The *CyberRat* Research Project (CRRP)

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Authors' Note:

While an undergraduate at Rollins College, KMM conducted a series of live animal experiments that provided empirical data for *CyberRat* 2.0. These experiments were especially focused on topics where published data were not available. The project began as a summer student-faculty collaborative research program with KMM collaborating with RDR in 2001 and continued through KMM's subsequent year-long senior research project. This document presents the original summaries of these research data which were previously available as a series of webpages (CyberRat's Research Community Pages).

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Abstract

A series of experiments is reported using rats as subjects, water as reinforcement, an operant chamber as the experimental apparatus, and various Behavioral Systems Methods (cf. Ray & Delprato, 1989) for analyses that supplement standard operant cumulative recordings of bar press rates. The series was conducted to establish parametrics suitable for guiding simulation design in *CyberRat* V2.0 and subsequent releases. This was necessary because the literature offered insufficient guidance on these specific combinations of experimental conditions and measures. Reported here are statistical summaries of behavioral sequences and patterning across habituation to the chamber, measures of bar press rates under pre-experimental satiation vs. deprivation of the reinforcing stimuli (water) used, as well as data on session times associated with warm-ups and within-session satiety under constant reinforcement conditions. Extinction parametrics as well as intermittent reinforcement schedule explorations are also reported.

The *CyberRat* Research Project (CRRP)

The Behavioral Systems Dynamics research which inspired the development of the original *CyberRat* V 1.0 were first introduced by Ray and Brown (1975) and Ray and Ray (1976). These and subsequent projects were fully summarized in an integrative article published by Ray and Delprato (1989). *CyberRat* itself was an elaboration of a cartoon simulation of a trainable monkey summarized in Ray (1992) and in Ray and Mitchell (1993); while the first "proof-of-concept" computer program using video of rats in an operant chamber was drafted by Ray in 1993. From these humble beginnings the first commercial level development of *CyberRat*, programmed by Victor Begiashvili, began in 1993. In March, 1996, *CyberRat* V1.0 was introduced to the consumer via Brown and Benchmark Publishers. The subsequent sale of Brown and Benchmark, along with other Times-Mirror Higher Education Publishing Group companies, to McGraw-Hill in 1996 transferred distribution rights to McGraw-Hill. Distribution rights were returned to Ray's research and development umbrella company, $(AI)^2$, Inc., in late 1999. When development started on *CyberRat* Version 2.0 in January, 2001, all sales activity of *CyberRat* were frozen until the new version could be completed. That and subsequent updates (V2.x) of *CyberRat* included a rewrite of all algorithms and matrices, as well as a re-taping/editing of new video footage recorded from a different vantage perspective than was used for V1.0. Version 3.0 of *CyberRat* was completed in 2012 and involved a total computer-graphics and user interface redesign while retaining the v2.x video corpus and simulation engine.

Version 2.x was Redesigned to Reflect Empirical Data

CyberRat V2.x was founded upon three fundamental sets of models: 1) behavioral kinematics measured by conditional probability matrices and represented by corresponding video clips of each behavioral category; 2) transitional functions suitable for modeling gradual evolutions from existing matrices to new ones--thus adding a “third dimension” to kinematic matricies; and 3) post-transitional "switching" functions allowing for situationally specific matrix selection/translation dependent upon appropriate setting conditions, including establishing (deprivation/satiation) and discriminative training (S+/S-) settings. We limited the scope of our modeling efforts to a singular lever/bar as the operandum and to simple schedules, but wanted to offer the most realistic effects possible for those conditions being simulated. The primary purpose of this document is to share with potential adopters and the scientific community at large the specific empirical research used to define the V2.x & V3.x *CyberRat* parameters that were used to guide the simulations.

