CONCURRENT PHENCYCLIDINE AND SACCHARIN ACCESS: PRESENTATION OF AN ALTERNATIVE REINFORCER REDUCES DRUG INTAKE

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Six monkeys self-administered orally delivered phencyclidine ("angel dust") and saccharin under concurrent fixed-ratio 16 schedules during daily three-hour sessions. Liquid deliveries were contingent upon lip-contact responses on solenoid-operated drinking spouts. Three saccharin concentrations (0.003%, 0.03% and 0.3%, wt/vol) were tested in a nonsystematic order. For each saccharin concentration, the following series of phencyclidine concentrations (mg/ml) was presented: 0.25, 0.5, 1, 0.25 (retest), 0.125, 0.0625, 0.0312, 0.25 (retest) and 0 (water with stimuli signaling phencyclidine). As the saccharin concentration increased, the number of drug deliveries decreased, and the peaks of the concentration-response functions were shifted to the right. The lowest saccharin concentration (0.003%, wt/vol) maintained responding in excess of phencyclidine levels in only one monkey. The two higher saccharin concentrations maintained behavior far in excess of phencyclidine, but saccharin deliveries decreased in some monkeys as phencyclidine concentration and intake (mg/kg) increased. The time course and patterns of phencyclidine-reinforced responding were also altered when saccharin was concurrently available. The results are discussed in terms of strategies to reduce drug-reinforced behavior, preference between different reinforcers, and measures of reinforcing efficacy.

Key words: phencyclidine, saccharin, reinforcing efficacy, suppression of drug-reinforced behavior, oral drug self-administration, concurrent fixed-ratio schedules, lip-contact response, rhesus monkeys

Concurrent schedules have been used extensively for assessing response-strengthening effects of reinforcer magnitudes (Brownstein, 1971; Catania, 1963, 1966; Herrnstein, 1970; Rachlin & Baum, 1969). A majority of the work has been conducted with nutritive reinforcers and interval schedules. Concurrent schedules have also been used to study choice between intravenously delivered drugs (Johanson, 1975; Johanson & Schuster, 1975) and drug doses

(Iglauer & Woods, 1974; Johanson, 1975; Johanson & Schuster, 1975). Drugs and water are often presented concurrently to demonstrate that orally delivered drugs are functioning as reinforcers (Carroll & Meisch, 1979; Myers & Veale, 1972; Roehrs & Samson, 1981). Other than the concurrent drug and water studies, there have been relatively few comparisons of responding maintained by concurrently available drug and nondrug reinforcers across a range of reinforcer magnitudes. Previous research showed that ethanol-reinforced responding in the rat decreased with increasing concentrations of a sucrose solution (Lester & Greenberg, 1952; Samson & Falk, 1974; Samson, Roehrs, & Tolliver, 1982). The present research extended the generality of these findings to a noncaloric drug (phencyclidine) presented along with an alternative noncaloric substance (saccharin).

A practical purpose for testing a concurrent schedule of phencyclidine and saccharin access in the present experiment was to de-

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termine whether an additional reinforcing substance would compete with the drug and effectively reduce drug-reinforced behavior. A primary focus of research in behavioral pharmacology has been to identify behavioral and pharmacological variables that establish and maintain drug-reinforced behavior (see reviews by Griffiths, Bigelow, & Henningfield, 1980; Johanson, 1978; Johanson & Schuster, 1981). Only a few studies have been concerned with the suppression of drug-reinforced behavior (cf. Johanson & Schuster, 1981). Most of the methods for reducing drug-reinforced behavior have employed a form of punishment, defined as a reduction in responding maintained either by presentation of a stimulus or removal of a stimulus (Azrin & Holz, 1966). A goal of the present study was to reduce drug intake without applying a punishment contingency.

