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Differential Sensitivity of Operant Behaviors to Changes in the Concentration of a Sucrose Reinforcer: Effects of Pimozide

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VIGORITO, M., C. B. KRUSE AND J. C. CARRETTA. *Differential sensitivity of operant behaviors to changes in the concentration of a sucrose reinforcer: Effects of pimozide.* PHARMACOL BIOCHEM BEHAV **47**(3) 515–522, 1994.– The sensitivity of operant response rates to changes in a sucrose reinforcer was examined in well-trained animals maintained on a variable ratio (VR) or variable interval (VI) schedule (experiment 1). Although VR performance showed greater resistance to small reductions in the concentration of the sucrose reinforcer than VI performance, VR performance was more sensitive to large reductions in the sucrose concentration. Despite this differential sensitivity only the smallest dose of pimozide (0.125 mg/kg) differentially affected these behaviors by reducing VI rates without affecting VR rates. These and other results support the view that low doses of pimozide reduce the hedonic impact of the reinforcer. The results also indicate that the attenuation of operant responding by higher doses (0.25, 0.5, and 1.0 mg/kg) cannot be solely a result of the blunting of reward. Experiment 2 demonstrated that when rats drink in daily, brief one-bottle tests they show greater resistance to reductions in the sucrose concentration than when they lever-press for sucrose, and require a higher dose of pimozide (2.0 mg/kg) to attenuate consumption. Together the results of both experiments suggest that the greater the resistance to reductions in the reinforcement value, the greater the dose of pimozide necessary to attenuate performance. We discuss the importance of attaining a more complete understanding of the factors in control of operant performance in order to better assess the effects of neuroleptics on reward.

Reinforcement value Reward Pimozide Rat Operant responding Resistance to change Sucrose intake

IT has been argued that neuroleptic drugs suppress operant responding maintained by food reinforcers by attenuating the hedonic impact of the reinforcer (39,40). If this anhedonia hypothesis is correct, then one would expect to observe changes in operant responding following neuroleptic treatment that resemble changes in responding following reductions in the value of the reinforcer. Unequivocal support for the anhedonia hypothesis has been difficult to establish, for at least two reasons. First, neuroleptics have motor-impairing effects (12,13), so consequently it is difficult to establish whether neuroleptic-induced reductions in operant response rates are a result of motor-impairing or reward-attenuating effects. This anhedonia/motor-deficit debate has commanded considerable attention (2,3,10–12,15,16,18–20,24–28,34,36–40). To date, experimental support has been provided for both sides, but the debate has not been fully resolved.

Second, operant response rates are often insensitive to changes in the value of the reinforcer, particularly when simple schedules of reinforcement are used [see (5) for a review]. Interestingly, many studies that have examined the effects of neuroleptic drugs on food-rewarded behavior have utilized simple schedules of reinforcement (2,3,12,13,17,19,26,27, 34,39). However, investigators often do not examine the behavioral sensitivity of response rates to changes in the reinforcer, perhaps because operant response rates are simply assumed to be sensitive to such changes. An anhedonia

A preliminary report of this work was presented at the 1990 Eastern Psychological Association meeting in New York City.

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interpretation of neuroleptic action on operant performance is best made when the sensitivity of the behavior to changes in the reinforcement value is clearly established. Thus, the failure to directly test the sensitivity of operant response rates to changes in the value of the reinforcer is a problem prevalent in the literature [cf. (37)].

Several authors, having recognized the insensitive nature of operant response rates, have rejected response rate as an adequate measure of reward strength and have introduced other dependent variables [e.g., (13,15,20,38)]. This rejection of response rate as a measure of reward strength is strongly rooted in the tradition of the law of effect (30,32) where, because reinforcement is seen as a strengthening variable, response rate is expected to vary directly with the value of the reinforcer. Several contemporary explanations of instrumental performance, on the other hand, do not view operants as behaviors that strengthen with reinforcement, but as reflections of the reorganization of behavior (1,6,31,33). Thus, rather than reject response rate as a dependent variable we took advantage of the fact that operant response rates are not always sensitive to changes in the reinforcer. It would be instructive, for example, to examine the effects of neuroleptic drugs on operant behaviors that are differentially sensitive to changes in the value of the reinforcer.