Feedback from users of *CyberRat* V1.0 was critical in defining our total commitment to re-writing and re-taping video for the new *CyberRat* V2.x. For example, Ray (1996) reported that *CyberRat* V1.0 had a limited bar pressing repertoire due to its relatively small sample-of-video-clips used for showing bar-press variations. More importantly, each of the various clips in this original sample incorporated not only the bar press itself, but also a subsequent visitation to the water reservoir. As Dr. Paul Brandon (personal communication, May, 1999) graciously pointed out originally (unfortunately too late for us to correct it in the first version), this resulted in a critical artificiality in the V1.0 *CyberRat* simulations on two important fronts: 1) no bar-press response "runs" involving bar pressing were possible wherein only successive bar presses occurred without reservoir visitations; and 2) maximum bar-press response rates were kept significantly and artificially low as a result of the excessive durations of our representative video clips of bar pressing (since visitations to reservoir were included), thus elongating the "duration" of each occurrence, thereby translating into artificially long periods between bar presses, or inter-response times (IRTs). The minimum duration of clips was between 3-4 seconds, and thus the original minimum IRT reflected this parameter.

A second design-imposed artificiality in *CyberRat* V1.0 was pointed out by Dr. Richard Malott (personal communication, August, 1996) during our many demonstrations of the pre-release of the product at the Brown and Benchmark display booth at a meeting of the American Psychological Association. After successfully magazine training an animal in *CyberRat*, the animal rarely responded within a sufficiently short latency to shift from ongoing behaviors to the natural "run to the water reservoir" typical of a well established elicited change in behavior (cf. Ray & Brown, 1976). Unfortunately video clips are used and must "play out" to their "natural" ends. Also, some of these clips are relatively long (a matter of a few seconds), which translates into an unavoidable delay in sequencing. This criticism continues, to some degree, to apply to subsequent versions of *CyberRat* as well. Nevertheless, we were mindful of the effect and made every effort to minimize it.

We tried our best to correct as many obvious errors through V2.x as possible and thus relied much more heavily on empirical probes and published data to guide those efforts. The following pages share those data explicitly with the scientific community. Many of these necessary parameters were found missing because the literature upon which we relied was silent on parameter specifications required for guiding realistic simulation and model construction--especially using rats (as opposed to the more common use of pigeons) as subjects. This is especially true where water is used instead of food as the reinforcer, as is the case with all *CyberRat* versions.

Despite its breadth, the current *CyberRat* is still somewhat limited in aspirations for a variety of simulations--especially regarding multiple and complex reinforcement schedules, multiple operanda, and the potential use of aversive consequences. The new version especially targets realistic simulations of the experimental operations illustrated in Table 1, which also anticipates our order of subsequent presentation of experiments and outcomes.

Table 1

Experimental Operations and Associated Processes of Interest Guiding the Research Projects Guiding Development of CyberRat V2.x.

Operation	Process	Expected Outcome
Simple Observation & Setting Presentation	Behavioral Sequence Dynamics & Habituation	Shifts in Behavioral Hierarchy across the session.
Interactive Consequential Operation	Targeted Response Shaping	Acquisition of a new behavior.
Establishing Operation – A	Satiety	*Ad Lib* water availability prior to experimental session depresses bar press rates.
Establishing Operation – B	Deprivation Schedules	Depriving or water availability prior to experimental session gradually accelerates bar press rates across sessions.
Constant Scheduling of Reinforcement	CRF schedule	Relatively slow and constant bar press rate. If session is sufficient in length, satiety will slow and/or stop bar pressing.
Removal of Existing Consequential Operation	Extinction & Spontaneous Recovery	Gradual development of selective responding only under S+ condition.

Signaling Consequential Operation	Stimulus Discrimination	First an increase, then a rapid decline in bar press rates within session. Slight return to bar pressing in subsequent session.
Intermittent Scheduling of Reinforcement: Fixed Ratio	Transition to FR stabilization	Gradual appearance of “break-run” pattern of responding.
Intermittent Scheduling of Reinforcement Fixed Interval	Transition to FI stabilization	Gradual appearance of “scalloped” pattern of responding.
Intermittent Scheduling of Reinforcement: Fixed Temporal	FT schedule with no specified behavioral contingency…only “time” contingent.	Superstitious Ritualized Behavior and/or decreased latency in responding to water delivery.
Intermittent Scheduling of Reinforcement: Variable Ratio	Transition to VR stabilization	VR schedule-induced high and steady rate of responding.
Intermittent Scheduling of Reinforcement: Variable Interval	Transition to VI stabilization	VI schedule-induced steady rate of responding.

