Published in final edited form as:

J Neurosci Methods. 2014 October 30; 236: 11–18. doi:10.1016/j.jneumeth.2014.07.024.

Cocaine Self-Administration in Social Dyads Using Custom-Built Operant Conditioning Chambers

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Abstract

Background—Traditionally, the analysis of intravenous drug self-administration is limited to conditions in which subjects are tested in isolation. This limits the translational appeal of these studies because drug use in humans often occurs in the presence of others.

Newmethod—We used custom-built operant conditioning chambers that allowed social dyads visual, olfactory, auditory, and limited tactile contact while concurrently self-administering cocaine. Male rats were trained to respond according to a fixed interval schedule of reinforcement (with a limited hold) in order to determine if patterns of cocaine (0.75 mg/kg/infusion) self-administration became more similar over time in social pairs. Cocaine self-administration was tested across five days according to a 10-min fixed interval schedule (with a 5-min limited hold). Quarter-life values (time at which 25% of responses were emitted per interval) were analyzed using intraclass correlations.

Results—The total number of reinforcers obtained did not vary across the five days of testing; however, quarter-life values became progressively more similar between individuals within the social dyads.

Comparison with existing methods—Standard operant conditioning chambers are unable to assess responding in multiple animals due to their small size, the need to prevent subjects from responding on the lever of their partner, and the need to prevent infusion lines from entangling. By using custom-built social operant conditioning chambers, we assessed the effects of social contact on cocaine self-administration.

Conclusion—Social operant conditioning chambers can be used as a preclinical method to examine social influences on drug self-administration under conditions that approximate human substance use.

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Keywords

cocaine; fixed interval; operant; self-administration; social

1. Introduction

Substance use is typically modeled in laboratory animals using the drug self-administration procedure. In this procedure, operant responding is reinforced by the contingent delivery of a drug according to a schedule of reinforcement programmed by the experimenter. Most studies that employ intravenous drug self-administration (i.e., the delivery of drug to a peripheral vein) use commercially available operant conditioning chambers distributed by established manufacturers (e.g., Med Associates, Lafayette Instruments, Harvard Apparatus). These chambers allow the experimenter to record responses (e.g., lever presses) and program experimental events (e.g., drug infusions) according to a theoretically infinite number of schedule parameters. One limitation of commercially available chambers is that only one animal may be tested in a chamber at a time. This limitation is due to (1) the small size of commercially available chambers, (2) the need to prevent infusion lines from becoming tangled, and (3) the need to prevent one animal from pressing the response lever of another animal. This also limits the translational appeal of studies that employ intravenous drug self-administration because drug use in humans often occurs in the presence of others.

Several investigators have recently described innovative approaches to overcome this limitation by using modified operant conditioning chambers. For instance, Gipson et al. (2011) and Chen et al. (2011) examined amphetamine and nicotine self-administration, respectively, in laboratory rats using customized chambers that permitted a social partner (without access to drugs) to be present during experimental sessions. Similarly, we recently developed custom-built chambers that permit two rats to be tested in a single experimental session, with the caveat that both rats have access to drugs and data can be collected from both rats simultaneously (Smith, 2012). One novel aspect of this arrangement is that it allows for comparison of individual response patterns from each subject within a social pair. Comparisons of this nature are relevant because social learning models of substance use predict that individual patterns of drug self-administration should become progressively more similar over time within a social group (see reviews by Andrews and Hops, 2010; Kandel, 1986; Pandina et al., 2010).

Most drug self-administration studies use schedules of reinforcement that engender stable rates of responding prior to each reinforcer, interspersed with periods of non-responding after each reinforcer (e.g., fixed ratio schedules, progressive ratio schedules). Inter-subject differences in responding on these schedules are typically limited to overall rates of responding, total number of responses, and total number of reinforcers (Panlilio and Goldberg, 2007; Richardson and Roberts, 1996). In contrast, in a fixed interval (FI) schedule, the first response after a fixed period of time has elapsed is reinforced. This schedule engenders a particular pattern of responding characterized by low rates of responding early in the interval, moderate rates of responding in the middle of the interval,

and high rates of responding late in the interval (Balster and Schuster, 1973; Dougherty and Pickens, 1973; Ferster and Skinner, 1957; Guilhardi and Church, 2004; Schneider, 1969). Individual response patterns on this schedule can be summarized and quantified by quarter-life values, which correspond to the time point within an interval at which one quarter of the responses occur (Herrnstein and Morse, 1957).

