertrial interval (ITI), during which only the houselight was on, a new trial began. Training continued in this way until 85% accuracy occurred for at least 5 consecutive days.

After this initial training, the contingencies for P7 and P72 were abruptly changed to a

multiple fixed-ratio (FR) 3 fixed-interval (FI) 10-s reinforcement schedule with a sequence terminating with a matching response as the reinforced unit of behavior; the whole sequence is designated a "match." A sequence terminating with a response on the nonmatching key is called a "mismatch." Blackouts and intertrial intervals no longer occurred. During the FR 3 component, three small white circles were superimposed horizontally on the sample key and access to grain followed the third match. During the FI 10-s component, a white triangle was superimposed upon the sample key and access to grain followed the first match to occur after 10 s elapsed. Whenever the overall accuracy during both components on the preceding day exceeded 67%, the schedule was simultaneously changed toward a larger FR and a longer FI. Early in training, the length of the FI was adjusted to approximately equal the time required to complete the FR. The only stimulus change following matches was the reinforcer presentation when the schedule requirement was fulfilled or the next trial; the only stimulus change following mismatches was the onset of the next trial.

Position preferences were initially eliminated using a correction procedure—a configuration was presented repeatedly until a match occurred. The correction procedure led to switching between left and right keys, behavior which produced a chance accuracy level of 67%, so a "resetting" ratio was introduced in which a mismatch reset the ratio counter. The resetting ratio was effective in eliminating key biases and improving accuracy on both the interval and ratio components. Eventually the reset feature of the ratio schedule was removed.

The performance of P3 did not survive the change to a multiple schedule so discrete-trial training was reinstated. The IRIs and time-outs were gradually reduced and then an FR 2 resetting schedule (with the three circles superimposed on the sample key) was begun. This was increased to an FR 5 resetting ratio, and when performance stabilized, an FI 10-s schedule was introduced and the FI parameter was gradually increased. At one point performance deteriorated again, so discrete-trial training

was reinstated and was changed gradually to the multiple schedule once again. Eventually a multiple FR 20 FI 300-s schedule maintained greater than 70% overall accuracy with no correction procedure, blackouts, IRIs, or resetting ratio.

Baseline and Drug Sessions

The FR schedules were adjusted so that pause and run times were about equal for all birds. As a result, two birds, P3 and P72, were maintained on a multiple FR 20 FI 300-s schedule of reinforcement, and one bird, P7, was maintained on a multiple FR 10 FI 300-s schedule. The operant was a simultaneous MTS response with no correction procedure or blackouts imposed for mismatches. The only consequence to follow matches or mismatches was presentation of the next trial or access to grain following some matches; the sequence terminating with a peck on the matching key was thus treated as single-key pecks normally are treated under FR and FI schedules. The interval and ratio components alternated after each grain delivery. The sessions terminated after 50 components and typically lasted about 3.5 hours. Sessions were conducted 5 days per week.

Imipramine was administered in increasing doses after accuracy during the ratio and interval components, interval quarter-life, and color or position bias showed no systematic variation over 30 sessions. Imipramine hydrochloride was dissolved in a 0.9% saline solution such that one ml of solution per kg of body weight could be injected at all doses (0.56, 1, 3, 5.6, and 10 mg/kg, calculated as the salt). At the highest dose, as much as an hour elapsed after the beginning of the session before responding began. The imipramine solution was made up on the day it was used, and injections were made into the breast muscle of the pigeon 20 min before it was placed into the chamber. Both control and drug sessions began 10 min after the bird was placed into the chamber. After several injections of saline, imipramine was administered in increasing and then decreasing doses; then doses were administered in an irregular order. Drug days were Tuesday, Wednesday, or Thursday and

were always separated by at least 6 nondrug days. Sessions immediately before drug days served as control sessions.

Matches, mismatches, pause times, and run times were recorded during the FR component. Pause time was the time from the onset of the ratio component to completion of the first match. Run time was the time from the first match to the delivery of grain. During the interval component the number of matches and mismatches in each of ten 30-s segments and the time required to complete the interval were recorded. Further, accuracy on each of the four color configurations was recorded. That is, for each of two sample colors, the matching stimulus could be on the left or the right so there were four possible configurations of stimuli for this procedure. These are designated as RRG (red left comparison key, red sample, and green right comparison key), GRR, RGG, and GGR. All measures were accumulated over the session so they represent session averages.

After the imipramine data were collected, the experiment was discontinued for a few months. When it was resumed, a brief training procedure was reinstated but stable performance quickly developed so baseline was then reestablished and chlorpromazine sessions began. The FR parameter was again adjusted so the pause and run times were about equal across subjects. Hence, Pigeons P3 and P7 were maintained on a multiple FR 10 FI 300-s schedule and P72 on a multiple FR 20 FI 300-s schedule. Chlorpromazine hydrochloride was dissolved in a 0.9% saline solution on the day of the session such that 1 ml of solution per kg of body weight could be injected. Chlorpromazine was injected intramuscularly 20 min before placing the bird in the chamber and the session began 10 min later. Drug days were separated by at least 6 nondrug days. Control sessions were the sessions immediately before drug sessions. Doses of 1, 3, 5.6, 10, and 17 mg/kg (calculated as the salt) were injected in ascending and descending doses.

RESULTS

Overall Effects

Figure 1 shows cumulative records of the

P 7 IMIP

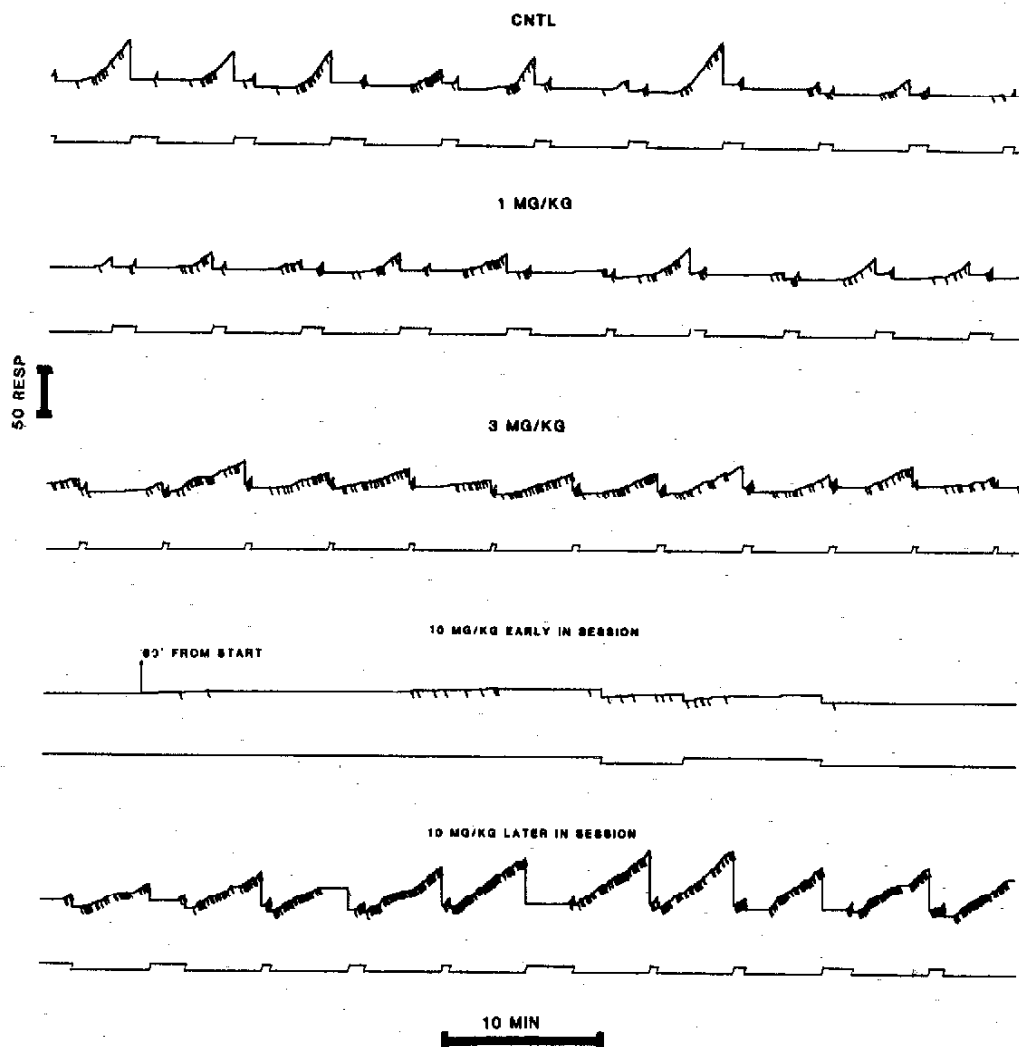


Fig. 1. Cumulative records of responding for control sessions and several imipramine sessions for Bird P7. The response pen advanced for each match and deflected, without advancing, for each mismatch. The event pen was up during the ratio component and down during the interval component. At the highest dose responding is shown early in the sessions and later in the same sessions.

performance of P7 under control conditions and under several doses of imipramine. Responding during the FR component was characterized by a pause followed by a high rate of responding, whereas that during the FI component was characterized by a pause followed

by a moderate-to-high rate of responding. Mismatches, which were never directly reinforced, usually occurred early in the ratio or interval, although they were occasionally found at all points. It was not unusual to find strings of 20 or more consecutive matches.