Most of our experimental animals used in the above studies were also used for the new video taping for *CyberRat*. For more information on *CyberRat* as a commercial product, please visit http://www.ai2inc.com

Experiment I: Behavioral Organization Dynamics During Habituation to an Operant Chamber

Ray and Brown (1975) were among the first to investigate, through systematic observation, the sequential behavioral organization in rats as they habituated during their first exposure to being placed inside a standard laboratory operant chamber. In fact, that publication also established the fundamentals of the Behavioral Systems research methodology that was eventually used to guide the creation of *CyberRat*. Unfortunately, the technology available in the early 1970's required Ray and Brown to use direct behavioral observation time-sampling techniques which only approximated true behavioral sequences and the associated unconditional and conditional behavioral probabilities during the various experimental conditions explored. Durations were also not possible to measure, as instances and sequences of each type of behavior occurring within the "five-second observation /15-second recording" window were the only elements recorded. To make *CyberRat* as realistic as possible, a series of investigations were conducted on behavioral system dynamics observed during rats' first experiences inside an operant conditioning chamber using continuous and inclusive observation techniques that relied upon video tapes. This and subsequent experiments allowed us both to establish parametric ranges applicable to the simulation and to illustrate for interested *CyberRat* users exactly how behavioral systems principles can be modeled via the combination of digital video and controlling computer algorithms. In other words, such experiments help to illustrate how *CyberRat* was created and how it works.

Method and Procedures

Two rats were videotaped for 30 minutes, and a third rat for 45 minutes during their first experience (habituation) of being placed inside an operant conditioning chamber. All animals were approximately 3-4 months of age. Behavioral observations were made using a relatively mid-grained, but mutually exclusive and inclusive, behavioral category system that included:

- **Rest** - Subject shows no movement, other than fibrissa, for sustained period (>3 seconds).
- **Freeze** - Subject shows no movement, including fibrissa, for sustained period (>3 seconds).
- **Bar Press** - Subject depresses the lever operandum sufficiently to trigger a monitoring light diode.
- **Bar Touch** - Subject touches the lever operandum with nose or paw(s).
- **Dipper Entry** - Subject breaks the plain of the dipper/wall barrier with nose.
- **Object Touch** - Subject touches lights, top latch, or wall screws with nose or paw(s).
- **Groom Self** - Subject licks self or paws, including movement of paws over nose.
- **Bite Self** - Subject divides fur and bites at self during grooming.
- **Scratch Self** - Subject uses hind foot to scratch self during grooming.
- **Move** - Subject moves at least one hind paw, thus changing location(s) and/or orientation(s) in the chamber.
- **Explore** - Subject moves upper body, but not hind feet, thus changing orientation(s) and/or level(s) in the the chamber. One forepaw may be raised from the floor in this activity, but not both at the same time.
- **Rear** - Subject raises both forepaws off the floor in upright exploration, but remains fixed in the placement of both hind feet.

Initial recordings were made with a digital video camcorder. These digital tapes were subsequently transferred to computer and edited into successive 15 minute compressed digital video recordings saved on recordable CDs. Compressions were set for 15-frames per second. These digital CD recordings of each subject were made with time markings appearing that graphically depicted date, hour, minute, and seconds. An in-house authored software system was used to synchronize computer video play times with this graphical clock, thus allowing for a highly accurate interpolation of actual frame numbers as well. This software system was then used to apply the above coding taxonomy to the synchronized digital recording, resulting in a file which identified each successive state of behavior and the time it was initiated (i.e., continuous coding using exhaustive and mutually exclusive categories). Subsequent analyses of these data included a sequential (kinematic) matrix reflecting the number of each preceding-succeeding behavioral sequence. These numbers were then used to generate both unconditional (independent of preceding behavioral state) and conditional (specific to each preceding behavioral state) probabilities for all above behaviors. Finally, a Cohen's *kappa* (Bakeman & Gottman, 1997) was calculated periodically to assure ongoing reliability in excess of 90% between two coders.

Results

Both static and dynamic analyses were accomplished for each subject and for the combined records of all subjects. Static analysis combined all data within the entire session into one summary of the total session. Dynamic analyses included measurement of various behavioral parameters within each successive 5 minute window of the 30 (and 45) minute sessions. We will first discuss static and dynamic summaries for all subjects combined, across all sessions, to form a general description of behavioral dynamics prior to discussing detailed individual change dynamics across sessions for each subject.