Dickinson and colleagues (8,9) have shown that the sensitivity of operant response rates maintained by simple schedules to changes in the reinforcer depends on the schedule of reinforcement; under some conditions interval performance is less sensitive to reinforcer devaluation procedures than ratio performance. The first half of experiment 1 sought to determine if ratio and interval schedules of reinforcement produce operant response rates that are differentially sensitive to changes in the concentration of a sucrose reinforcer under conditions amenable to pharmacological investigations (i.e., repeated testing of well-trained animals in short daily sessions). Rats were trained to lever-press for a 16% sucrose solution under a variable ratio (VR) or variable interval (VI) schedule. During occasional probe sessions the sucrose concentration was changed and operant rates examined. After establishing the sensitivity of operant response rates to changes in the sucrose reinforcer, we examined the effect of pimozide on the response rates maintained by the ratio and interval schedules.

EXPERIMENT 1

Method

Animals. Eight experimentally naive adult female albino rats obtained from the Holtzman Company (Madison, WI) were used. The mean free-feeding body weight prior to the start of the experiment was 300 g (range: 296–313). After one week acclimation to the vivarium, the rats were placed on a food regimen to maintain them at 85% of their free-feeding body weights. Water was always available in their home cages. The animals were housed individually in a climatically controlled (21°C) vivarium kept under a 12-h light–dark schedule (light on at 0800).

Apparatus. Two identical two-lever Gerbrands operant chambers (Model G7322), each housed in a larger sound-attenuated chamber and equipped with ventilation fans, were used. The interior dimension of the chambers was 20 cm in width × 19 cm in height × 23 cm in length. The front and rear walls and grid floor were stainless steel. The side walls and ceiling were clear acrylic. In the center of the front stainless steel wall was a food receptacle where a dipper arm (Gerbrands model G5600) could deliver a cup containing 0.1 ml of a sucrose solution, which served as the reinforcer. Mounted on the left side of the front wall (2 cm left of the food receptacle) was a lever that was 6 cm wide and 9.5 cm above the floor of the chamber. The lever required a minimum force of 34 g for depression. The lever on the right side of the front wall was removed and the hole was covered with a stainless steel plate. Two cue lights above each of the levers were not used. Two small side-by-side pilot lights on the chamber ceiling were illuminated at the start of a lever-pressing session and were extinguished at the end of the session. Schedules of reinforcement and data collection were controlled by an IBM-XT computer. All programs were written in Turbobasic.

Procedure.

Experiment 1a. Lever-pressing sessions were conducted Monday through Saturdays. Lever-pressing sessions were not given on Sundays, but the animals were weighed and given their food rations. Standard shaping procedures were used to train the animals to lever-press for 16% sucrose solution reinforcement. Once shaping was complete the animals were given four consecutive sessions of continuous reinforcement (CRF). At the completion of CRF training the rats were divided into two groups. Four rats (group VR) were reinforced on a variable ratio schedule and the remaining four rats (group VI) were reinforced on a variable interval schedule. Lever-pressing sessions were 20 min throughout the experiment. The VR group was first placed on a VR 5 schedule and gradually increased to VR 15 over four days. The VI group began with a VI 20-s schedule and over four days was gradually increased to VI 60-s. VR 15 and VI 60-s were the final schedule values for the VR and VI groups, respectively. The reinforcement throughout the experiment was 16% sucrose except during probe sessions where the sucrose concentration was changed.

Four weeks of daily lever-pressing sessions were given so as to stabilize operant response rates. Beginning the fifth week, one or two probe sessions were administered each week. On probe sessions, the 16% sucrose solution was replaced with one of seven sucrose concentrations. The order of the sucrose concentrations, which was randomly determined, was 8%, 32%, 2%, 4%, 24%, 6%, and 28%. At least two consecutive baseline sessions with 16% sucrose reinforcement preceded every probe session. When all the concentrations of the sucrose reinforcer were presented, the same series of sucrose concentrations was repeated in the same order. At the completion of the second series an additional 0% sucrose (water) probe session was given.

Sucrose was prepared by weight (sugar/sugar + water) and was mixed at least 24 h before use from commercial-grade sugar and tap water.

Experiment 1b. Two weeks elapsed between the end of experiment 1a and the start of experiment 1b. During the two-week period the rats were subjected to their usual lever-pressing sessions with 16% sucrose reinforcement. The procedure of experiment 1b was the same as that described for experiment 1a except that during probe sessions the sucrose concentration was not changed (it remained 16%) and pimozide was administered prior to the lever-pressing session.

Drug. Pimozide (Sigma Chemical Co., St. Louis) was dissolved in a vehicle of lactic acid and Tween 80 (0.75 ml of 85% lactic acid + 20 ml of water + 1 ml of Tween 80). All injections were made in a volume of 1 ml/kg and administered IP 4 h before a session. The order of the doses was randomly determined for each rat, with a minimum of four drug-free days between tests. The test doses were 0.0, 0.125, 0.25, 0.5,

and 1.0 mg/kg. The vehicle was used for the 0.0-mg/kg dose.