P 7 CPZ

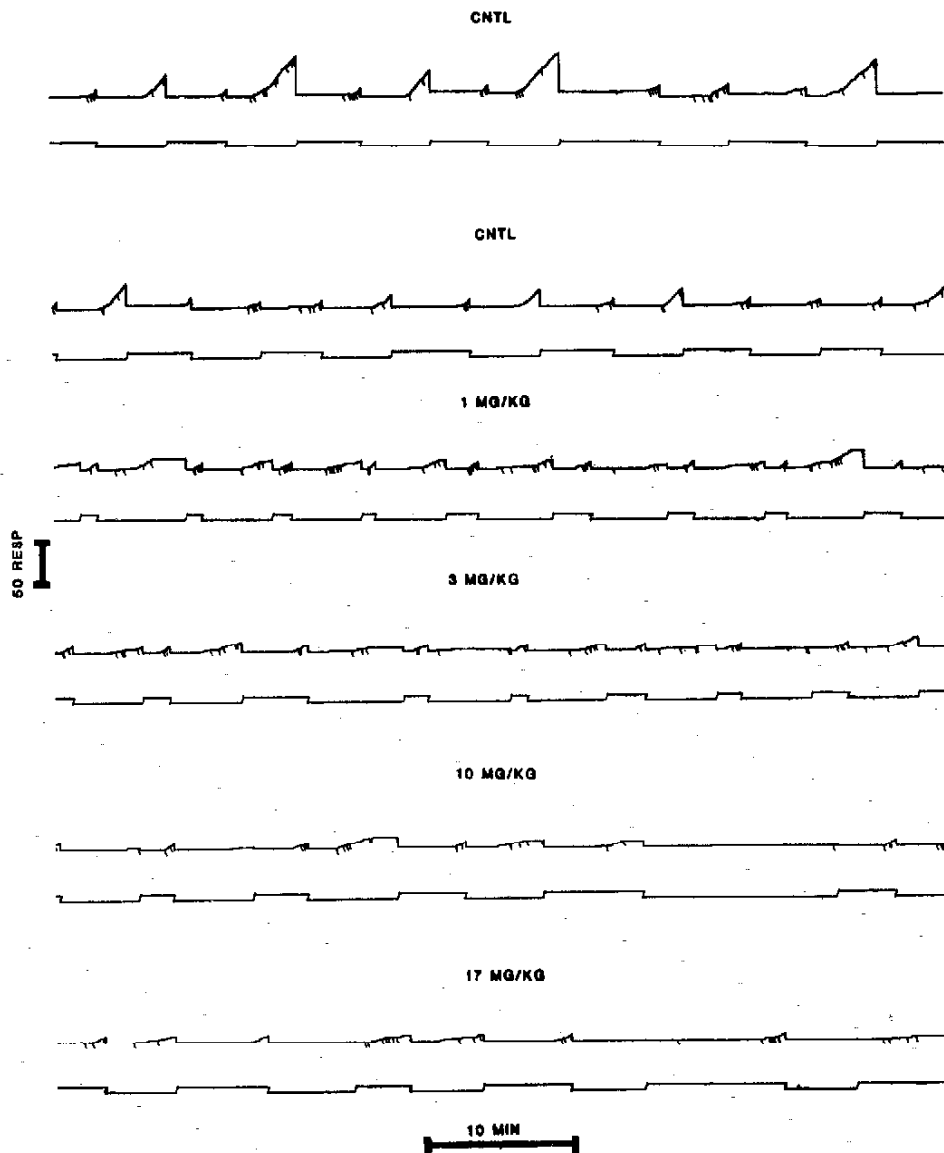


Fig. 2. Cumulative records of responding for control sessions and several chlorpromazine sessions for Bird P7. Markings as in Figure 1.

The major effects of imipramine on response rate, accuracy, and response pattern are evident in the cumulative records. Imipramine removed the characteristic features of responding during both components in a dose-dependent fashion. Mismatches became

evenly distributed through both the interval and ratio components. The postreinforcement pause was diminished and responding appeared as a steady rate showing little differentiation with respect to the schedule in effect or to the multiple-schedule stimuli on the keys.

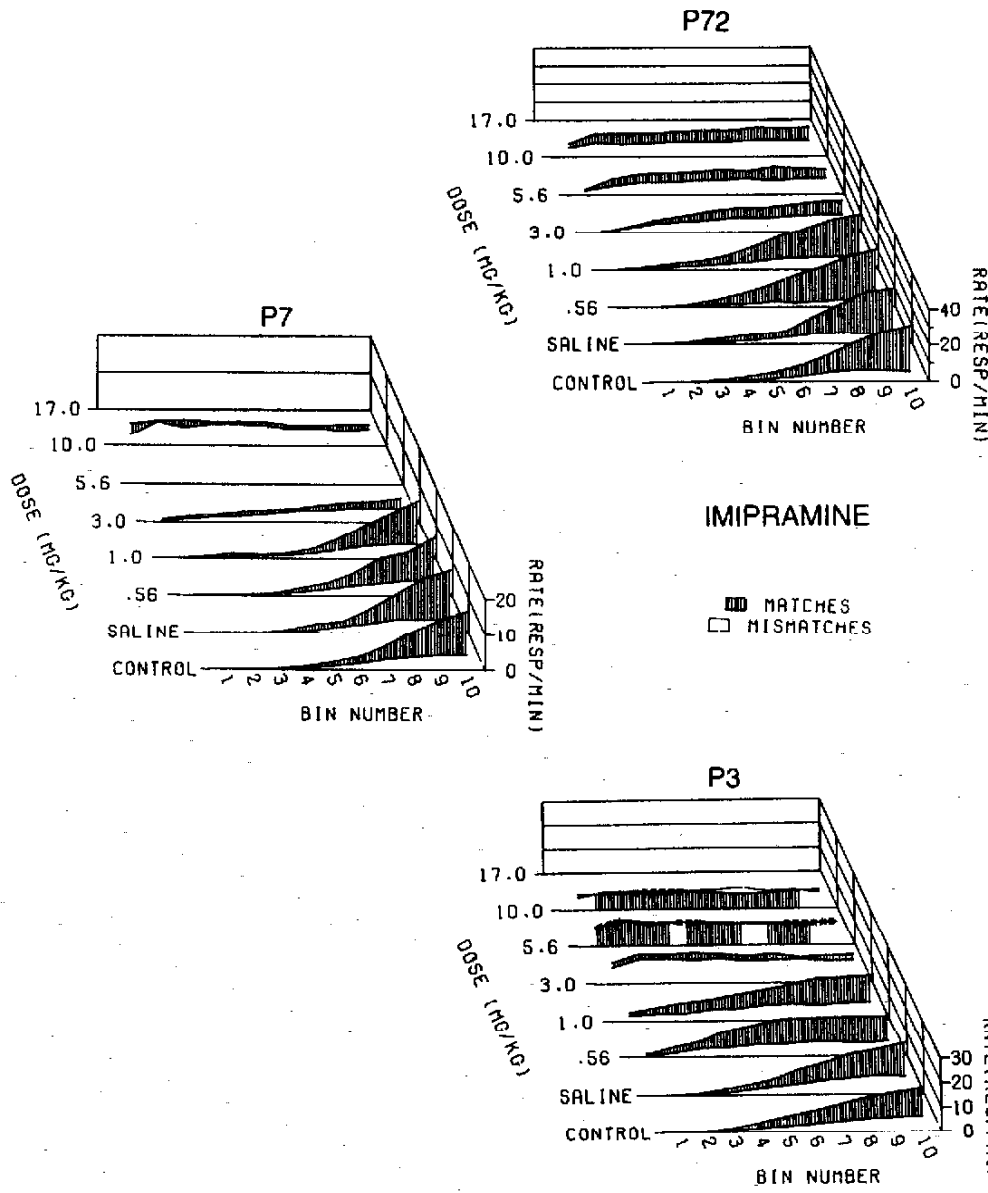


Fig. 3. Rates of matches and mismatches during the fixed-interval component as functions of bin and dose of imipramine. The top curve shows matches and the bottom curve shows mismatches. Striations fill in the area between the two curves. Bands of white on P3's graph denote when the mismatch rate exceeded the match rate.