In the present study, we describe the use of custom-built operant conditioning chambers to examine cocaine self-administration within social dyads in which both subjects have simultaneous access to cocaine. To this end, pair-housed rats were surgically implanted with intravenous catheters and trained to self-administer cocaine on a FI schedule of reinforcement. Once training was completed, intraclass correlations were determined for each dyad using quarter-life values obtained from both rats. Unlike most other correlations (e.g., Pearson Product-Moment), intraclass correlations operate on data structured as groups rather than as paired observations. Consequently, they may be used to determine the degree to which individuals within a dyad resemble one another (Griffin and Gonzalez, 1995; Shrout and Fleiss, 1979). Intraclass correlation coefficients were determined over five consecutive days, with the prediction that responding would become progressively more similar over time within each dyad.

2. Materials and Methods

2.1 Animals

Male, Long-Evans rats were obtained at weaning (~21 days) from Charles River Laboratories and immediately assigned to pair-housed conditions. Rats were housed together in standard laboratory cages (interior dimensions: 50 × 28 × 20 cm) until the beginning of self-administration testing. At that time, all rats were transferred to custom-built, operant conditioning chambers that served as home cages for the remainder of the study (see below). All rats were kept in a temperature- and humidity-controlled colony room on a normal 12-hr light/dark cycle with lights on at 0500 (5:00 am) for the duration of the study. Fresh food and water were continuously available in home cages throughout the study except during lever-press training (see below). All rats were maintained in accordance with *The Guide for the Care and Use of Laboratory Animals* (Institute of Laboratory Animal Resources, 2011).

2.2 Apparatus

All drug self-administration sessions were conducted in custom-built, operant conditioning chambers specifically designed to allow visual, auditory, olfactory, and limited tactile contact for pair-housed rats (Faircloth Machine Shop, Winston-Salem, NC; see Figure 1). Chambers were cubic in design (30 × 30 × 30 cm) and separated by a 14-gauge wire-screen panel. The wire screen restricted each subject's access to the tethering system and response lever of its partner. Each rat had access to a single active response lever mounted on the rear wall of the chamber. The distance between the response levers was 13 cm, 6.5 cm from the wire screen. Drug infusions were delivered via Tygon tubing protected by a stainless steel spring and connected to a counter-balanced swivel above the chamber. An infusion pump (3.33 rpm) was mounted behind the cage and connected to interfacing equipment from Med Associates, Inc. (St Albans, VT, USA). In contrast to standard operant conditioning

chambers, our custom-designed chambers allow for within-session, social contact manipulations (Figure 1).

Lever-press training was conducted in standard, commercially available, operant conditioning chambers from Med Associates, Inc. These chambers were equipped with two response levers, two white stimulus lights above the response levers, a house light, and a food pellet receptacle located between the two response levers.

2.3 Lever-press training

One goal of this project was to establish responding reinforced by cocaine on a FI schedule of reinforcement. There are very few studies describing the use of FI schedules in drug self-administration studies, and there is no standardized protocol for training laboratory rats in this procedure. Given the limited lifespan of jugular catheters (~ 30 days in our laboratory), it was necessary to expedite self-administration training as much as possible by initially training rats to respond on a FI schedule using food reinforcement. This was done through a series of sessions in which responding was initially reinforced on a fixed ratio schedule (to establish the response), then on a variable ratio (VR) schedule (to establish responding under conditions of intermittent reinforcement), and finally on a FI schedule (to establish responding on an interval schedule in which reinforcement is not a direct function of response rate). Later, once catheters were implanted, self-administration training advanced through these same three schedules using cocaine as the reinforcer.