Statistical analysis. The data were analyzed using two-way mixed design analyses of variance (ANOVAs) and one-way repeated-measures ANOVAs. Where appropriate the two-way ANOVAs were supplemented by tests of simple main effects. Post hoc comparisons were made with Newman-Keuls tests.

Results

Experiment 1a. Operant response rates, although quite stable from day to day, can drift, particularly if subjects are tested for extended periods of time as in the present study. Therefore, baseline response rates were examined. Mean baseline response rates for each probe session (probe baselines) in which the sucrose concentration was changed were calculated by averaging lever-presses during the two sessions prior to a probe session. The baseline data for each group were subjected to separate Test Series (2) × Probe Baselines (7) within-subject ANOVAs. For the VI group the mean baseline response rates significantly increased from the first test series (M = 236.29, SE = 26.91) to the second test series (M = 360.36, SE = 13.76), $F(1, 39) = 29.22, p < .05$. Mean baseline lever-presses for group VR in the first series (M = 1906.31, SE = 67.67) and second series (M = 1975.79, SE = 52.69) did not differ, $F(1, 39) = 3.17, p > 0.05$. The main effect of probe baselines was not significant for either schedule ($ps > .05$).

Because of the group differences in baseline lever-pressing the number of lever presses during each probe session was expressed as the percent of mean lever presses during the two previous baseline sessions. Thus, scores below or above 100% indicate that lever presses were lower or higher, respectively, than the lever presses maintained by 16% sucrose. The effects of changing sucrose concentration on operant lever-pressing did not differ between the two series for the VR group, main effect of series, $F(1, 39) < 1, p > 0.05$; interaction, $F(6, 39) = 1.19, p > 0.05$, or the VI group, main effect of series, $F(1, 39) = 3.47, p > 0.05$; interaction, $F(6, 39) < 1.0, p > 0.05$; thus the data from the two series were averaged for further analysis.

Figure 1 shows operant response rates for both groups as a function of sucrose concentration, expressed as the percent of the 16% sucrose baseline. The two groups were differentially sensitive to the changes in the sucrose reinforcer: Schedule × Sucrose Concentration interaction, $F(7, 42) = 4.37, p < .01$. Responding decreased with decreasing (below 16%) sucrose concentrations in both groups. However, significant differences in lever-pressing between the VR and VI groups were found at the 0%, 2%, and 6% sucrose concentrations. A significant reduction in responding was observed in the VI group when the sucrose concentration was diluted to 6%, but the VR group required a dilution to 4% sucrose before reduced response rates were observed. However, the VR rats were more sensitive to the largest reductions in sucrose concentration (0% and 2%) than the VI rats. This comparison indicates that the VR animals were more resistant to small changes in the reinforcer than were the VI animals, but once this initial resistance yielded, the VR rats were more sensitive to the largest reductions in reinforcer value than were the VI rats. The two groups were also differentially sensitive to increases in the sucrose concentration. The VR animals, but not the VI animals, showed a reduction in responding at the 24% and 32% sucrose concentrations.

Figure 2 presents the number of reinforcers that were earned by both groups during probe sessions. In the VI group, although operant response rates decreased at the three lowest concentrations (as seen in Fig. 1), there were no significant losses in the number of earned reinforcers; responding was distributed throughout the test sessions such that most of the available reinforcers were obtained. With ratio schedules, unlike interval schedules, there is a linear relationship between response rate and reinforcement rate. Thus, in the VR group the number of reinforcers per probe session decreased with decreasing sucrose concentration. This description of the results was corroborated by a Schedule (2) × Sucrose Concen-

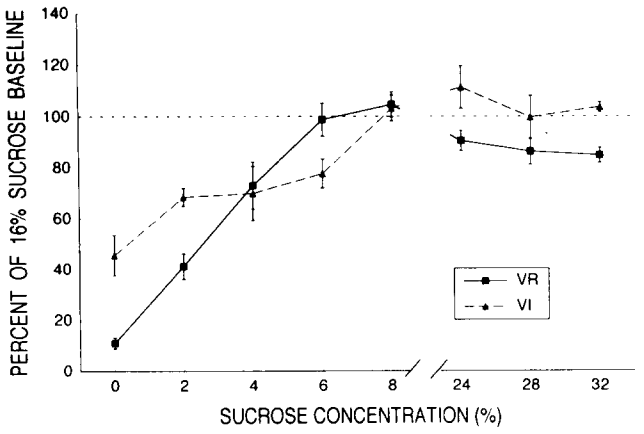

FIG. 1. Mean lever-press response rates during probe sessions expressed as the percent of 16% sucrose baseline. During probe sessions the 16% sucrose solution was replaced with one of eight sucrose concentrations.