Global Behavioral Organization During Habituation: Unconditional Probability Dynamics

As a means for depicting unconditional behavioral probability measures and how they change across the duration of the session, we collapsed many associated categories into an even more "macro-level" set of descriptions (cf. Ray & Delprato, 1989). This was accomplished by grouping our coding categories described above into related "behavioral families" as follows:

- **Inactive Behavior** (rest and freeze)
- **Object-directed Behaviors** (bar press, bar touch, dipper entry, and object touch)
- **Self-directed Behaviors** (groom self, bite self, scratch self)
- **Spatially-directed Behaviors** (move, explore, and rear)

Subsequent figures illustrate unconditional probabilities for each of these "macro" categories across each successive 5 minute window of the 30 minute habituation session for all subjects combined.

These unconditional probability graphs illustrate that subtle changes occurred in behavioral probability across the duration of the habituation session. They reveal relatively high probabilities of object-directed behavior (see Figure 1) at the start of the habituation session up to minute 15. At the same time spatially-directed behavior (see Figure 2) is maintained at a high probability, with a minor dip and rebound at the end. With self-directed behavior (see Figure 3) we see a gradual increase until minutes 16-20, and afterwards it declines. Inactive behavior (see Figure 4), while brief, does increase in probability.

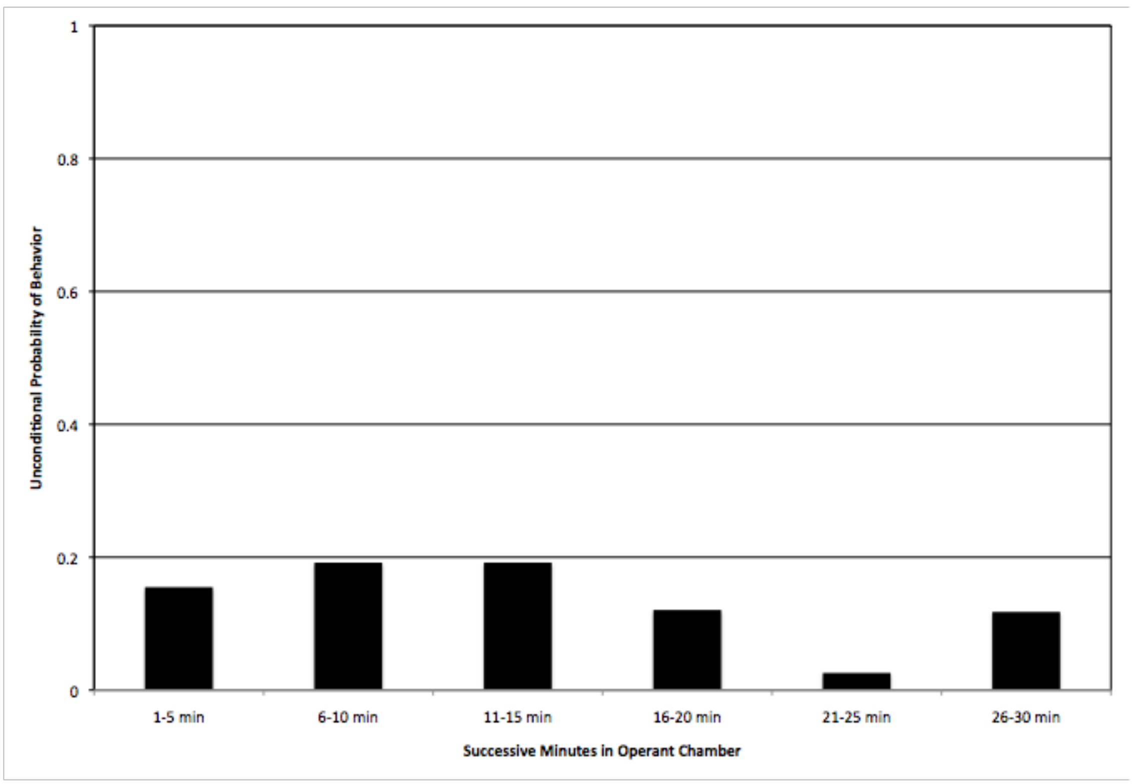


Figure 1. Object-directed behavior for all subjects combined during a 30 minute habituation to operant chamber session.