Prior to beginning lever-press training, rats were left undisturbed in their home cages to mature. Approximately four weeks after arrival (~ 7 weeks of age), subjects were restricted to 90% of their free-feeding body weight and trained to press a response lever using food reinforcement. Rats were handled daily by the experimenters from this day forward. During initial lever-press training, responding was reinforced on a fixed ratio (FR-1) schedule of reinforcement with a single 45 mg grain pellet. Sessions terminated after 40 reinforcers were received. Following three consecutive FR sessions, subjects advanced to a variable-ratio (VR) schedule of reinforcement, a schedule in which the ratio value varies around a predetermined average. Rats were allowed to lever press according to a VR-3 and VR-5 schedule on consecutive days for a maximum of 40 and 60 reinforcers, respectively. For six additional daily sessions, responding was maintained on a FI schedule, two FI-1 min and four FI-2 min sessions (1-hr duration). All subjects met the initial FR criterion, exhibited reliable responding throughout the remainder of training, and were returned to unrestricted feed within 12 days.

2.4 Surgery

Six weeks after arrival, rats were surgically implanted with intravenous catheters for drug self-administration. Rats were anesthetized with a combination of xylazine HCl (8.0 mg/kg, ip) and ketamine (100 mg/kg, ip), and an intravenous catheter was inserted into the right jugular vein that exited the body on the dorsal surface of the scapulae. Each rat was administered Ketoprofen (3.0 mg/kg, sc) as a post-operative analgesic immediately following surgery and allowed to recover for 3 days prior to the beginning of behavioral testing. For seven days after surgery, a solution of heparinized saline and ticarcillin (20

mg/kg, iv) was infused through the catheter daily to maintain patency and prevent infection. After the initial seven days, ticarcillin administration was discontinued and catheter patency was maintained by daily infusions of heparinized saline.

2.5 Drug self-administration training

Throughout self-administration training and testing, all sessions were 3 hr in duration and began when lights went off at 1700 (5:00 pm). Each self-administration session began with a priming infusion of cocaine (0.75 mg/kg/infusion; National Institute of Drug Abuse, Research Triangle Institute, Research Triangle Park, NC). During the initial self-administration training sessions, responding was reinforced on a FR-1 schedule. Each lever press produced a 2.5–4.0 sec infusion (based on body weight) of cocaine and simultaneous retraction of the response lever for 20 sec. Retraction of the response lever thus provided an auditory, visual, tactile, and contextual cue that was always associated with cocaine delivery. Once subjects received 30 or more infusions in two consecutive FR sessions they advanced to a VR schedule. Similar to lever press training, rats responded according to VR-3 and VR-5 schedules during subsequent training sessions. Rats were required to obtain a minimum of 30 reinforcers on the VR-3 and VR-5 schedule prior to advancing to FI sessions.

After meeting the VR schedule criterion, contingencies were changed and responding was maintained on a FI schedule with a 5-min limited hold (LH). The LH is a window of time, after the FI has elapsed, in which the subject must respond in order to receive reinforcement. If the subject does not emit a response during the LH, then the FI schedule “resets” and begins again. For example, the first day of FI self-administration was a FI-1 min (LH 5-min). Thus, following 60 sec of the FI (during which no responses were reinforced) rats received an infusion if one response was emitted during the next 300 sec. Responding during the LH resulted in a cocaine infusion and retraction of the response lever for the remaining duration of the LH. Thus, if a subject responded 30 sec into the LH, the lever remained retracted for 270 sec until the next FI began and the lever was reinserted into the chamber. By utilizing the LH, each interval was synchronized between subjects for the duration of the session, which allowed for direct comparison of responding for each pair of rats. Pairs of subjects advanced to longer FI durations at 1-min intervals (i.e., 1 min to 2 min, 2 min to 3 min, etc.) when both subjects received at least 50% of the available infusions in the same session. Throughout training, the total number of FI (LH) components within a session decreased as the duration of the FI increased. For instance, there were 30, FI-1 min (LH 5-min) components ($6 \text{ min/component} \times 30 = 180 \text{ min}$) but 18, FI-5 min (LH 5-min) components ($10 \text{ min/component} \times 18 = 180 \text{ min}$).