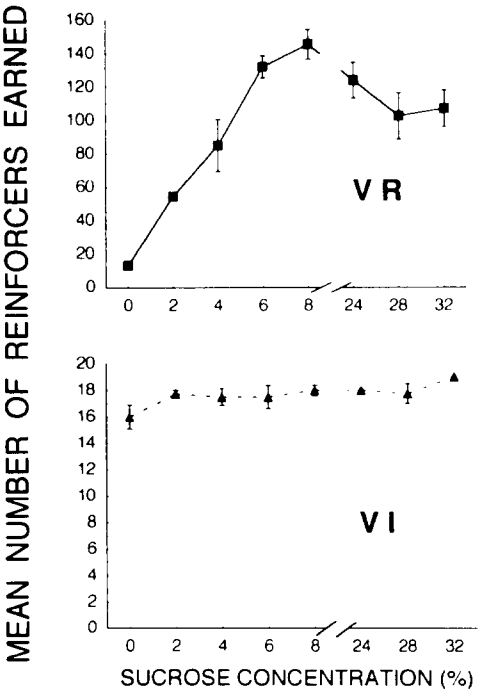

FIG. 2. Mean number of earned reinforcers during probe sessions in experiment 1a. During probe sessions the 16% sucrose solution was replaced with one of eight sucrose concentrations.

tration (8) mixed ANOVA on the number of reinforcers that were earned, which yielded a significant interaction, $F(7, 42) = 22.16, p < .01$.

Experiment 1b. Figure 3 shows that pimozide dose-dependently reduced lever-press responding in both groups. A Schedule (2) × Dose (5) mixed-design ANOVA on the data yielded a significant main effect of dose, $F(4, 24) = 50.48$, $p < .001$, and a nonsignificant main effect of schedule, $F(1, 6) < 1$, $p > 0.05$. The lowest dose (0.125 mg/kg) reduced responding in the VI rats but not the VR rats, whereas the highest doses attenuated lever-press response rates in both groups. However, the Schedule × Dose interaction failed to be significant, $F(4, 24) = 1.99$, $p > 0.05$. Inspection of the individual animals' data indicated that three out of the four VI rats responded less than 80% of their 16% sucrose baseline on the 0.125-mg/kg dose test day, whereas all four VR rats responded greater than 90% of baseline. One-way repeated-measures ANOVAs and post hoc tests calculated for each group separately indicated that all doses reduced responding in the VI group; however, all except the lowest dose attenuated responding in the VR group: VI group, $F(4, 12) = 21.4$, $p < .001$; VR group, $F(4, 12) = 30.7, p < .001$.

The effect of pimozide on the number of reinforcers that were earned by both groups is shown in Fig. 4. A Schedule (2) × Dose (5) mixed ANOVA on the data yielded a significant interaction, $F(4, 24) = 26.86$, $p < .001$. The interaction reflected the fact that the VR group earned more reinforcers than the VI group at the lowest three doses only. For the VI group, the 0.5- and 1.0-mg/kg doses reduced the number of earned reinforcers. This drug-induced reduction in earned reinforcers in the VI group is unlike the effect of the lowest sucrose concentrations (experiment 1A) which reduced lever-presses but did not affect the number of reinforcers that were earned. However, the 0.125- and 0.25-mg/kg doses reduced response rates (see Fig. 3), but did not significantly reduce the number of earned reinforcers (Fig. 4). This pattern of effects by low doses of pimozide is similar to the effects observed when reducing the concentration of sucrose (experiment 1a). The number of reinforcers earned per session by the VR group decreased at the three highest doses. Newman-Keuls tests yielded significant differences between all contrasts except between the 0- and 0.125-mg/kg doses and between the 0.5- and 1.0-mg/kg doses.