At the highest dose a very long pause was followed by erratic, low-rate responding. Later during this same session undifferentiated, high-rate responding developed. These very long pauses found early in the session were not included in calculations of rate or pausing for the dose-response plot.

Chlorpromazine's effects differed from those of imipramine. Figure 2 shows cumulative records of responding during control and chlorpromazine sessions. Chlorpromazine decreased response rate but both accuracy and schedule patterns remained comparatively intact at most doses. Both the ratio and interval com-

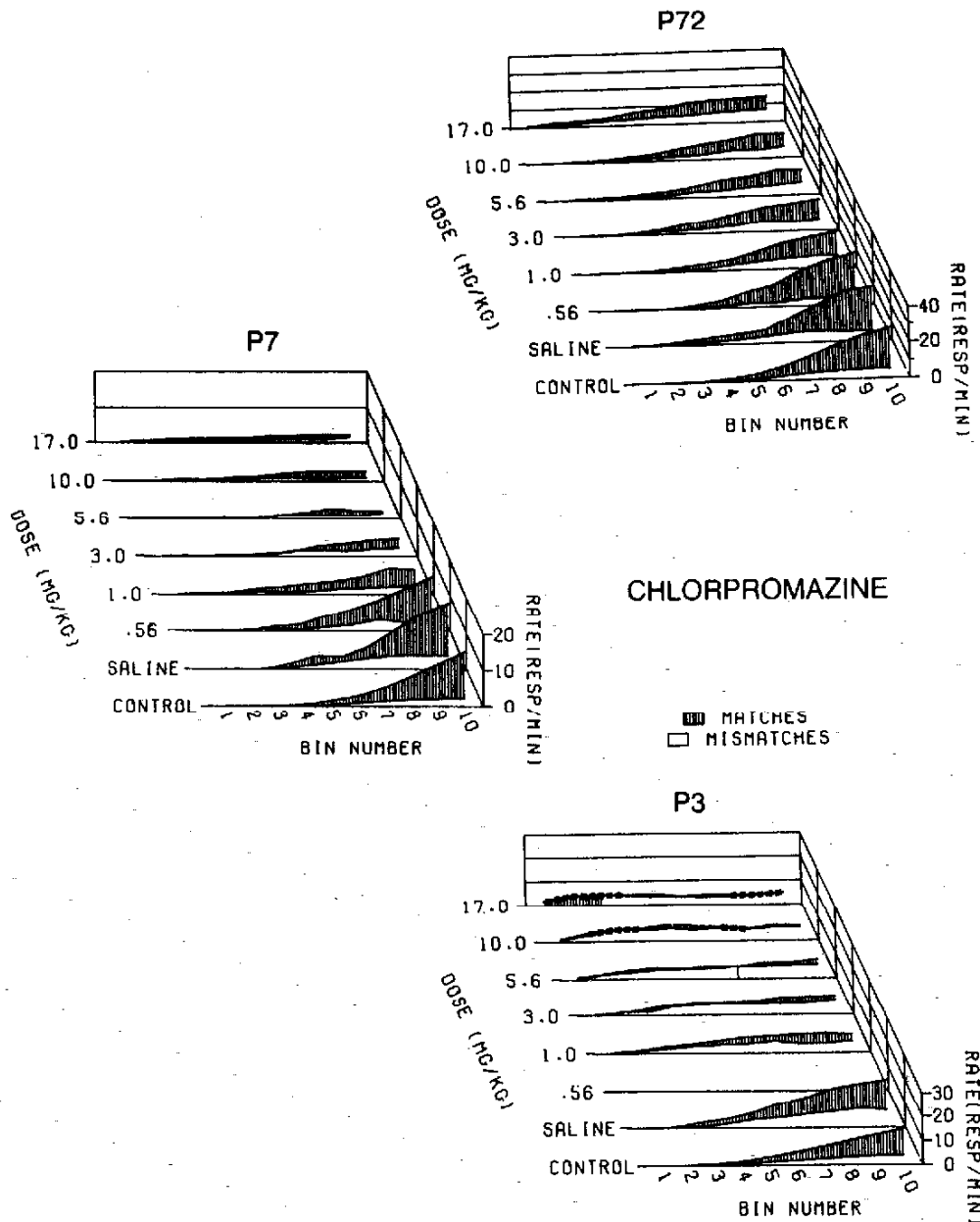


Fig. 4. Rates of matches and mismatches during the fixed-interval component as functions of interval bin and dose of chlorpromazine. Markings as in Figure 3.

ponents began with pauses, and rate tended to increase at the ends of the intervals. Long runs of consecutive matches appeared at the highest dose of chlorpromazine, a dose which substantially suppressed the rate of responding.

Figure 3 shows the rates of matches and

mismatches through the fixed interval for each dose of imipramine. For two birds, P7 and P72, the rate of matches during control sessions increased steeply toward the end of the interval while the rate of mismatches did not. Pigeon P72 showed a slight decrease in the

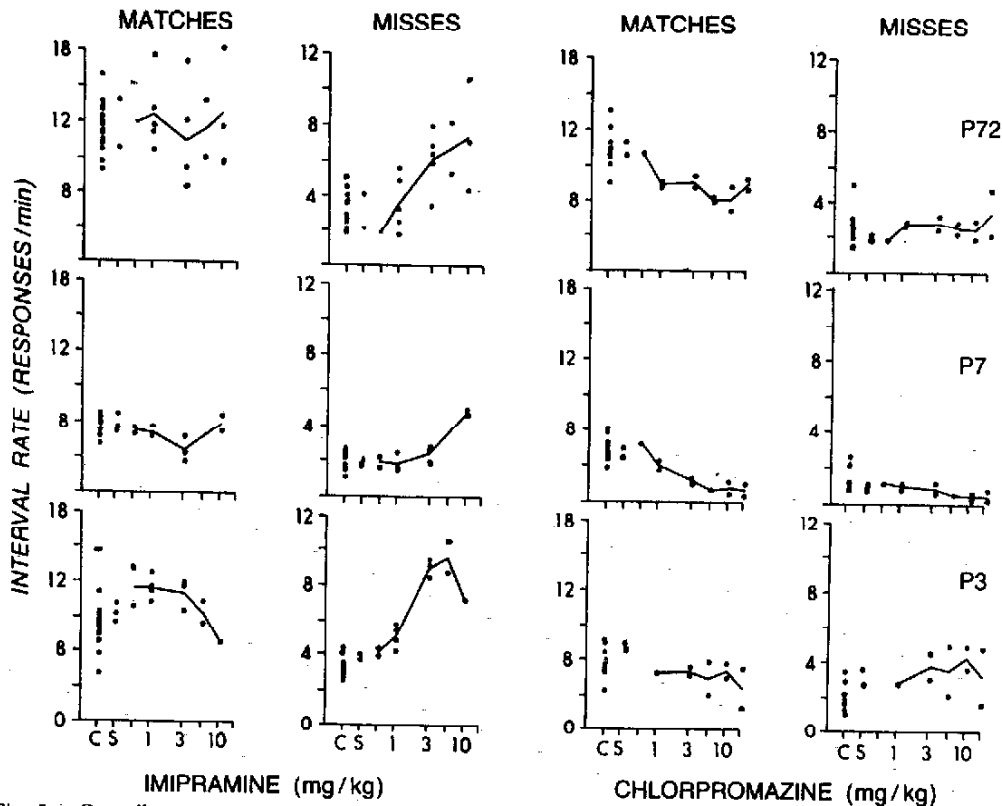


Fig. 5. Overall rates of matches and mismatches (misses) during the fixed-interval component for control, saline, imipramine, and chlorpromazine sessions. Each point represents a single session; the curve is drawn through the mean at each dose. Note that the scales on the ordinate are different for matches and mismatches.

rate of mismatches at the end of the interval. The high rate of matches late in the interval decreased, whereas the low rate of matches and mismatches early in the interval increased. At 10 mg/kg all traces of temporal patterning disappeared, but for 2 birds the match rate continued to slightly exceed the mismatch rate.

Figure 4 shows the distributions of matches and mismatches throughout the interval for each dose of chlorpromazine. Although the drug produced a slight rate increase early in the interval and a profound rate decrease late in the interval, both interval patterning and accuracy remained relatively intact. That is, there was a small increase in rate through the interval and match rate exceeded mismatch rate for 2 of the 3 birds.

Figure 5 shows that increasing doses of imipramine increased the overall rate of mismatches during the FI component. The mean

of the overall rate of matches was relatively unaffected by imipramine for two birds, although the data for P72 are quite variable. Increasing doses of chlorpromazine decreased the rate of matches and had little effect on mismatches, an effect directly opposite to that of imipramine.