2.6 Drug self-administration testing on a FI schedule of reinforcement

Training continued until both rats of a social pair received at least 50% of the available infusions on a FI 9-min (LH 5-min) schedule of reinforcement within the same training session. On the following day, self-administration testing commenced on a FI-10 min (LH 5-min) schedule of reinforcement. All test sessions were 180 min in duration and consisted of 12 individual FI (LH) components (see Figure 2). Otherwise, all experimental events were

identical to those encountered during self-administration training. Test sessions were conducted over five consecutive days in which all schedule parameters remained constant.

2.7 Data analysis

Social pairs in which at least one rat lost catheter patency before completion of all behavioral tests ($n = 3$ pairs), or in which at least one rat failed to obtain at least 50% of the available reinforcers required to advance to the FI-10 min criterion ($n = 3$ pairs), were removed from the study and their data were not used in the statistical analysis. A total of 9 social pairs reached the FI-10 min (LH 5-min) criterion with intact catheters. The subsequent five days of responding from these 9 pairs were used for data analysis. Total reinforcers obtained and responses emitted in daily test sessions were recorded for each subject. Quarter-life values were determined as the time (in seconds) into each fixed interval at which a quarter of the responses were made (Herrnstein and Morse, 1957). Only intervals in which both members of the pair (1) emitted four or more responses and (2) received an infusion in the previous interval were included in quarter-life analyses. The former stipulation was necessary because at least four responses are needed to calculate quarter-life values (i.e., the time at which the 25th percentile response occurs). The latter stipulation was necessary to ensure that the time since the previous infusion was held constant between each member of a social pair. Daily reinforcers, responses, and quarter-life values were compared using repeated-measures ANOVA with day as the repeated-measures factor. All analyses were conducted in SPSS Statistics (SPSS 20 IBM 2011) with statistical significance set at $p < 0.05$.

In order to measure the similarity of response patterns between members of a social pair, and how the similarity of the response patterns changed over time, single-measure intraclass correlation coefficients were calculated for quarter-life values on each day of testing. The intraclass correlation provides a measure of how closely members of the same group (e.g., social pairs) resemble one another in a given trait or characteristic (e.g., quarter-life values) with a value closer to 1.0 indicating a greater degree of similarity (Shrout and Fleiss, 1979). Statistical significance was obtained when the 95% confidence limits did not overlap 0.

3. Results

3.1 Individual response variables

During most components, subjects exhibited a pattern of responding typical of FI schedules. Specifically, most subjects exhibited low levels of responding at the beginning of components, following by increasing rates of responding toward the end of components (Figure 3). When averaged across rats, at least 75% of the available reinforcers were obtained on each of the five days of testing (Table 1). Quarter-life values were typical of a FI schedule, averaging greater than 25% of the interval (i.e., 150 seconds) on all five days of testing. The total number of responses decreased systematically across the five days of testing ($F_{(4, 68)} = 2.956, p = 0.026$); however, the number of reinforcers obtained and quarter-life values did not differ as a function of test day ($F_{(4, 68)} = 0.472$ and 0.317 , respectively, p values > 0.756).

3.2 Social-pair response variables

To compare response patterns within social pairs, intraclass correlation coefficients (ICC) were determined for quarter-life values on each day of behavioral testing. Examination of these coefficients indicated an increase in the degree of association between social pairs across test days (Figure 4). Specifically, on Day 1, quarter-life values were not associated among social pairs ($ICC = -0.039$, $p = 0.538$). Although Day 2 values were more closely related, this association was not significant ($ICC = 0.361$, $p = 0.141$). Significant ICC values were observed starting on Day 3 and remained significant for the remaining days of testing ($ICC = 0.683$ to 0.77 ; p values < 0.011). Although the quarter-life values of all social partners became more similar across the five days of testing, some social partners exhibited greater degrees of similarity than others (compare data from Pair 1 and Pair 2 in Figure 3).