In previous experiments with animals, reducing drug intake has been accomplished by the presentation of electric shock contingent upon a response that was being maintained by intravenous self-administration of amphetamine, morphine (Smith & Davis, 1974), or cocaine (Bergman & Johanson, 1981; Grove & Schuster, 1974; Johanson, 1977), or by oral ethanol self-administration (Poling & Thompson, 1977a). The amount of reduction in drug intake was a function of the intensity and frequency of shock, and in some cases, reduced drug intake persisted when the punishment contingency was removed (Poling & Thompson, 1977c; Smith & Davis, 1974). Punishment of drug-reinforced behavior has also been accomplished by removing the availability of a positive reinforcer contingent upon drug-reinforced behavior. One method of suppressing drug-reinforced behavior has been to delay food availability as a consequence of drug-maintained responding (Poling & Thompson, 1977b, 1977c). The amount of drug intake was suppressed depending upon the length of the delay and the drug concentration.

In an experiment with human subjects, it was shown that electric shock decreased alcohol consumption; however, responding

returned when the punishment contingency was removed (Wilson, Leaf, & Nathan, 1975). Other clinical experiments have demonstrated that loss of access to reinforcing stimuli as a consequence of drug self-administration (Bigelow, Griffiths, & Liebson, 1975; Griffiths, Bigelow, & Liebson, 1974) or presentation of nondrug reinforcers as incentives contingent upon the absence of drug taking (Boudin, 1972; Cohen, Liebson, & Faillace, 1971; Hunt & Azrin, 1973; Rosen & Lichtenstein, 1977; Stitzer, Bigelow, & Liebson, 1979) can effectively reduce or eliminate drug-reinforced behavior.

In the present experiment phencyclidine and saccharin were available under concurrent (independently operating) fixed-ratio (FR) schedules; thus, a punishment contingency was not in effect. Both phencyclidine (Carroll, 1982b) and saccharin (Carroll, 1982c) have been shown to function as highly effective reinforcers for rhesus monkeys. Phencyclidine (PCP, "angel dust") was developed in the 1950s by the Parke-Davis Company as a dissociative anesthetic. Although it held great promise as an anesthetic, it was removed from clinical trials in 1965 due to dysphoric emergence phenomena. The drug was subsequently available for veterinary use, but due to its high rate of illicit use in the late 1970s, it is no longer commercially produced. There is still considerable phencyclidine abuse among a young adult population due to its ease of synthesis and low cost. Phencyclidine has a slightly bitter taste, but its taste properties have been shown to contribute to its reinforcing effectiveness (Carroll, 1982a).

An additional objective of the present research was to determine whether concurrent presentation of a fixed concentration of saccharin would serve as a standard for comparing the relative reinforcing efficacy of different phencyclidine concentrations. The relative decrease in phencyclidine deliveries as a function of concentration when concurrent saccharin was present compared to when concurrent water was present would serve as a measure of reinforcing efficacy,

and the results could be compared to those obtained using other measures.

METHOD

Subjects

Six adult male rhesus monkeys (*Macaca mulatta*) whose free-feeding weights ranged from 8.3 to 13.3 kg served as subjects. Four of the monkeys (M-B2, M-G2, M-M, and M-P1) were experimentally naive prior to their introduction to concurrent phencyclidine and water. Monkey M-B had previous experience with oral self-administration of the potent opioid, etonitazene (Carroll & Meisch, 1978), and M-G2 had intravenously self-administered a variety of drugs, including phencyclidine, in another laboratory. Throughout the experiment, each monkey was maintained at 85% of its free-feeding body weight by restricting access to food (Purina High Protein Monkey Chow, #5045). The monkeys were housed individually in their experimental chambers in a room maintained at 24 °C, with a 12-hr light/dark cycle.

Apparatus

The experimental chambers were stainless-steel Hoeltge (No. HB-108) primate cages, equipped with a work panel on one wall. The work panel contained two brass drinking spouts 2.7 cm long and 1.2 cm in diameter, spaced 30 cm from each other, and stimulus lights that signaled experimental events. Lip-contact responses operated a solenoid for approximately 120 ms and released 0.55 ml of liquid from the spout. When a drug solution was available from a spout, two small green lights (mounted directly behind a Plexiglas plate supporting the spout) were illuminated for the duration of each lip contact. Similarly, when water or saccharin was available from a spout, two small white lights were illuminated for the duration of each lip contact. Larger green lights above the drinking spouts were illuminated when water was present during sessions and intersession periods, and yellow lights were illuminated to indicate saccharin