Figure 6 confirms the imipramine-induced decreases in ratio pause time that were apparent in the cumulative records. Chlorpromazine substantially reduced pause time at the low doses but the function is U shaped; pause time returned to or exceeded control values at the highest dose. Imipramine increased run time during the ratio in a dose-dependent fashion. Chlorpromazine's effects on run time were inconsistent: Clear increases are evident for P7 but not for P3 and P72. Run time for P3 was lower than control values at the highest dose.

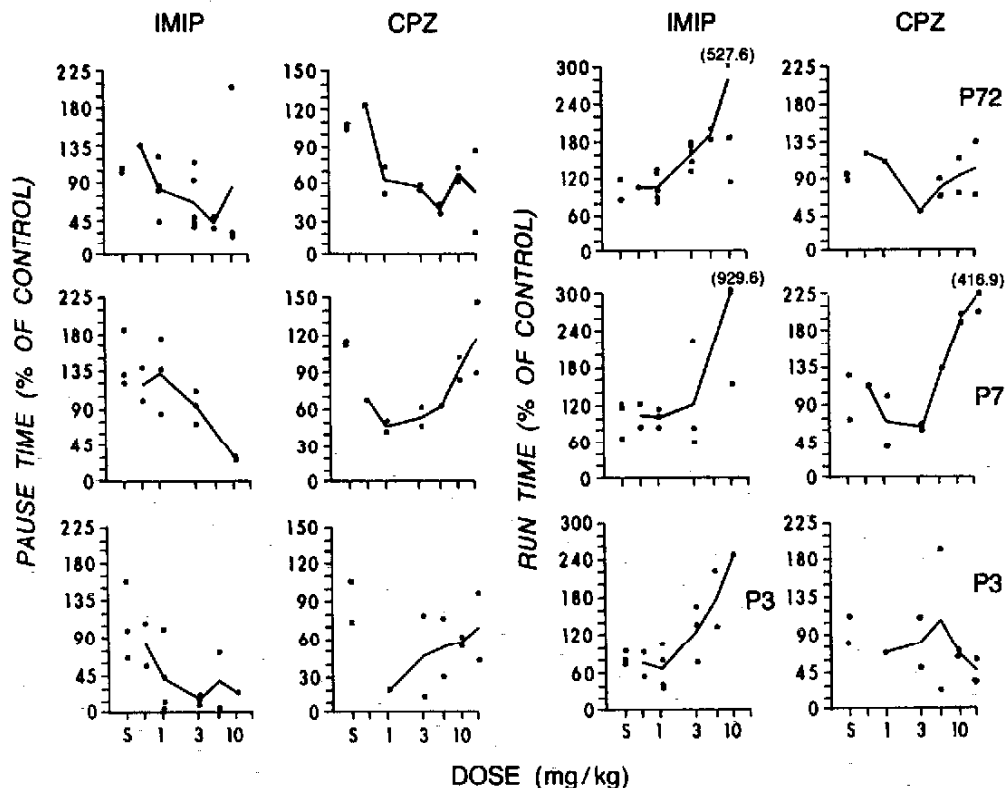


Fig. 6. Ratio pause and run time for saline, imipramine, and chlorpromazine sessions. Numbers are presented when the value exceeds the maximum ordinate value. Each entry represents a percentage of the control session on the previous day.

Rate-Dependency Analysis

That imipramine raised the low rate of mismatches suggests that response rate is important and that the type of response—match or mismatch—modulates the relationship between rate and drug effects. Therefore, an analysis of the relationship of control rate to drug rate of responding was performed, while taking into account the two different types of response available. The analysis was performed in two steps for each bird. A multiple regression was performed on the data for a bird at all doses of a single drug. The main reason for including all doses is that it reduces the number of F ratios calculated and therefore the number of spuriously significant ones. The overall test was performed using BMDP1R (Dixon & Brown, 1979). A regression was first performed using response rate under the drug as the dependent variable and dose and control response rates as the independent variables.

The analysis was then repeated with dose, response rate, and response type (match or mismatch) as independent variables. The regression sum of squares due to this latter analysis was compared with that of the previous analysis to determine whether a significant increase in the variance accounted for occurred when a term for response type was included.

If the overall test was significant (at $p \leq .05$), then a series of tests was performed to determine at what doses the differences occurred and whether the difference was in the slope or in the intercept of the curve. This sequence does not partition sums of squares as formal post-hoc tests do, but the use of the overall test prior to the individual tests should reduce spurious errors. The second stage was performed using a method described by Kerlinger and Pedhazur (1973). To test for the difference in slopes it was determined whether

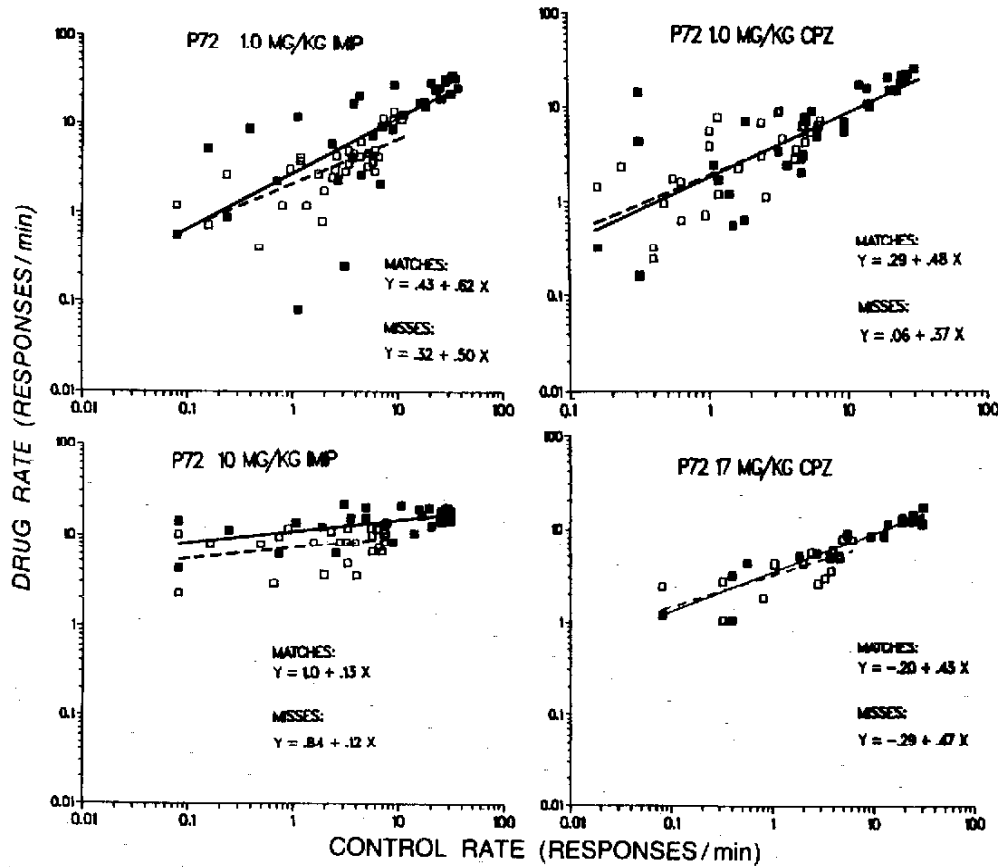


Fig. 7. Scatter plots of interval response rates for Bird P72 during drug sessions and control sessions. The fixed interval was divided into ten 30-s bins. The ordinate represents response rates during each of these bins during control sessions and the abscissa represents rates from the same bins during drug sessions. The equation of the least-squares regression line is indicated on each plot. Filled squares and the solid line show matches; unfilled squares and the dashes show mismatches. The intercepts are significantly different at 10 mg/kg. The equations were calculated from the log of the rates.

a regression using separate slopes for each response type produced a significantly larger regression sum of squares than using a common slope. If it was found that the slopes were the same, then the common slope was used to compare the effect of having two regression lines and different intercepts with a single pooled regression line and one intercept.

Figure 7 contains sample scatter plots of drug versus control rates of responding during each of ten 30-s segments of the fixed interval. These data represent one bird's performances at the highest and lowest dose of each drug. Separate regression lines were computed for matches and mismatches. One scatter plot contains two regression lines that were deter-

mined to be significantly different (10 mg/kg of imipramine); the other three plots contain regression lines that did not differ statistically. The figure reveals the nature of the effects of the two drugs on matches and mismatches.