4. Discussion

In this study, we compared the response patterns of two animals self-administering cocaine concurrently in the same chamber. Specifically, we observed a progressive increase in the similarity of response patterns within social dyads across five days of testing. This was accomplished by using custom-built chambers that allowed socially housed rats concurrent access to intravenous cocaine, and by using a schedule of reinforcement that engendered a range of response rates within individual rats. Additionally, the use of intraclass correlations allowed us to compare responding between individual rats within a social dyad, and to determine how the similarity in responding changed over time. The data generated suggest that proximal social cues (i.e., cues that are immediately present during periods of drug self-administration) can influence patterns of substance use, and that this effect becomes progressively more apparent over time.

The FI schedule (with LH) offered unique advantages for assessing the similarity of responding within social dyads. Unlike many schedules used in drug self-administration research (e.g., fixed ratio, progressive ratio), FI schedules engender varying but predictable rates of responding during discrete intervals of time between each reinforcer. This allowed us to compare individual response patterns during a period of time in which low, moderate, and high rates of responding were observed. Moreover, the limited hold (and subsequent time out) allowed us to compare responding during periods of time when brain concentrations of cocaine were theoretically similar between subjects.

On average, rats received over 75% of the available reinforcers during each testing session and this did not change over the course of testing, suggesting that performance on the FI schedule (at least as measured by reinforcement rate) did not change. During test sessions, only one cocaine infusion was available in a 15-min component. This duration was chosen because it exceeds the mean inter-response interval for 0.75 mg/kg/infusion cocaine on continuous reinforcement schedules (~ 6 min; Covington and Miczek, 2001), and thus maximized the likelihood that responding would occur during each component. Only data from intervals in which both rats received a cocaine infusion in the previous interval were analyzed, thus controlling for potential differences in cocaine concentrations between individuals that would otherwise influence responding.

Quarter-life values in the present study were typical of a FI-10 min schedule, exceeding 25% of the interval (i.e., 150 seconds) in most instances (for details on quarter-life values, see Gollub, 1964; Guilhardi & Church, 2004; Herrnstein & Morse, 1957). Furthermore, examination of the cumulative records indicated that responding was concentrated in the later half of the interval during most components. These data suggest that responding was controlled by the maintaining event (i.e., cocaine infusion and lever retraction) and the schedule of reinforcement. Importantly, these data are not consistent with the possibility that responding was due to nonspecific increases in motor activity induced by cocaine or by the social context. If these effects were due to cocaine-induced motor activity, then the greatest amount of responding would occur early in the interval, when cocaine concentrations are highest. If these effects were due to context-induced motor activity, then responding would be consistent throughout the interval, given that the social context did not vary between reinforcers.

Average quarter-life values did not vary across the 5-day testing period, but the similarity in quarter-life values (as determined by intraclass correlations) increased over time. These data indicate that the response patterns of rats within social dyads became increasingly similar over the five days of testing. Importantly, these findings are consistent with our primary hypothesis and support a social learning model of substance use. Furthermore, these data are consistent with previous studies in humans that reported similarities in drinking patterns between a model and observer (Caudill and Marlatt, 1975; Larsen et al., 2009; Lied and Marlatt, 1979).

Assessing intravenous drug self-administration in social dyads using traditional operant conditioning chambers is difficult because those chambers are limited to the collection of data from a single organism. The design of the social chambers described in the present study allowed visual, auditory, olfactory, and limited tactile contact between social partners. Rats had concurrent access to cocaine reinforcement, were in no danger of becoming entangled with the tethering system of their social partner, and were prevented from responding on the lever of a social partner. We recently demonstrated that these chambers could be used to show how one peer can influence the drug intake of another peer (Smith, 2012; Peitz et al., 2013), and how drug self-administration can influence a preference for one peer over another (Smith and Pitts, 2014). In this paper, we show that these chambers may also be used to compare individual patterns of responding between social partners, and how these patterns of responding become more similar over time. This was accomplished through the use of novel procedural manipulations (i.e., a FI schedule with LH) and statistical procedures (i.e., an ICC analysis) that have not typically been used in self-administration research.