availability. The large green light above the drinking device blinked (10 Hz) during the session signaling availability of the drug solution. Liquids were contained in covered stainless-steel reservoirs, and there was no measurable evaporation. Experimental sessions were automatically controlled, and data were recorded and printed by microcomputers (Micro Interfaces) located in an adjacent room. Lip-contact responses and liquid deliveries were also recorded on cumulative recorders (Gerbrands). Complete details of the control and recording equipment, drinking devices, and experimental chambers have been described elsewhere (Carroll, Santi, & Rudell, 1981; Henningfield & Meisch, 1976; Meisch & Henningfield, 1977, respectively).

Phencyclidine HCl was provided by the National Institute on Drug Abuse (Research Triangle Institute: Research Triangle Park, NC). Saccharin was obtained from Sigma Chemical Co. (St. Louis, MO). Concentrations refer to the salt. Solutions were prepared in tap water 20 hr before use, and liquids were presented at room temperature.

Procedure

Prior to this experiment, the monkeys had been trained to self-administer phencyclidine and water under concurrent FR-16 schedules during daily 3-hr sessions according to methods previously described (Carroll, 1982b, Carroll & Stotz, 1984). Concurrent phencyclidine- and water-reinforced behavior has already been studied across a wide range of drug concentrations with these six monkeys (Carroll & Stotz, 1984); thus, data from the earlier study were included in this experiment.

In the present experiment, three saccharin concentrations (0.003%, 0.03%, and 0.3%, wt/vol) were presented in a nonsystematic order with concurrent phencyclidine. Each liquid was available under an independently operating FR-16 schedule. No changeover delays (to prevent responding on one drinking device from coming under partial control of the reinforcement schedule on the other) were programmed. Schedule changeovers

occur infrequently with concurrent FR schedules, and if they occur, it is usually after reinforcement (Catania, 1966). The independence of responding under the FR schedules was confirmed in the present study by examination of the cumulative response records. For each saccharin concentration, six phencyclidine concentrations and water were tested in the following order: 0.25, 0.5, 1, 0.25 (retest), 0.125, 0.0625, 0.0312, 0.25 (retest) and 0 (water with stimuli signaling phencyclidine) mg/ml. A retest was also conducted at the end of this series with concurrent phencyclidine (0.25 mg/ml) and water. Each phencyclidine concentration was presented until at least five sessions of stable behavior were obtained. Stability was defined as no steadily increasing or decreasing trend in the number of liquid deliveries and no consistent change in the pattern of responding over a five-session interval.

Experimental sessions took place daily (7 days per week) from 9:00 a.m. to 12:00 p.m. for M-M and M-B, and from 10:00 a.m. to 1:00 p.m. for the other monkeys. Each 3-hr session was preceded and followed by a 1-hr timeout when solutions were changed and data were recorded. The daily food allotment was provided immediately after the session, and water was freely available throughout the 19-hr intersession period. Stimulus lights were not illuminated during the timeouts, and behavior had no programmed consequences. The side positions of phencyclidine and water had been alternated daily in the previous study (Carroll & Stotz, 1984); phencyclidine and saccharin sides remained fixed throughout this experiment to avoid contamination of water and phencyclidine solutions with the potent taste of saccharin. In a previous experiment, the saccharin side was alternated every 21 days, and no changes in responding due to side preference were reported (Carroll, 1982c). Furthermore, the earlier study of concurrent phencyclidine and water self-administration with these six rhesus monkeys revealed no side preferences (Carroll & Stotz, 1984).

RESULTS

Figure 1 shows the mean number of phencyclidine and saccharin deliveries and drug intake as a function of concentration. Phencyclidine deliveries as a function of concentration are described by an inverted U-shaped function, and phencyclidine intake (mg/kg) increased as a function of concentration. As the saccharin concentration increased, the phencyclidine concentration-response functions were lower and the peaks were shifted to the right. Drug intake (mg/kg) was markedly suppressed at the lower phencyclidine concentrations when the two higher saccharin concentrations were concurrently available, but there was little or no change in drug intake at the high drug concentrations. Changes in phencyclidine or saccharin concentrations were accompanied by rapid changes in the rates and patterns of responding. Phencyclidine- and saccharin-reinforced responding usually stabilized within 5 to 10 sessions after the change in concentration.