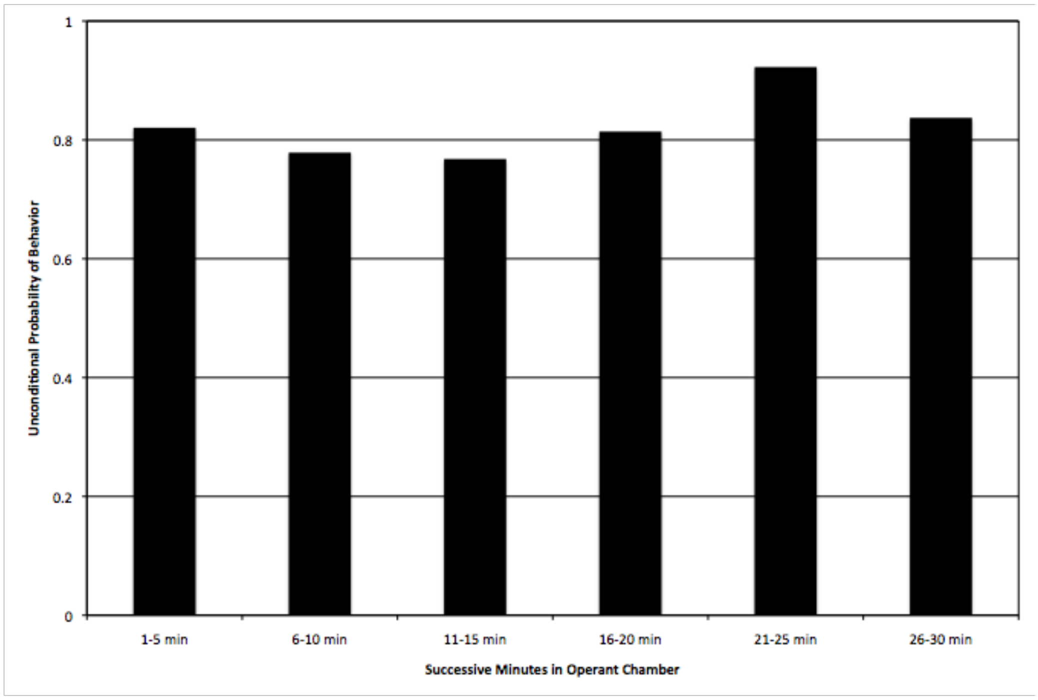


Figure 2. Spatially-directed behaviors for all subjects combined during a 30 minute habituation to operant chamber session.