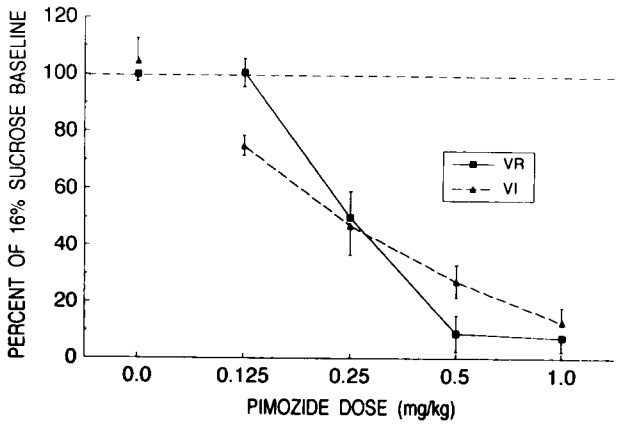

FIG. 3. Effect of pimozide on the number of lever-presses in experiment 1b expressed as the percent of 16% sucrose baseline. The sucrose concentration during test sessions was 16%. Pimozide was administered 4 h before the start of a session.

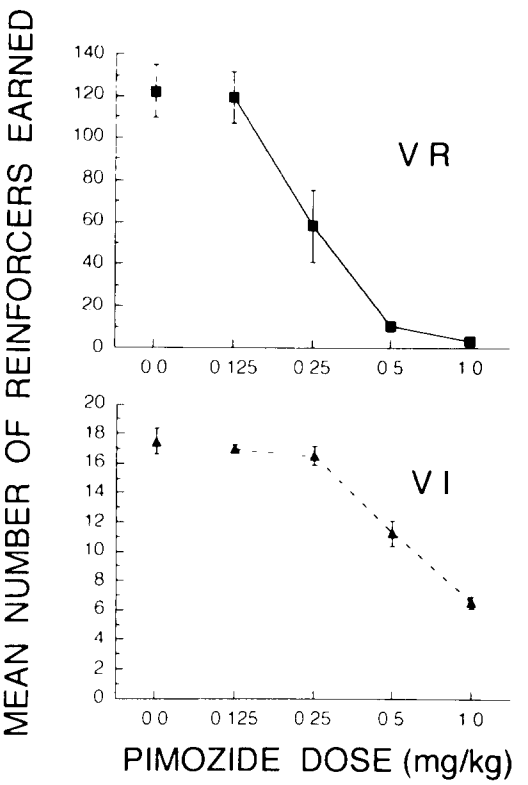

FIG. 4. Effect of pimozide on the number of earned reinforcers during probe sessions in experiment 1b. The sucrose concentration during test sessions was 16%. Pimozide was administered 4 h before the start of a session.

Discussion

The sensitivity of operant lever-pressing maintained by simple schedules of reinforcement to changes in the reinforcer value depends on the schedule of reinforcement. The VR animals required a larger reduction in the reinforcer value (to 4% sucrose) than did the VI animals (to 6% sucrose) before attenuated response rates were observed. Thus, the VR schedule produced operant response rates that showed greater resistance to small changes in the reinforcer than the response rates produced by the VI schedule. On the other hand, the largest dilutions of sucrose produced more pronounced attenuation of response rates in the VR rats than in the VI rats. This differential sensitivity of operant response rates at the low end of the behavior-sucrose concentration function indicates that VR rates are a more reliable quantitative measure of the hedonic strength of the reinforcer than VI rates. Similar differences in resistance to change between VR and VI schedules have been replicated in this laboratory (36).

If pimozide attenuates the hedonic impact of reinforcers, then one would expect differential effects of pimozide on behaviors differentially sensitive to reductions in reinforcer value. Because the VR response rates showed greater change (greater overall sensitivity) with decreasing sucrose concentrations than did the VI response rates, pimozide should have had greater rate-reducing effects on VR performance than on VI performance. Yet, the highest doses (0.5 and 1.0 mg/kg)

had similar rate-reducing effects on both schedules, suggesting that pimozide's primary mechanism is not through a reduction in the hedonic impact of the reinforcer. However, the hypothesis that pimozide attenuates reward value cannot be entirely dismissed. At the lowest dose (0.125 mg/kg) pimozide attenuated VI rates but not VR rates. Because VR rates showed a greater resistance to small changes in the sucrose reward than VI rates, this result is consistent with the hypothesis that low doses of pimozide reduce the rewarding impact of sucrose solutions.

A reward-attenuating effect of pimozide is also suggested by the similarities seen when comparing effects of low doses of pimozide (experiment 1b) with reinforcer dilution (experiment 1a) on VI performance. In both cases there was a significant reduction in responding with little effect on number of reinforcers that were earned. (A similar comparison with the VR animals is not useful, since VR response rates are directly proportional to number of reinforcers that are earned.) The highest doses had a more profound attenuating effect on the number of earned reinforcers within a session than did the effects of reducing the concentration of the reinforcer. Similar intrasession declines in performance following pimozide treatment have been observed elsewhere [e.g., (3)].