At the higher saccharin concentrations, saccharin deliveries generally decreased in four of the six monkeys as phencyclidine concentration increased. Thus, saccharin intake (mg/kg) formed an inverse relationship to phencyclidine intake (mg/kg). The lowest saccharin concentration (0.003%, wt/vol) did not maintain responding in excess of phencyclidine levels except in one monkey (M-B2). At the other two saccharin concentrations (0.03% and 0.3%, wt/vol), saccharin-maintained responding was at least 10 times higher than phencyclidine-maintained responding. Almost no liquid deliveries were obtained when water replaced phencyclidine, even though the stimulus signaling phencyclidine (blinking light) was present.

Table 1 also shows that phencyclidine deliveries were lower at higher saccharin concentrations. In Figure 1 the value shown for 0.25 mg/ml phencyclidine represents the first time that concentration was given (for each saccharin concentration). Table 1 shows that saccharin retest values (at the 0.25

Fig. 1. Mean liquid deliveries and phencyclidine intake (mg/kg) $\pm$ S.E. per 3-hr session are presented as a function of phencyclidine and saccharin concentration. Phencyclidine (or water) and saccharin (or water) were available under concurrent FR-16 schedules. Filled circles refer to phencyclidine deliveries; the 0 concentration indicates water had replaced phencyclidine, but visual stimuli signaling drug remained in effect. Unfilled circles refer to saccharin deliveries; the 0 concentration indicates water had replaced saccharin. Data from the frames showing 0 for the saccharin concentration were redrawn from data reported in an earlier publication (Carroll & Stotz, 1984); the 0,0 point was obtained as part of the present study. Each point represents the mean of the last five sessions of stable behavior at each condition.

Table 1

Mean phencyclidine (0.25 mg/ml), saccharin and water (0) deliveries from the initial presentation of 0.25 mg/ml phencyclidine and the retest at the end of each phencyclidine concentration series.

Saccharin Concentration (wt/vol)			Subject					
			M-P1	M-M	M-B	M-B2	M-G1	M-G2
0*	Initial	Phencyclidine	245.0	256.0	342.2	529.8	390.4	257.4
		Water	17.4	9.8	2.0	71.6	13.2	6.7
	Retest	Phencyclidine	230.0	194.4	389.4	542.3	315.0	312.0
		Water	15.8	3.0	0.6	27.5	9.2	44.0
.003%	Initial	Phencyclidine	311.0	223.0	381.2	488.8	299.3	323.2
		Saccharin	139.0	2.8	68.6	674.6	42.3	47.6
	Retest	Phencyclidine	371.0	287.6	448.2	578.8	305.8	297.4
		Saccharin	113.6	0.4	20.6	602.0	64.2	6.4
.03%	Initial	Phencyclidine	83.4	172.2	65.4	20.4	23.4	281.0
		Saccharin	891.8	517.8	1142.4	1461.6	1087.6	1156.8
	Retest	Phencyclidine	86.4	169.7	15.8	11.6	9.4	262.6
		Saccharin	1079.4	382.7	811.4	1466.4	1005.4	877.4
.3%	Initial	Phencyclidine	237.6	51.8	75.8	3.0	179.8	261.6
		Saccharin	1011.8	869.8	1368.2	1457.0	1023.0	633.2
	Retest	Phencyclidine	252.2	120.6	60.6	7.8	55.2	33.7
		Saccharin	1089.4	558.2	999.2	1770.2	1070.0	603.0

*Previously reported by Carroll & Stotz (1984).

mg/ml phencyclidine concentration) obtained at the end of each concentration series were very close to the number of liquid deliveries obtained during the initial determination that was plotted in Figure 1. Phencyclidine (0.25 mg/ml) retest values taken during the middle of the concentration series (not

shown) were also close to those obtained during the initial presentation of 0.25 mg/ml and those obtained at the end of the phencyclidine concentration series.