The regression lines for matches and mismatches were quite similar. The pair of lines that differed statistically (10 mg/kg of imipramine) are only slightly different: The intercepts for matches and mismatches are, respectively, 10 and 6.9 responses per minute in this plot. It is also apparent from Figure 7 that the variability in the scatter is greatest at low response rates at low doses. The low control response rates correspond to early segments of the fixed interval and probably repre-

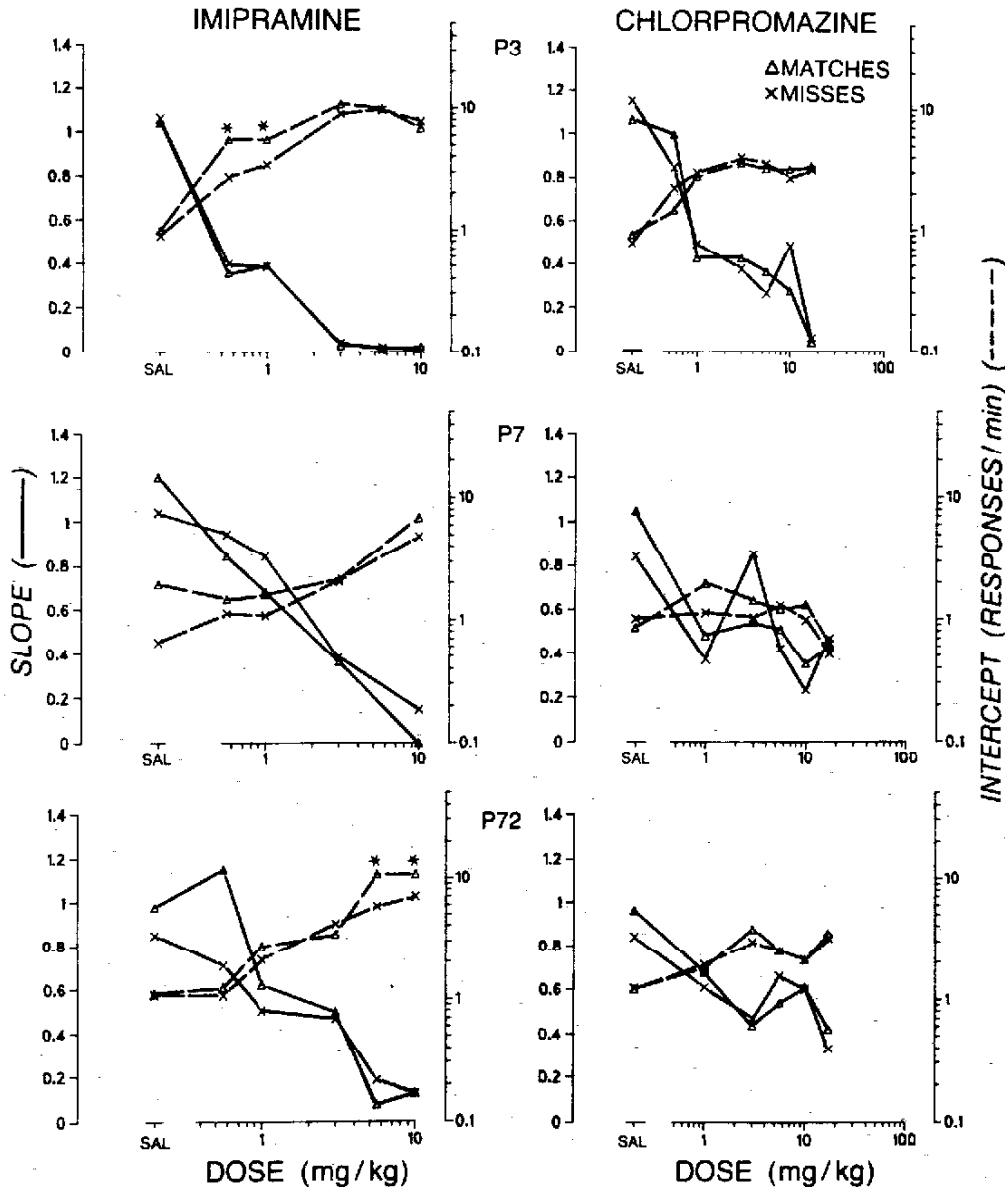


Fig. 8. Slope (solid line) and intercept (dashed line) of the regression lines as functions of dose for imipramine and chlorpromazine for each bird. The slope corresponds to the left ordinate and the intercept corresponds to the right ordinate. Points for saline and the lowest dose are connected for visual clarity. Stars indicate points where the parameter for matches was significantly different ($p \leq .05$) from mismatches (misses).

sent the differences in the onset of the responding during the interval (Branch & Gollub, 1974). The cumulative records (Figures 1 and 2) support this interpretation; they reveal a pattern of pausing for a variable length of time and then responding at a constant rate. The

highest dose of imipramine produced a constant rate of responding (the slope was close to zero) through the interval, but a graded increase in response rate (represented by a positive slope) is still evident at the highest dose of chlorpromazine.

The similarity of matches and mismatches was replicated in the other two birds (Figure 8). The most striking feature of Figures 7 and 8 is the similarity between matches and mismatches. Where differences do appear, they are small.

The effects of the two drugs on the regression parameters differed. Imipramine reduced the slopes of the regression lines to zero, indicating that response rate during the interval component was constant after imipramine (cf. Figures 1 and 3). Chlorpromazine, however, had a less substantial effect on slope for the two birds: The dose-effect function was more shallow and the slope at the highest dose was still positive, indicating that some temporal patterning in responding remained after all doses of chlorpromazine (cf. Figures 2 and 4). The two drugs also had different effects on the intercepts: They were higher for imipramine than for chlorpromazine. The higher intercepts obtained from imipramine appear to cor-

respond to the rate increases produced by this drug. Rate decreases, such as those obtained from chlorpromazine, cannot be read directly from Figure 8 because overall rate is a complex function of the slope and intercept of the rate-dependency function represented.

Stimulus Control of Matching to Sample

In order to specify the sources of errors, matches and mismatches were recorded for each of the four possible configurations of stimuli. Figure 9 shows accuracy supported by each configuration for the first 270 s of the interval, the last 30 s of the interval, and when the ratio and interval schedules required only one match before reinforcement. The data from P7 and P72 demonstrate that the errors appearing early in the interval were mainly restricted to one or two configurations, and that there was more session-to-session variation in accuracy reported by these configurations than in the accuracy on the other configurations. The improvement in overall accuracy in the terminal response reflected a change on a single configuration—RGG for P7 and RRG for P72.

Figure 10 shows drug-induced changes in accuracy on each configuration. Most of the errors produced by P72 under control conditions occurred on a single configuration, GGR, and the variability in accuracy on this configuration was greater than that for the other three configurations. In P7's case, two configurations (RRG and GGR) consistently exerted precise control over responding under nondrug conditions whereas two others (GGR and RRG) were less consistent and supported more mismatches. Control performance for P3 was virtually unbiased and each configuration maintained approximately the same levels of accuracy.

Both drugs produced biased performance in P3. Imipramine consistently produced a right position bias, performance that could be described as stereotypic sequential responding on the center and right key. Chlorpromazine produced a left position bias for this bird, but note that one configuration, RGG, maintained a substantial level of right-key responding (matches).

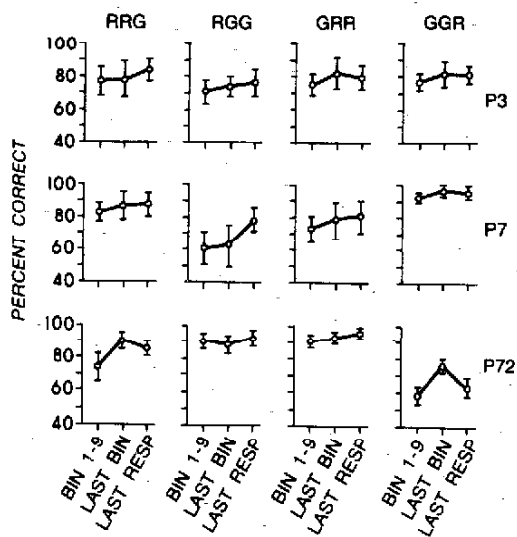


Fig. 9. Accuracy accompanying each configuration during the first 270 s of the interval, during the last 30 s of the interval, and when a single additional match was required for reinforcement from either schedule. The letters describing the configurations refer to the color on the left comparison key, the sample key, and the right comparison key. For example, RRG refers to a red sample and left comparison key and a green right comparison key. Error bars represent \pm two standard errors taken across sessions. All data came from control sessions.