Neither group showed augmented lever-press responding when sucrose values greater than the 16% were provided. An *attenuation* of responding was observed with the VR schedule, which may reflect postingestive satiating effects of sucrose consumption (29). Augmented responding in VR animals following increases in the sucrose concentration may have been precluded by ceiling effects, since the animals were lever-pressing at very high rates. The failure to observe augmented responding in the VI animals, however, is unlikely to be due to a motoric ceiling effect or to satiating effects of the sucrose. The VI rate of responding was approximately 15% of the VR rate of responding. Satiating effects of the sucrose provide an unlikely explanation as well, since the VI animals consumed less than 2 ml of sucrose per session. Phillips and colleagues (25,26) recently reported that very sweet rewards reduce operant response rates under conditions that could not be explained by postingestive satiety or by any aversive effects of the intense rewards. The failure of VI rates to change with increasing sucrose concentration in the present experiment, however, suggests that the rate-reducing effects of intense rewards do not always occur.

EXPERIMENT 2

The analysis of pimozide effects on operant behaviors differentially sensitive to changes in reinforcer value confirms previous findings that high doses of neuroleptics reduce operant performance through effects other than the reduction of the hedonic impact of the food reinforcer (12,13,18,34). However, the results of experiment 1 also suggest that low doses of pimozide decrease some aspect of reward that is reflected in a measure of resistance to change. Evidence of the reward-attenuating effects of neuroleptics is also provided by studies of dopamine antagonist drugs on consumption of palatable solutions [e.g., (14,21,25,37,41)]. Generally, lower doses of neuroleptics are necessary to reduce operant lever-pressing maintained by reinforcers than are needed to reduce consumption of the same reinforcing stimulus (12,17,34). The differential effects of drugs on various reward-motivated behaviors have been attributed to differences in the difficulty of the tasks (35), differences in the "preparedness" of the behaviors (19), or differences in the central nervous system (CNS) mechanism mediating the behaviors (17). Another possibility is that operant and consummatory behaviors may differ in their resistance to change. Behaviors that are more resistant to changes in the value of the reinforcing stimulus that are maintaining the behaviors may require higher doses of neuroleptics to attenuate performance. In experiment 2 we tested the rats from experiment 1 on a brief consummatory task so that the sucrose concentration function obtained with lever-pressing in experiment 1 could be compared with sucrose concentration function obtained with a brief consummatory behavior. The overall procedure was the same as experiment 1 except that rats consumed sucrose in daily 6-min sessions rather than by lever-pressing for sucrose reward. The effects of pimozide on this brief consumatory behavior were also examined.

Method

Subjects. Six animals from experiment 1 served as subjects. Four were from the VR group and two were from the VI group. The housing and general maintenance conditions remained unchanged.

Apparatus. Rats were trained and tested in a room adjacent to the animal vivarium. Six wire mesh cages identical to the home cages were mounted side by side on a wood frame. Sucrose solutions were provided in graduated cylinders through stainless steel drinking tubes. Prior to testing, the drinking tubes were mounted on a large wood carrier in front of the cages. The carrier was designed so that up to two drinking tubes could be mounted per cage. To start a session the carrier was manually moved into position such that the drinking tubes were easily accessible to the animals. At the end of a session the carrier was manually retracted. Sucrose consumption was measured to the nearest 0.5 ml.

Procedure. The animals were adapted to drink a 16% sucrose solution (by weight) from one drinking tube during brief daily sessions. All sessions were 6 min in duration and occurred seven days a week. The side on which the solution was offered was alternated each session. Once a stable baseline was achieved (approximately two weeks), probe sessions were introduced. During probe sessions the 16% sucrose solution was replaced with one of seven sucrose concentrations (0%, 2%, 4%, 6%, 8%, 24%, and 32%). The sucrose concentrations were presented in random order, with at least three days between probe sessions. Following testing with all seven sucrose concentrations, the animals were tested with five doses of pimozide (0.0, 0.25, 0.5, 1.0, and 2.0 mg/kg). The procedure was the same as before except that during probe sessions the sucrose concentration was not changed (it remained 16%) and pimozide was administered (IP) 4 h prior to the session.