Table 2 compares the number of liquid deliveries when phencyclidine and water were concurrently available before and after

Table 2

Mean phencyclidine (0.25 mg/ml), and water deliveries before and after concurrent presentation of phencyclidine and saccharin solutions.

	M-P1	M-M	M-B	M-B2	M-G1	M-G2
Before Concurrent Saccharin Presentation						
Phencyclidine	223.5* (13.7)	256.4 (21.7)	404.0 (9.8)	432.4 (20.1)	370.6 (9.0)	315.5 (17.5)
Water	14.0 (1.9)	1.4 (0.7)	.4 (0.4)	68.8 (29.4)	0 0	29.5 (7.8)
After Concurrent Saccharin Presentation						
Phencyclidine	287.2 (16.4)	253.4 (6.5)	469.0 (10.8)	502.4 (10.0)	383.4 (11.4)	244.8 (13.8)
Water	65.2 (10.0)	1.0 (0.3)	0.8 (0.2)	16.0 (6.1)	14.8 (5.0)	23.4 (13.1)

*Each point refers to the mean ($\pm$ S.E.) of the last five sessions at each condition.

Fig. 2. Mean liquid deliveries cumulated at 10-min intervals over 3-hr sessions are presented for three saccharin concentrations (0.003, 0.03, and 0.3% wt/vol) and three phencyclidine concentrations (0.0625, 0.25, and 1.0 mg/ml). Phencyclidine and saccharin were available under concurrent FR-16 schedules. *Filled circles* refer to phencyclidine deliveries and *unfilled circles* refer to saccharin deliveries. Each point refers to the mean of the last five sessions of stable behavior under each condition.

saccharin was substituted for water. When saccharin was replaced by water at the end of the experiment, both phencyclidine and water deliveries returned to previous levels for two monkeys (M-M and M-G1); phencyclidine deliveries remained slightly higher for three monkeys (M-B, M-B2, and M-P1), and they decreased for M-G2. Thus, the elevated rates of responding generated by saccharin did not have a substantial effect on subsequent performance maintained by phencyclidine or water.

Figure 2 shows cumulative liquid deliveries over the 3-hr sessions for phencyclidine and concurrent saccharin at three concentrations of each. When the lowest saccharin concentration (0.003%, wt/vol) was concurrently available with phencyclidine, drug-

maintained responding followed a negatively accelerated function, and almost all deliveries were always obtained during the first half of the session. Cumulative saccharin deliveries followed a similar pattern. As the saccharin concentration increased to 0.03% and 0.3%, phencyclidine-maintained responding became more evenly distributed throughout the 3-hr interval. Saccharin-maintained responding occurred at a high, steady rate throughout most of the session, although there was a decrease in the rate of drinking during the last third of the session. There was an inverse relationship between phencyclidine concentration (and amount of phencyclidine consumed in mg/kg) and the number of saccharin deliveries in 13 of 18 cases (6 monkeys, 3 saccharin concentra-

Fig. 3. Three sample cumulative phencyclidine (0.25 mg/ml) response records are presented for each monkey for three concurrent saccharin concentrations (0.003, 0.03, and 0.3% wt/vol). The cumulative pens stepped upward with each phencyclidine-reinforced response and reset at approximately 400 responses. Downward deflections of the upper event pen also represent phencyclidine deliveries; however, this pen was not consistently functioning on two of the monkeys' recorders (M-B and M-M). Downward deflections of the lower event pen represent saccharin deliveries. Each record was selected as the one with the total numbers of phencyclidine and saccharin deliveries that were closest to the means of the last five sessions at each condition.

tions), and a partially inverse relationship occurred in three additional instances. Saccharin-reinforced responding usually surpassed phencyclidine-reinforced responding during the first 10 min of the session, suggesting that the saccharin preference was based upon taste rather than postingestional effects. However, at the phencyclidine concentration (0.25 mg/ml) that was near the peak of the concentration-response curve, drug-maintained responding often preceded saccharin-maintained responding. The time course of phencyclidine and concurrent water intake have been previously reported (Carroll & Stotz, 1984). These data were similar to those shown here for the lowest saccharin concentration.