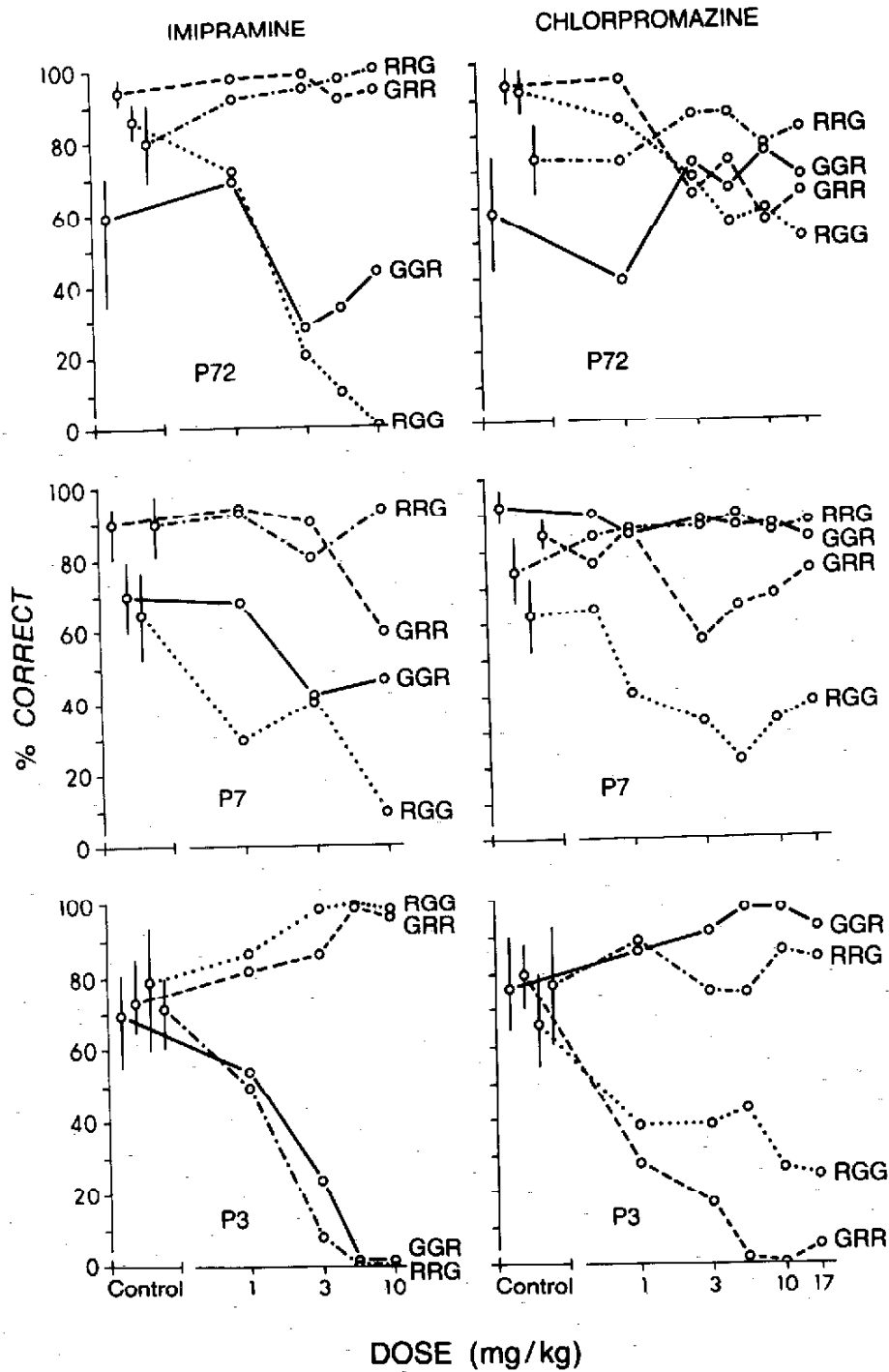


Fig. 10. Accuracy for each of four stimulus configurations during control, saline, and drug sessions, shown separately for each bird. Each line represents a single configuration. The bars around the control values represent ranges.

Table 1
Overall Accuracy and Bias for Each Pigeon During Control, Saline, and Drug Sessions¹

Drug	Dose (mg/kg)	Pigeon P3			Pigeon P7			Pigeon P72		
		Accuracy	Left Bias	Red Bias	Accuracy	Left Bias	Red Bias	Accuracy	Left Bias	Red Bias
Control ²	—	71	43	51	75	60	68	80	41	57
(range)		67-77	28-53	42-63	71-84	50-70	53-78	72-86	37-45	46-67
Saline	—	71	39	46	77	65	69	78	41	55
Imip	1	67	32	47	75	56	68	78	39	61
Imip	3	56	13	37	62	50	72	62	65	83
Imip	5.6	49	1	45				62	59	84
Imip	10	49	4	45	55	72	76	64	66	89
Control ²	—	74	51	51	77	62	53	79	37	55
(range)		67-82	40-62	38-60	71-83	54-78	35-70	73-82	30-43	46-62
Saline	—	70	36	47	77	70	65	78	41	53
Cpz	1	60	77	46	75	62	61	72	32	61
Cpz	3	56	78	38	68	69	57	72	56	53
Cpz	5.6	55	83	33	66	71	60	70	54	59
Cpz	10	54	89	40	69	69	62	68	56	48
Cpz	17	52	86	41	69	57	56	66	58	57

¹All values are expressed as percentages. A red bias of 100% represents exclusive responding on the red comparison key, 50% represents equal responding on both red and green comparison keys, and 0% represents exclusive responding on the green comparison key.

²The session on the day preceding the administration of a drug or vehicle is the control session.

The drug effects for P7 and P72 cannot be described simply in terms of position bias because they were configuration-specific. For example, in Table 1 it appears that in P7 imipramine simultaneously produced a red color bias and a left position bias. Figure 10 clarifies this perplexing result. Two configurations (GRR and GGR) maintained nearly chance performance at the highest dose, a substantial drop in accuracy for GRR, whereas configurations RRG and GGR maintained high and low levels of accuracy, respectively. A pattern can be described as follow: When the left and right comparison keys were red and green, respectively, the response occurred on the left key; but when they were green and red, the response occurred on either key. If this describes the source of stimulus control under imipramine, then the sample key was irrelevant to this performance.

Imipramine's effect on P72's performance appears in Table 1 as a red color bias but Figure 10 suggests that this effect, too, is more complicated; once again, no simple rule describes the performance. One configuration,

RGG, was affected substantially; two configurations, GGR and GRR, were unaffected.

Chlorpromazine reduced overall accuracy for P72 by reducing accuracy on two configurations, GRR and RGG, whereas the other two configurations were unaffected. Chlorpromazine disrupted control by configuration RGG for P7 but the effects on the other configurations were less consistent. The rather mild effect of chlorpromazine on accuracy at moderate doses, apparent in Table 1, belies substantial alterations in the structure of performance, particularly in the case of P7.

In general, no specific rule describes the drug effects. A clear position bias did not emerge, except for P3 under imipramine. Configurations supporting low accuracy were not specifically affected, preexisting biases were not exacerbated, and no sample-specific biases appeared. It is interesting that under imipramine, the sample key may have been irrelevant to P7's performance. Overall, the effects of the two drugs were idiosyncratic with respect to the subject and to the configuration.

DISCUSSION

Schedule Patterns

Both the rates and patterns of matches during the ratio and interval components resemble those produced by FR and FI schedules of simpler response units (Ferster & Skinner, 1957). The one exception is that the pause times during the ratio component resemble those found in much larger ratio schedules (Ferster & Skinner, 1957). The similarity of the FR 20 of matching to sample to larger ratios is further supported by imipramine's reduction of pause time. Weiss and Gott (1972) reported that imipramine increased pause time in an FR-30 schedule of key pecking, but Marr and Bradford (1977) reported a decrease in the long pauses produced by an FR-500 schedule. In the present experiment, long pause times were decreased by imipramine.

Imipramine's other effects on response rate also resemble its effect on simpler response units. The high rates of responding in the ratio component and at the end of the interval component were reduced while interval response rates at other points in the interval increased (Weiss & Gott, 1972). Chlorpromazine reduced response rates during the ratio and interval schedules and decreased pause time at the lower doses as it does with schedules contingent upon simple key pecking (Leander, 1981a; Leander & McMillan, 1974).

Rate Dependency

An inverse relationship between control and drug response rates is a behavioral effect of many drugs (Sanger & Blackman, 1976). The interpretation of this finding is an issue of debate (Gonzalez & Byrd, 1977; Ksir, 1981; McKearney, 1981), but the plots of drug rate versus control rate remain a useful way of presenting data.

In the present experiment, the relationship between drug rates and control rates was investigated in order to evaluate the differential effects of the drugs on matches and mismatches. This was accomplished by regressing drug rate on control rate both with and without a second term for response type

(match or mismatch), and comparing the resulting sums of squares.

In only a few isolated incidents was imipramine's reduction of the regression slope modulated by the response type. The intercept of the regression was sometimes higher for matches than for mismatches, but this effect was small and inconsistent when compared across doses. The clearest case appears in Figure 7 (Bird P72, 10 mg/kg). The inconsistency of imipramine's differential effect on matches and mismatches suggests that it may be either spurious or the result of drug effects occurring at a different level. The overall impression is that matches and mismatches were not differentially affected by imipramine.