The FI 10-min (LH 5-min) schedule of reinforcement required a different training protocol than that used in previous studies. In order to expedite self-administration training, we initially trained the subjects to lever press on a FR schedule using food reinforcement to establish the response, then on a VR schedule to establish responding under conditions of intermittent reinforcement, and finally on a FI schedule to establish responding on an interval schedule in which reinforcement is not a direct function of response rate. Once catheters were implanted, training advanced through these same three schedules using

cocaine as a reinforcer. It is not known whether all these steps were necessary to establish responding on the FI 10-min (LH 5-min) schedule, but prior training on ratio schedules is common in studies that use interval schedules of reinforcement (e.g., Cantor, 1971; Corrigan & Coen 1989; Skinner & Morse, 1957) and prior lever-press training with food is a common practice in drug self-administration research (e.g., Aarde et al., 2013; Pich et al. 1997).

We believe these chambers will have considerable utility in answering questions regarding the influence of social contact on drug self-administration. For instance, we previously reported that drug self-administration could either be facilitated or inhibited in these chambers, depending on whether one rat or both rats had access to cocaine (Smith, 2012). Specifically, cocaine self-administration was facilitated if both rats had access to cocaine, but cocaine self-administration was inhibited if only rat of the pair had access to cocaine. One technical advantage of our chambers is that they are modular in design and can be disassembled/reassembled rapidly. This capability allows different configurations to be arranged, including a three-compartment chamber that allows one rat (in the center) to be flanked by two rats on each side. Using this arrangement, we reported that a rat self-administering cocaine (in the center compartment) preferred to self-administer cocaine on a lever in close proximity to a partner that was also self-administering cocaine (in a side compartment), rather than on a lever in close proximity to a rat that did not have access to cocaine (in the opposite compartment; Smith and Pitts, 2014).

These chambers may also be used to examine more complicated social phenomena that arise when different drugs, schedules of reinforcement, and populations are involved. For instance, we have previously shown that cocaine self-administration is facilitated if a social partner is also self-administering cocaine, but it is not known if a similar effect would be observed if the partner was self-administering another drug, particularly one that produced a state of intoxication dissimilar to that of cocaine (e.g., heroin, ethanol). Furthermore, we do not know how drug self-administration would be altered if two rats were self-administering cocaine under different schedules of reinforcement, such as one that maintained very high rates of responding (e.g., a second-order schedule) versus one that maintained very low rates of responding (e.g., differential reinforcement of low rates). Finally, we do not know whether these findings extend to adolescent or female populations. This latter point is particularly relevant because the effects of social influence on drug-seeking behavior differ across age and sex (Doremus et al., 2005; Maldonado et al., 2008; Yates et al., 2013).

Additional modifications to our chambers could allow more complicated questions to be asked. For instance, a motorized opaque screen that could be raised and lowered could be used to make social contact part of a reinforcement or punishment contingency. For instance, social learning models of substance use propose that drug use is established and maintained, in part, because of social reinforcement from others (Andrews and Hops, 2010; Pandina et al., 2010). One could positively reinforce drug self-administration by making social contact (i.e., raising the screen) contingent on self-administering a drug. In order to decrease drug self-administration, one could negatively punish drug self-administration by removing social contact (i.e., lowering the screen) contingent on self-administering a drug (technically, this is response-cost contingency, with each response costing the subject an opportunity for social contact). Finally, one could differentially reinforce behavior other

than drug self-administration (and thereby reduce drug intake) by making social contact (i.e., raising the screen) available only after a period of time in which the subject does not self-administer a drug. Collectively, these manipulations would allow researchers to examine a host of social interventions to decrease drug self-administration, further enhancing the translational appeal of the chambers.

One of the most reliable prognosticators of drug use in adolescents and young adults is whether individuals in their peer group use drugs (Bahr et al., 2005; Simons-Morton and Chen, 2006). Social learning theories suggest that substance use behaviors are modeled by some group members and that similar behaviors are selectively reinforced within the peer group (Andrews and Hops, 2010; Pandina et al., 2010). Our findings contribute to the understanding of social learning in the context of drug use and the patterns of use that emerge during the formation of peer groups. Importantly, the use of our novel social model will provide a platform by which social theories of drug use can be tested and social interventions to reduce drug use can be examined.