Figure 3 shows sample cumulative response records for the six monkeys at the 0.25 mg/ml phencyclidine concentration and three saccharin concentrations (0.003, 0.03, and 0.3%, wt/vol). As the saccharin concentration increased, the records show a change in the distribution of phencyclidine-reinforced responding from the beginning of the session to patterns of responding that persisted throughout the session. In addition, phencyclidine drinking bouts were separated by longer pauses as the saccharin concentration increased. For some monkeys, phencyclidine drinking started later in the session at the higher saccharin concentrations. At the two lower saccharin concentrations, phencyclidine and saccharin drinking bouts

were often separated in time. However, at the highest saccharin concentration, four of the six monkeys rapidly alternated their responding between the two drinking spouts. Inspection of the cumulative records revealed that changeovers were made after liquid deliveries were obtained. Changes in patterns of responding were found at all drug concentrations for some monkeys; however, the rapid alternation between drug and saccharin spouts was more common at high saccharin and/or high drug concentrations.

DISCUSSION

Concurrent presentation of phencyclidine and saccharin solutions yielded the basic finding that preference for a reinforcer increases with reinforcer magnitude (concentration). These results were consistent with the general outcome of previous studies employing concurrent schedules and both nutritive (e.g., Brownstein, 1971; Catania, 1963, 1966; Herrnstein, 1970; Rachlin & Baum, 1969) and drug (Johanson & Schuster, 1975) reinforcers. The present study extended the relationship between relative preference and reinforcer magnitude to infrequently used concurrent FR schedules. The present results also concur with earlier studies of concurrent ethanol and sucrose intake (Lester & Greenberg, 1952; Samson et al., 1982) and concurrent ethanol and dextrose or saccharin intake (Samson & Falk, 1974). The present findings extend these results to the concurrent availability of two noncaloric substances, thus providing evidence against a caloric-substitution interpretation of previous results.

Saccharin, across a 10-fold concentration range (0.03 to 0.3%, wt/vol), substantially reduced phencyclidine-reinforced responding, but the magnitude of this effect decreased as phencyclidine concentration increased. Similarly, higher phencyclidine concentrations decreased saccharin-reinforced behavior. However, this relationship appeared in only four of the six monkeys, and the effect was not reduced by increasing the saccharin concentration. The somewhat

inverse relationship between phencyclidine and saccharin consumption might indicate that the two substances are partially substitutable as reinforcers (Rachlin, Battalio, Kagel, & Green, 1981). However, the relative orderliness of the present results may have been related to the fact that the 3-hr sessions placed a limit on the amounts of the substances consumed. The applicability of reinforcer-substitution analysis to human drug dependence may be further limited by drug-related factors such as the presence of tolerance and behavioral and/or physical dependence. Data from this laboratory suggest that these monkeys were tolerant to phencyclidine (Carroll, 1982c).

In addition to a reduction in total drug intake, the time course of phencyclidine-reinforced behavior also was altered as the saccharin concentration increased. Typically, when phencyclidine and water are concurrently available, most phencyclidine deliveries occur within the first hour of the 3-hr session (Carroll, 1982b; Carroll & Stotz, 1984). The typical patterns of phencyclidine-maintained responding that have been reported previously (Carroll, 1982b; Carroll & Stotz, 1984), and those that were shown here by cumulative response records for the low saccharin concentration, are characterized by a negatively accelerated rate of responding that consistently began immediately at session onset. When the two higher saccharin concentrations were concurrently available with phencyclidine, phencyclidine-maintained responding often began at a lower rate and sometimes continued throughout the 3-hr session. Long pauses also occurred between drinking bouts, and rapid alternation between the phencyclidine and saccharin drinking spouts occurred on some occasions. Disruptions in patterns of responding probably were not due to drug-induced effects on stimulus control, as they occurred immediately after session onset, often before phencyclidine intake had commenced and usually before the disruptive effects of phencyclidine have been shown to appear (Carroll, 1982a). Although total drug intake was relatively unchanged by the con-

current availability of saccharin (at the higher phencyclidine concentrations), the temporal distribution of responding was clearly disrupted. These results, as well as earlier findings comparing the effects of food deprivation and food satiation on the patterns of drug intake (Carroll, Stotz, Kliner, & Meisch, 1984), suggest that as a dependent measure, time course of responding may vary independently of overall response rate or drug intake.