Chlorpromazine's effects also were not differential with respect to the type of response; indeed, chlorpromazine's effect appeared completely rate-dependent at this level (cf. Leander, 1981b). Both the slope and intercept of matches and mismatches were virtually the same at each dose of chlorpromazine. That the effect of this drug on rate was identical for matches and mismatches suggests that chlorpromazine affected response rate only.

Matching as a Response Unit

Under the contingencies used, mismatches never immediately preceded reinforcement but matches sometimes did; therefore, two response classes (matches and mismatches) could be defined. If this procedural distinction is reflected in behavior, then patterns of matches and drug effects on matches should resemble patterns and effects of simpler response units (cf. Marr, 1979). During control sessions, matches were quite distinct from mismatches and the pattern of matches more closely followed the expected schedule patterns than did the pattern of mismatches. Mismatches typically occurred on specific configurations in early portions of schedules, and they did not increase substantially in rate through the interval. By contrast, an increase in matches developed through the interval. For two birds, this increase was configuration-specific: Early in the interval two configurations maintained low and highly variable levels of accuracy, and accuracy on at least one of these configurations

increased through the interval. These data correspond to those reported by others, indicating that matching to sample, when placed under various reinforcement contingencies, follows schedule-typical patterns (Boren & Gollub, 1972; Clark & Sherman, 1970; Mintz, Mourer, & Weinberg, 1966; Nelson, 1978).

The picture presented by the analysis of stimulus control maintained by each configuration does not contradict the conclusion that matches and mismatches constitute different response units, but rather suggests a way in which the operant was structured under the contingencies employed. A simple discrimination emerged and discriminative control over behavior varied at different points in the interval and ratio schedules.

The drug effects offer a more complex picture of the response unit in this procedure. At the level of overall rates it appeared that the two drugs differentially affected matches and mismatches: Imipramine increased mismatches and chlorpromazine decreased matches. However, the rate-dependency analysis provided a plausible alternative interpretation that although two distinct response units emerged during nondrug sessions, the effect of the drugs on both units depended only upon their baseline response rates.

The rate-dependency account is complicated by the fact that the drug effects depended upon the configuration present. With some configurations the response unit may have been altered by the drug. An extreme example of shifting response units can be seen in imipramine's effect on the behavior of P3 where a pronounced position bias emerged; at the highest dose the response unit changed to one of alternately responding on the sample and right comparison keys. Thus, the rate-dependency analysis must be qualified insofar as it assumes that the response unit remains the same after drug exposure.

Drug Effects on Schedule Patterns and on Stimulus Control

At doses that also altered the rate of responding, imipramine lowered overall accuracy and eliminated the differences in the

pattern of behavior maintained by the two schedules. At this level of analysis, then, the relative effects of imipramine on rate and on stimulus control cannot be disentangled, and in this respect the result corresponds with imipramine's effect on behavioral chains (Thompson, 1976) but not with that on a concurrent (mixed FR 30 EXT, mixed EXT FR 30) schedule (Vaillant, 1964). When the stimulus configuration is considered, this conclusion is altered only in that imipramine's disruption of stimulus control did not occur on all configurations. It is unclear what modulated this effect, but preexisting biases and sample-specific biases were ruled out. It was also not the case that only low levels of accuracy (poor stimulus control) were affected. Lanson, Eckerman, and Berryman (1979) also demonstrated, with pentobarbital, that drug-induced changes in accuracy were unrelated to preexisting biases or accuracy.

The present experiment can help clarify the conflicting literature on the effects of chlorpromazine on stimulus control. Some investigators (e.g., Laties, 1972; Laties & Weiss, 1966; Vaillant, 1964) have reported disruptions in stimulus control, but the present results and others report little effect (Berryman et al., 1962; Dearing & Branch, 1981; Leander, 1981b; Wiltz et al., 1974). Rate and stimulus control might be disentangled when more than two keys are used. Berryman et al. (1962) reported that chlorpromazine induced only a small and inconsistent decrement in the accuracy of discrete-trial, simultaneous matching to sample. Dearing and Branch (1981) investigated chlorpromazine's effect on responding maintained by food or by the presentation of a stimulus correlated with the schedule of food-reinforced responding, and found that chlorpromazine did not reduce the differences in response patterns produced by their procedures. Laties' (1972) fixed-consecutive-number procedure also used two keys and revealed no effect of chlorpromazine on stimulus control at doses below 27 mg/kg. Wiltz et al. (1974) showed that chlorpromazine lowered the rate of responding to an S+ but had no effect on responding in the presence of an S- when the S- maintained

no responding during control conditions. Chlorpromazine altered the speed of responding but not the differential allocation of responses, and so appears to have had no effect on stimulus control. This result also confirms that chlorpromazine-induced increases in rate during extinction require a nonzero rate of baseline responding (cf. Terrace, 1963).

The fixed-interval pattern was largely unaffected by chlorpromazine in the present experiment at doses that lowered response rate. The literature is less ambiguous about this effect. Waller (1961) demonstrated that chronic chlorpromazine did not alter in dogs the tendency of responding to occur late in the interval, and Byrd (1974) reported a similar finding with chimpanzees. Marr (1970, 1979) reported that when an FI schedule was the component in a second-order schedule, chlorpromazine enhanced the fixed-interval pattern produced by pigeons when control response rates were low. A direct comparison can be made with reports by Leander (1981a) and Leander and McMillan (1974), who investigated the effects of chlorpromazine on pigeons' performance on a multiple FR FI schedule. Chlorpromazine produced a decrease in response rate and a slight decrease in quarter-life, but the distinction between the FR and the FI schedule remained intact.

Stimulus Control in Matching-to-Sample Procedures

There are three ways in which the conditional-discrimination procedure may control behavior (Carter & Werner, 1978). Control may be by the abstract stimulus dimension of a concept of matching, by the color on the sample key, or by the configuration of keys presented. Substantial evidence has accumulated to show that pigeons' behavior can come under the control of the sample key (e.g., Carter & Werner, 1978; Wright & Sands, 1981). Whether or not the behavior of non-humans can come under the control of an abstract dimension of matching remains unclear; evidence has been offered that it can under certain circumstances (Honig, 1965; Premack, 1978; Zentall, Edwards, Moore, & Hogan, 1981), but a careful analysis of stimulus control

in conditional-discrimination procedures suggests otherwise (Sidman, Rauzin, Lazar, Cunningham, Tailby, & Carrigan, 1982).

The present experiment provides evidence that under certain circumstances the matching-to-sample procedure supports behavior that is neither matching nor a conditional discrimination. The analysis of stimulus control for each configuration demonstrates that under both drug and nondrug conditions each configuration supported its own pattern of responding. Such stimulus control would not have been evident if overall accuracy and bias, rather than accuracy for each configuration, had been reported. Matching to sample describes the procedure used but not the behavior that emerged.

The finding that the stimulus configuration is the controlling stimulus is important because it specifies at least one set of conditions under which conditional discriminations in behavior are only apparent—the two-color, simultaneous matching-to-sample procedure. The acquisition of a conditional discrimination is not automatic and cannot be assumed. It remains to delineate the conditions under which simple and conditional discriminations emerge, but some relevant variables appear to be the size of the pool of sample stimuli (Wright & Sands, 1981), explicit sample-specific training (Cohen, Brady, & Lowry, 1981; Urcuioli & Honig, 1980), explicit discrimination training prior to conditional-discrimination training (Carter & Eckerman, 1975) or testing (Honig, 1965), and the species used (Sidman et al., 1982). Finally, the delay between the sample and the comparison stimuli may affect the nature of the discrimination that occurs. In the simultaneous matching-to-sample procedure, as used in the present experiment, simple configuration-specific discriminations may be more likely to appear simply because all three stimuli are present when the response is made.