Results

The amount of sucrose solution consumed during each probe session was expressed as the percent of mean intakes during the two previous baseline sessions. Thus, scores below or above 100% indicate that intakes during probe sessions were lower or higher, respectively, than intakes maintained by 16% sucrose. The effects of sucrose concentration on intake are shown in Fig. 5. Analyses of the data yielded a significant effect of sucrose concentration, $F(6, 30) = 34.81$, $p < 0.05$. The rats showed large reductions in intake when consuming 2% sucrose solutions and even larger reductions when drinking water (0% sucrose). Intakes of the 4%, 6%, and 8% sucrose solutions were similar to intakes seen during the daily 16% sucrose solution presentations. Sucrose intake decreased

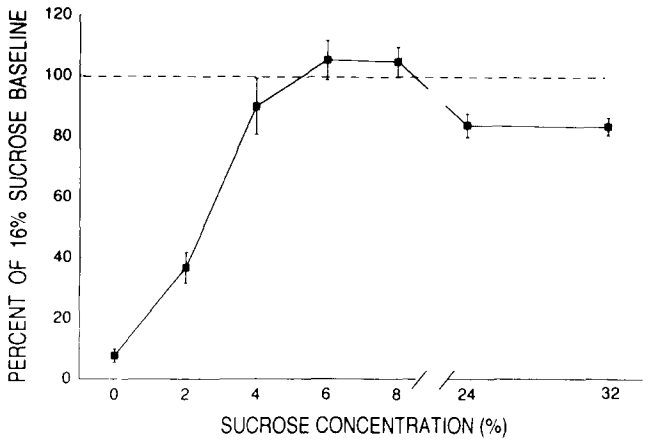

FIG. 5. Brief (6-min) intakes during probe sessions in experiment 2 expressed as the percent of 16% sucrose intake. During probe sessions the 16% sucrose solution was replaced with one of seven sucrose concentrations.

slightly at concentrations higher than 16%, but these intakes did not differ significantly from intakes on the 4%, 6%, and 8% sucrose concentration test days (*p*s > .05).

As illustrated in Fig. 6, pimozide dose-dependently reduced intake of 16% sucrose intake, $F(4, 20) = 4.39$, $p < 0.05$. Intake following 2.0-mg/kg treatment with pimozide was significantly lower than intakes following 0.0- and 0.25-mg/kg doses; all other comparisons were not significant.

Discussion

The findings of this experiment indicate that when rats are trained to drink a 16% sucrose solution in brief, daily sessions, intakes drop significantly when the sucrose concentration is diluted to 2% or less. Thus, a larger reduction in reinforcer value was necessary to attenuate performance (intakes) in the brief consumption task than in the VR (4% sucrose) or the VI (6% sucrose) operant tasks. Moreover, the sucrose concentration-intake function had an all-or-none property. That is, intakes resisted change following reductions in sucrose concentration, but once intakes dropped they did so precipitously. That intakes did not differ with 4% and higher sucrose concentrations does not suggest that these sucrose values were of equal hedonic strength. It is well known that one-bottle tests are not reliable measures of the hedonic strength of sucrose solutions (29). For example, a rat may consume more of a 8% sucrose solution than 32% sucrose solution in a one-bottle test, but when given a choice between these two solutions (two-bottle test), the 32% sucrose is typically preferred. Although one-bottle tests may be inappropriate for determining the relative hedonic strength of sucrose solutions, they may be a useful measure of the resistance to changes in the concentration of a sucrose solution.

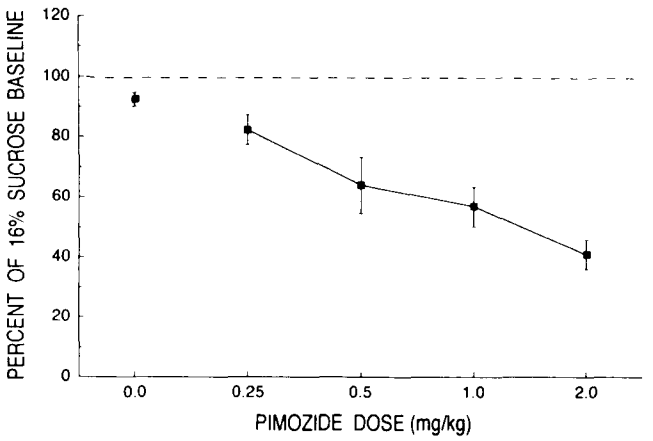

FIG. 6. Effect of pimozide on brief (6-min) intakes in experiment 2 expressed as the percent of 16% sucrose baseline. The sucrose concentration during test sessions was 16%. Pimozide was administered 4 h before the start of a session.