It should be noted that reduced phencyclidine-maintained behavior due to concurrent saccharin availability was demonstrated only at the two higher saccharin concentrations. Thus the generality of these results may be limited by concentration and other factors such as the type of nondrug reinforcer and the drug selected for study. Earlier studies employing mutually exclusive choice between food and intravenous drug infusions revealed different results based upon the type of drug used. For instance, the availability of food decreased heroin-reinforced behavior (Wurster, Griffiths, Findley, & Brady, 1977), but it did not decrease cocaine-reinforced responding (Aigner & Balster, 1978). The present results may have been influenced also by the level of food deprivation (85% of free-feeding body weights) that was held constant throughout the experiment. Food deprivation increases both saccharin (Hursh & Beck, 1971; Sheffield & Roby, 1950; Smith & Duffy, 1957) and phencyclidine (Carroll & Meisch, 1984) intake; however, the extent to which the level of food deprivation interacts with the type of reinforcer (saccharin vs. phencyclidine) is not known. It has been established that the effects of food deprivation (vs. satiation) interact with phencyclidine concentration (Carroll & Meisch, 1984).

The use of a concurrently available liquid nondrug alternative reinforcer also provided information regarding the effect of taste on the characteristics of the concentration-response functions obtained with the oral drug self-administration procedure. In earlier studies, concurrently available water was used as a vehicle control to demonstrate that

drugs were functioning as reinforcers (e.g., Carroll, 1982b; Carroll & Meisch, 1980). In these studies water intake was usually low; thus it was not clear whether the decrease in drug intake at higher concentrations was due to aversive taste, to satiation, or to the onset of rate-suppressant effects of the drugs. It was not likely that phencyclidine suppressed the overall rate of responding. Although the phencyclidine-maintained responding reported here declined at high concentrations, as it had in previous studies (e.g., Carroll & Stotz, 1984), the monkeys were able to continue responding for saccharin at very high rates. Furthermore, when phencyclidine and water are concurrently available, almost all drug intake at high drug concentrations usually occurs during the first 30 to 45 min of the session (Carroll & Stotz, 1984), and the rate-decreasing effects of phencyclidine have been shown to occur about 45 to 60 min after the onset of drinking (Carroll, 1982b). Thus, increasing evidence suggests that oral self-administration of high drug concentrations using the present experimental design may be limited by aversive taste rather than by satiation or rate-decreasing effects of the drug.

Because performance maintained by concurrent phencyclidine and saccharin is dependent upon the concentrations of these liquids, taste, schedule requirements, level of food deprivation, and a number of other factors, a direct comparison of the number of liquid deliveries or intake (mg/kg) between the two substances should be interpreted in terms of preference or choice rather than differences in reinforcing efficacy. However, under conditions whereby most of these variables are held constant, it may be possible to compare different drug concentrations in terms of relative reinforcing efficacy. For instance, taking a fixed concentration of saccharin (e.g., 0.3%, wt/vol), it is possible to compare concurrent phencyclidine deliveries, across the range of phencyclidine concentrations, to values obtained when water was concurrently available with the drug. Visual inspection of the present data reveals that saccharin suppressed phencyclidine-

maintained responding much more at the low drug concentrations than at higher ones. The resistance of the higher concentrations to saccharin's suppressant effects could be due to their greater reinforcing efficacy. It could also be due to the fact that only a minimal amount of responding is necessary to obtain sufficient reinforcing effects of the drug at high phencyclidine concentrations. One method for further testing this possibility would be to increase the FR and determine whether or not liquid deliveries remained constant. Others have similarly defined reinforcer strength or efficacy in terms of resistance to change produced by an experimental manipulation such as extinction, noncontingent food delivery (Nevin, 1974), or increased FR value (Lemaire & Meisch, 1984).