Acknowledgments

The authors thank Maryam Witte and Mary Kathryn Brophy for their expert assistance in performing this experiment, Scott Barrett for assisting in programming the operant contingencies used in this experiment, Dr. Scott Tonidandel for providing advice on the statistical analysis of social-pair response variables, and that National Institute on Drug Abuse for supplying the study drug. This research was supported by the National Institutes of Health (NIDA Grants R01DA031725 and R01DA027485).

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Highlights

We used custom-built chambers to assess social cocaine self-administration

Dyads exhibited reliable responding on fixed interval schedules with a limited hold

Dyadic responding became more similar across testing days

We characterized a preclinical model of social drug taking behavior in dyads

Figure 1.

The top panel is an overhead schematic of the chamber used to collect social cocaine self-administration data in the present experiment. The chambers are cubic in design ($30 \times 30 \times 30$ cm) and separated by a wire mesh screen (see picture in lower panel). Response levers were separated by 13 cm and drug infusion pumps were located outside of the chamber. Six weeks after arrival, subjects were housed in these chambers 24 hours/day with food and water freely available. Testing sessions were 3 hours in duration beginning at 1700 (5:00 pm). The lower panel is a photograph of a typical social dyad housed within the chamber.

Steel spring tethers attached to the subjects' dorsal surface protected Tygon tubing and allowed cocaine infusions during test sessions. The response levers are extended into the chamber (to the rear of the subjects) in the photograph. Subjects were able to move freely throughout the entire chamber at all times. Subjects had full view of their social partner throughout test sessions, including during periods of time in which both subjects were pressing the response lever.

Figure 2.

The upper diagram is a visual representation of a single FI 10-min (LH 5-min) component, with the FI represented in the open portion and the LH represented in the shaded portion.

The lower diagram is a visual summary of a 180-min test session with 12, FI 10-min (LH 5-min) components.

Figure 3.

Cumulative records from components yielding quarter-life values from two social pairs on the first (Day 1) and last (Day 5) day of testing on a FI 10-min (LH 5-min) schedule of reinforcement. Only responses from the 10-min fixed intervals are shown; responses from the 5-min limited holds are not depicted. Ordinates depict cumulative number of responses; abscissae depict elapsed time (min) within the interval. All reinforced responses delivered 0.75 mg/kg/infusion cocaine. Average quarter-life values from each session are shown by vertical broken lines originating from the abscissae. Data are shown from one pair (Pair 1: R-2099, R-2094) that was one of the least similar in terms of response rates (note different scales for ordinates) and quarter-life values, and one pair (Pair 2: R-2067, R-2066) that was one of the most similar in terms of response rates and quarter-life values (note identical ordinates and the alignment of quarter-life values on day 5).

Figure 4.

Intraclass correlation coefficients (ICC) for quarter-life values in social pairs across five days of fixed interval testing. Social pairs ($n = 9$ pairs) were tested on a 600 s FI schedule with a 300 s limited hold; quarter-life values were determined as the time into each fixed interval at which 25% of total interval responses were made. Error bars represent the 95% CI around single-measure ICC values. Dotted line is an ICC value of 0 and any ICC value with a 95% CI not intersecting this value was considered significant ($* p < 0.05$).

Table 1

Mean (SEM) reinforcers, responses, and quarter-life values on each test day

	Reinforcers	Responses	Quarter-life (sec)
Day 1	9.33 (0.56)	105.3 (15.0)	223.2 (22.0)
Day 2	9.67 (0.56)	100.8 (14.1)	202.7 (21.0)
Day 3	9.11 (0.60)	79.4 (9.5)	217.3 (19.3)
Day 4	9.11 (0.65)	72.8 (8.6)	231.5 (29.0)
Day 5	9.72 (0.68)	70.9 (9.2)	213.7 (28.3)

^a n = 18 rats from 9 social dyads responding on a 600-sec FI schedule with a 300-sec limited hold in daily 3 h sessions.