REFERENCES

- Berryman, R., Jarvik, M. E., & Nevin, J. A. (1962). Effect of pentobarbital, lysergic acid diethylamide and chlorpromazine on matching behavior in the pigeon. *Psychopharmacologia*, 3, 60-65.
- Boren, M. C. P., & Gollub, L. R. (1972). Accuracy of performance on a matching-to-sample procedure

- under interval schedules. *Journal of the Experimental Analysis of Behavior*, **18**, 65-77.
- Branch, M. N., & Gollub, L. R. (1974). A detailed analysis of the effects of *d*-amphetamine on behavior under fixed-interval schedules. *Journal of the Experimental Analysis of Behavior*, **21**, 519-539.
- Byrd, L. D. (1974). Modification of the effects of chlorpromazine on behavior in the chimpanzee. *Journal of Pharmacology and Experimental Therapeutics*, **189**, 24-32.
- Carter, D. E., & Eckerman, D. A. (1975). Symbolic matching by pigeons: Rate of learning complex discriminations predicted from simple discriminations. *Science*, **187**, 662-664.
- Carter, D. E., & Werner, T. J. (1978). Complex learning and information processing by pigeons: A critical analysis. *Journal of the Experimental Analysis of Behavior*, **29**, 565-601.
- Clark, H. B., & Sherman, J. A. (1970). Effects of a conditioned reinforcer upon accuracy of match-to-sample behavior in pigeons. *Journal of the Experimental Analysis of Behavior*, **13**, 375-384.
- Cohen, L. R., Brady, J., & Lowry, M. (1981). The role of differential responding in matching-to-sample and delayed matching performance. In M. L. Commons & J. A. Nevin (Eds.), *Quantitative analyses of behavior: Vol. 1. Discriminative properties of reinforcement schedules* (pp. 345-364). Cambridge, MA: Ballinger.
- Cumming, W. W., & Berryman, R. (1965). The complex discriminated operant: Studies of matching-to-sample and related problems. In D. I. Mostofsky (Ed.), *Stimulus generalization*. Stanford, CA: Stanford University Press.
- Dearing, M. E., & Branch, M. N. (1981). Effects of chlorpromazine on food-maintained and observing behavior. *Psychopharmacology*, **73**, 281-285.
- Dews, P. B. (1969). Studies on responding under fixed-interval schedules of reinforcement: The effects on the pattern of responding of changes in requirements at reinforcement. *Journal of the Experimental Analysis of Behavior*, **12**, 191-199.
- Dixon, W. J., & Brown, M. B. (1979). *BMDP biomedical computer programs*. Berkeley: University of California Press.
- Ferster, C. B., & Skinner, B. F. (1957). *Schedules of reinforcement*. New York: Appleton-Century-Crofts.
- Gonzalez, F. A., & Byrd, L. D. (1977). Mathematics underlying the rate-dependency hypothesis. *Science*, **195**, 546-550.
- Honig, W. K. (1965). Discrimination, generalization, and transfer on the basis of stimulus differences. In D. I. Mostofsky (Ed.), *Stimulus generalization* (pp. 218-254). Stanford, CA: Stanford University Press.
- Kerlinger, F. N., & Pedhazur, E. J. (1973). *Multiple regression in behavioral research*. New York: Holt, Rinehart and Winston.
- Ksir, C. (1981). Rate-convergent effects of drugs. In T. Thompson, P. B. Dews, & W. A. McKim (Eds.), *Advances in behavioral pharmacology* (Vol. 3, pp. 39-59). New York: Academic Press.
- Lanson, R. N., Eckerman, D. A., & Berryman, R. (1979). Effects of sodium pentobarbital on matching behavior in the pigeon. *Pharmacology, Biochemistry and Behavior*, **11**, 159-164.
- Latties, V. G. (1972). The modification of drug effects on behavior by external discriminative stimuli. *Journal of Pharmacology and Experimental Therapeutics*, **183**, 1-13.
- Latties, V. G., & Weiss, B. (1966). Influence of drugs on behavior controlled by internal and external stimuli. *Journal of Pharmacology and Experimental Therapeutics*, **152**, 388-396.
- Leander, J. D. (1981a). Drug effects on multiple and alternating mixed-schedule performance. *Journal of Pharmacology and Experimental Therapeutics*, **218**, 728-733.
- Leander, J. D. (1981b). Rate-dependence and the effects of phenothiazine antipsychotics in pigeons. In T. Thompson, P. B. Dews, & W. A. McKim (Eds.), *Advances in behavioral pharmacology* (Vol. 3, pp. 21-37). New York: Academic Press.
- Leander, J. D., & McMillan, D. E. (1974). Rate-dependent effects of drugs. I. Comparisons of *d*-amphetamine, pentobarbital and chlorpromazine on multiple and mixed schedules. *Journal of Pharmacology and Experimental Therapeutics*, **188**, 726-739.
- Marr, M. J. (1970). Effects of chlorpromazine in the pigeon under a second-order schedule of food presentation. *Journal of the Experimental Analysis of Behavior*, **13**, 291-299.
- Marr, M. J. (1979). Second-order schedules and the generation of unitary response sequences. In M. D. Zeiler & P. Harzem (Eds.), *Advances in analysis of behaviour: Vol. 1. Reinforcement and the organization of behaviour* (pp. 223-260). Chichester, England: Wiley.
- Marr, M. J., & Bradford, L. D. (1977). *A pharmacological analysis of large fixed-ratio performance*. Paper presented at the meeting of the American Psychological Association, San Francisco.
- McKearney, J. W. (1981). Rate dependency: Scope and limitations in the explanation and analysis of the behavioral effects of drugs. In T. Thompson, P. B. Dews, & W. A. McKim (Eds.), *Advances in behavioral pharmacology* (Vol. 3, pp. 91-109). New York: Academic Press.
- Mintz, D. E., Mourer, D. J., & Weinberg, L. S. (1966). Stimulus control in fixed ratio matching-to-sample. *Journal of the Experimental Analysis of Behavior*, **9**, 627-630.
- Nelson, T. D. (1978). Fixed-interval matching-to-sample: Intermatching time and intermatching error runs. *Journal of the Experimental Analysis of Behavior*, **29**, 105-113.
- Premack, D. (1978). On the abstractness of human concepts: Why it would be difficult to talk to a pigeon. In S. H. Hulse, H. Fowler, & W. K. Honig (Eds.), *Cognitive processes in animal behavior* (pp. 423-451). Hillsdale, NJ: Erlbaum.
- Sanger, D. J., & Blackman, D. E. (1976). Rate-dependent effects of drugs: A review of the literature. *Pharmacology, Biochemistry and Behavior*, **4**, 73-83.
- Seiden, L. S., & Dykstra, L. A. (1977). *Psychopharmacology: A biochemical and behavioral approach*. New York: Van Nostrand Reinhold.
- Sidman, M., Rauzin, R., Lazar, R., Cunningham, S., Tailby, W., & Carrigan, P. (1982). A search for symmetry in the conditional discrimination of rhesus monkeys, baboons, and children. *Journal of*

- the Experimental Analysis of Behavior*, 37, 23-44.
- Terrace, H. S. (1963). Errorless discrimination learning in the pigeon: Effects of chlorpromazine and imipramine. *Science*, 140, 318-319.
- Thomas, J. R. (1966). Differential effects of two phenothiazines on chain and tandem schedule performance. *Journal of Pharmacology and Experimental Therapeutics*, 152, 351-361.
- Thompson, D. M. (1973). Repeated acquisition as a behavioral baseline for studying drug effects. *Journal of Pharmacology and Experimental Therapeutics*, 184, 506-514.
- Thompson, D. M. (1974). Repeated acquisition of response sequences: Effects of *d*-amphetamine and chlorpromazine. *Pharmacology, Biochemistry and Behavior*, 2, 741-746.
- Thompson, D. M. (1976). Repeated acquisition of behavioral chains: Effects of methylphenidate and imipramine. *Pharmacology, Biochemistry and Behavior*, 4, 671-677.
- Urcuioli, P. J., & Honig, W. K. (1980). Control of choice in conditional discrimination by sample-specific behaviors. *Journal of Experimental Psychology: Animal Behavior Processes*, 6, 251-277.
- Vaillant, G. E. (1964). A comparison of chlorpromazine and imipramine on behavior of the pigeon. *Journal of Pharmacology and Experimental Therapeutics*, 146, 377-384.
- Waller, M. B. (1961). Effects of chronically administered chlorpromazine on multiple-schedule performance. *Journal of the Experimental Analysis of Behavior*, 4, 351-359.
- Weiss, B., & Gott, C. T. (1972). A microanalysis of drug effects on fixed-ratio performance in pigeons. *Journal of Pharmacology and Experimental Therapeutics*, 180, 189-202.
- West, K. B., Hernandez, L. L., & Appel, J. B. (1982). Drugs and visual perception: Effects of LSD, morphine and chlorpromazine on accuracy, bias and speed. *Psychopharmacology*, 76, 320-324.
- Wiltz, R. A., Jr., Boren, J. J., Moerschbaecher, J. M., Creed, T. L., & Schrot, J. F. (1974). Generalization gradients and combined-stimulus control after equal training with two related stimuli: II. Effects of "errorless" training. III. Effects of chlorpromazine. *Psychological Record*, 24, 449-468.
- Wright, A. A., & Sands, S. F. (1981). A model of detection and decision processes during matching to sample by pigeons. Performance with 88 different wavelengths in delayed and simultaneous matching tasks. *Journal of Experimental Psychology: Animal Behavior Processes*, 7, 191-216.
- Zentall, T. R., Edwards, C. A., Moore, B. S., & Hogan, D. E. (1981). Identity: The basis for both matching and oddity learning in pigeons. *Journal of Experimental Psychology: Animal Behavior Processes*, 7, 70-86.

Received March 12, 1984
Final acceptance May 16, 1985