A second strategy for assessing relative reinforcing efficacy of different phencyclidine concentrations would be to compare the decrease in concurrent saccharin intake with respect to saccharin intake when water (0 mg/ml phencyclidine) was concurrently present. It appears that at one or more saccharin concentrations for four of the six monkeys, saccharin deliveries decreased as drug intake (mg/kg) increased. These decreases in saccharin-reinforced responding did not appear to be due to general rate-decreasing effects of phencyclidine, for in many cases, the monkeys drank greater amounts of a different saccharin concentration at the high drug concentrations. The interpretation of the present findings as a measure of reinforcing efficacy agrees with results of other measures such as choice procedures between different drug doses (Iglauer & Woods, 1974; Johanson & Schuster, 1975), between drugs and food (Woolverton & Balster, 1981), changes in FR performance as a function of dose (Moreton, Meisch, Stark, & Thompson, 1977; Pickens & Thompson, 1968), and breaking point on progressive-ratio schedules (e.g., Griffiths, Brady, & Snell, 1978). These studies have shown that reinforcing efficacy is greater at higher doses. With the oral procedure, there remains the problem of equivalence of taste

as a function of concentrations. At high drug concentrations, aversive taste may limit drug-maintained responding; however, at lower drug concentrations, taste may function as a conditioned reinforcer that actually magnifies the reinforcing value of the drug (Carroll, 1982a; Carroll & Meisch, 1979). Although it has been shown that higher doses are selected over lower ones in intravenous self-administration choice situations (Iglauer & Woods, 1974; Johanson & Schuster, 1975), it has yet to be determined whether higher concentrations of orally delivered drugs are preferred to lower concentrations.

The present results also agree with those reported previously, in which the presentation of a nondrug reinforcer that was contingent upon the absence of drug taking reduced drug-reinforced behavior (Boudin, 1972; Cohen et al., 1971; Hunt & Azrin, 1973; Rosen & Lichtenstein, 1977; Stitzer et al., 1979). However, the present results suggest that such a contingency may not be necessary, as the simple availability of an alternative reinforcer reduced drug intake. In the present study, drug-reinforced behavior returned to previous levels when the nondrug reinforcer was removed. Some earlier studies have reported continued suppression of drug-maintained behavior that persisted after removal of a punishment contingency (Poling & Thompson, 1977c; Smith & Davis, 1974); however, others have shown a return to baseline levels (Grove & Schuster, 1974). In one study, stimuli associated with reduced drug-maintained behavior suppressed drug-maintained responding after a punishment contingency was removed (Poling & Thompson, 1977c). In the context of the present experiment, it is not known whether brief or intermittent exposure to the saccharin taste (after concurrent access to saccharin was terminated) would subsequently reduce phencyclidine-reinforced behavior. The visual stimuli correlated with saccharin (or drug) did not maintain responding during water substitution, but earlier studies have shown that visual stimuli presented with orally delivered drugs are relatively ineffective

(compared with taste and olfactory cues) in maintaining responding in the absence of the drug (Carroll, 1982a; Carroll & Meisch, 1979).

The evaluation of the reinforcing effects of drugs in an environment offering concurrent access to alternative reinforcers is an area of experimental investigation that has received little attention, although analyses of human drug dependence have effectively demonstrated the importance of the context in which a drug is taken (e.g., Falk, 1983). A practical result of the present study was that the concurrent availability of a saccharin solution effectively reduced phencyclidine-reinforced behavior. Skinner (1953) commented upon the desirability of reducing or eliminating behavior by reinforcing an alternative response rather than by punishment, extinction, or physical restraint. Such a strategy would seem to have potential benefits, in terms of improved patient compliance and resistance to relapse, for the treatment of drug dependence. However, more systematic work is needed to define the role of alternative reinforcing environmental factors in modifying drug-taking behavior.

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