The attenuating effects of pimozide on brief intakes were similar to the effects reported in the literature [e.g., (41)]. The reductions in intake were not as large as the reductions seen in operant performance, even though the largest dose used in the brief consumption task (2.0 mg/kg) was twice the largest dose administered during the operant tasks (1.0 mg/kg). These results, and the results of experiment 1, suggest that larger doses of pimozide may be necessary to reduce short-term consummatory behavior than are necessary to attenuate operant behavior because the former is more resistant to change than the latter. Resistance to change differed for each of the behaviors examined such that short-term intake > VR > VI. The lowest dose of pimozide necessary to significantly attenuate performance of each of the behaviors was similarly ordered.

GENERAL DISCUSSION

The present experiments indicate that the reward-motivated behaviors of well-trained animals can differ in their sensitivity to changes in the reinforcer value. In experiment 1, VR performance was more resistant to small reductions in the sucrose concentration than was VI performance. The result obtained with the lowest dose of pimozide was consistent with a reward-attenuating effect of the drug—the lowest dose reduced VI rates but not VR rates. Moreover, consummatory behavior (experiment 2) was even more resistant to change and required a higher dose for its attenuation. However, when comparing VR and VI rates on the decreasing limb of the sucrose concentration function, VI performance was more resistant to change (less sensitive to reinforcer reductions) than VR performance. The failure of the highest doses to have differential effects on VR and VI performance suggests that pimozide-induced attenuation of lever-pressing was not due solely to the reduction of the hedonic impact of the reinforcer. These results and others (26,36) underscore the importance of determining the sensitivity of the target behavior to changes in value of the reinforcer before interpreting drug-induced changes in responding as reflecting changes in the hedonic impact of the reinforcer.

What accounts for the differential sensitivity of VR and VI performance to small and large reductions in the value of a reinforcer? Recent research suggests that the associative control of operant performance is more complex than previously assumed [e.g., (7,9)]. Differential sensitivity of responding, therefore, may result when different factors control performance in different schedules of reinforcement. For example, Dickinson (8) noted that VR performance is likely to become autonomous of the reinforcer value when rats receive extensive training, as was done in the present study. Thus, high rates of VR responding may establish a behavioral mo-

mentum or habit that requires large reductions in the reinforcement value to disrupt performance. Dickinson (8) suggested that this behavioral momentum may result from the nature of the response-reinforcer contingency. With ratio schedules, but not interval schedules, there is a linear relationship between response rate and reinforcement rate. Thus, VR schedules generate high rates of responding and high rates of reinforcer delivery. Note that the brief intake task of experiment 2 is similar to a ratio schedule (FR 1) because there is also a linear relationship between responding (licking) and reinforcement rate (sucrose intake).

Once the initial resistance to change was "broken" and response rates dropped as sucrose concentration was diluted further, the VR schedule and brief consumption task yielded steeper functions than did the VI schedule. The relative insensitivity of VI rates to large reductions in reinforcement value may be mediated by Pavlovian associations, established during training, between contextual stimuli and the sucrose reinforcer (9,22,23). There is considerable evidence that Pavlovian incentive processes can have motivational control over instrumental performance (7,9). Moreover, Nevin and colleagues (22,23) showed that rate of responding during reinforced performance is controlled by the operant contingency, whereas resistance to change of that rate is under Pavlovian control. If differential contextual control was a critical factor in experiment 1, then it would appear that the context was maintaining VI performance more than VR performance in tests of resistance to change. Nevertheless, the arousing effects of contextual stimuli may be more apparent in tests where the value of the training reinforcer is sufficiently reduced, rather than during reinforced responding where the operant contingencies are in control of behavior.

These suggestions are primarily speculative. However, it is clear that a better understanding of the factors that control operant performance in training and in test would be beneficial for the pharmacological study of reward. The unequivocal demonstration of differential control of performance in training and in test would yield some interesting interpretations of the neuroleptic effects on reward. For example, Feldon and Weiner (11) recently showed that neuroleptics accelerated extinction without affecting the behavioral impact of reinforcement in acquisition. The authors interpreted this result to be a neuroleptic action on nonreward rather than on reward. However, because extinction is a special case of change, this result is consistent with the view that neuroleptics attenuate a reward or incentive/activational process (28) that is modulating performance in tests of resistance to change. Neuroleptics are known to disrupt responses elicited by conditioned stimuli that had been paired with the delivery of appetitive stimuli at doses that do not impair the consummatory response itself (4). Thus, low doses of neuroleptics would be expected to disrupt performance during extinction (where conditioned incentive stimuli are modulating performance) more than during training (where the operant contingency is controlling performance). Such an interpretation would be consonant with the numerous reports indicating that neuroleptics produce more rapid extinction and with the observation that neuroleptics have a more pronounced effect when given during extinction than when administered in training (11,18,24,34).

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