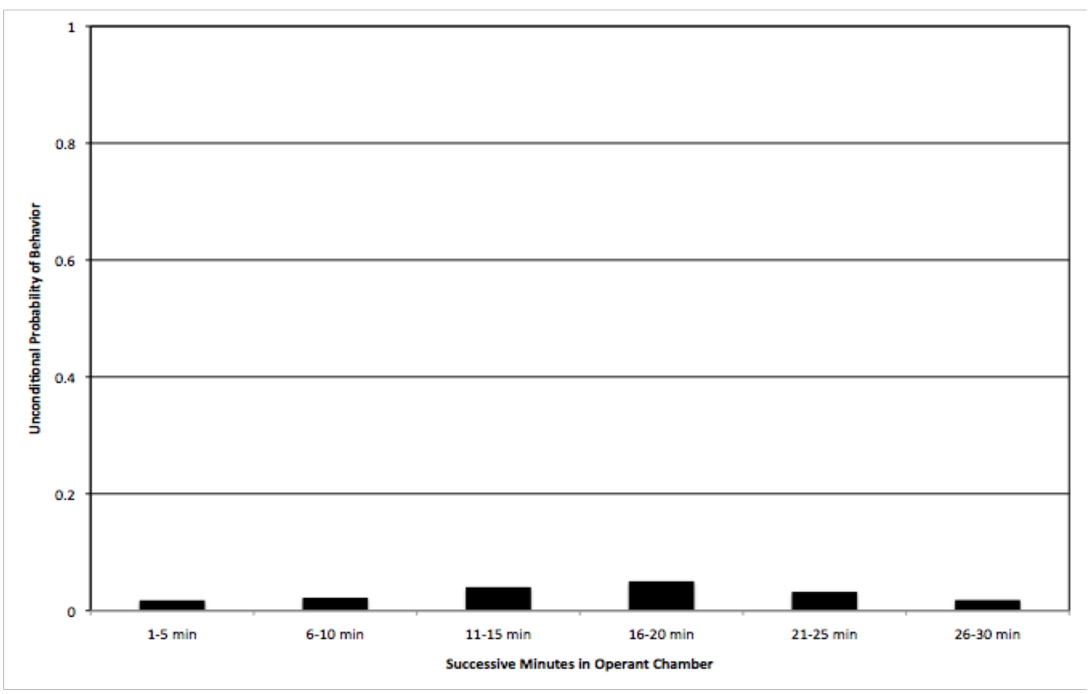


Figure 3. Self-directed behaviors for all subjects combined during a 30 minute habituation to operant chamber session.

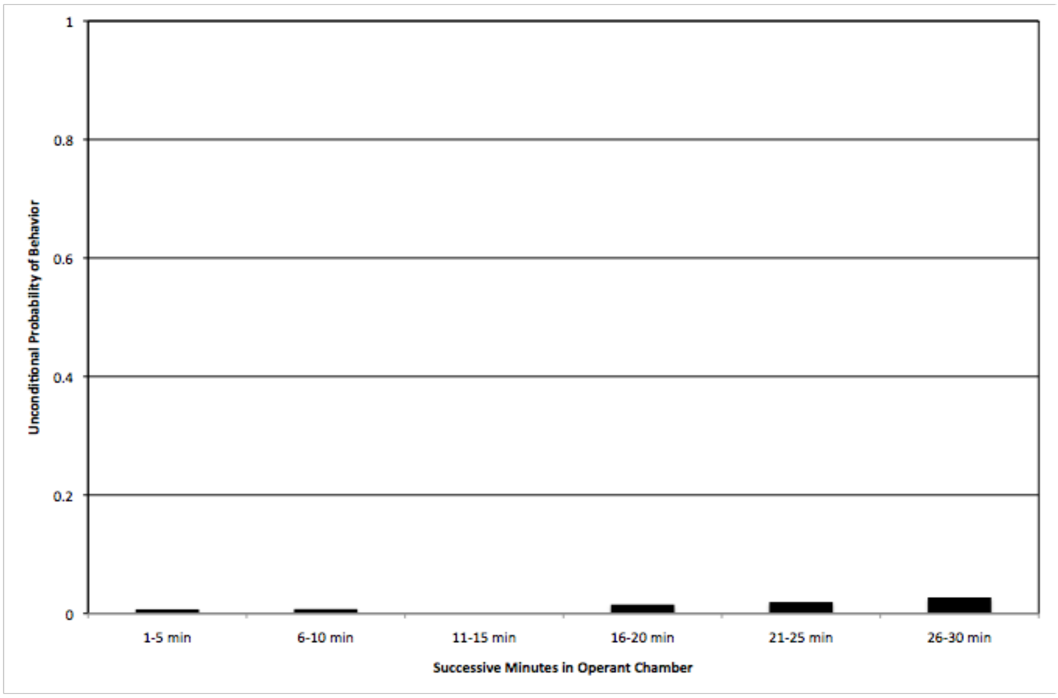


Figure 4. Inactivity as Behavior for all subjects combined during a 30 minute Habituation to operant chamber session.

Global Behavioral Organization During Habituation: Kinematics

Kinematic flow charts illustrating conditional probabilities of behavioral sequences based on the micro category system were determined for all subjects combined. The Kinematic Flow Chart depicted in Figure 5 represents only the highest probability paths of organization by dropping out all conditional probabilities with values less than .05. The most frequently occurring behavior illustrated in this Kinematic Flow Chart is Exploring, which accounts for 40% of all initiated behaviors for the entire 30 minute session. From Exploring behaviors, subjects engaged in Move 43% of the time, followed by Rearing and Dipper Entry each at approximately 10%. From Move and Rear, the animals were most likely to return to Exploring, with a probability of Move-to-Explore being .94 and Rear-to-Explore being approximately .40. Approximately 90% of all sequences involve these three behaviors.

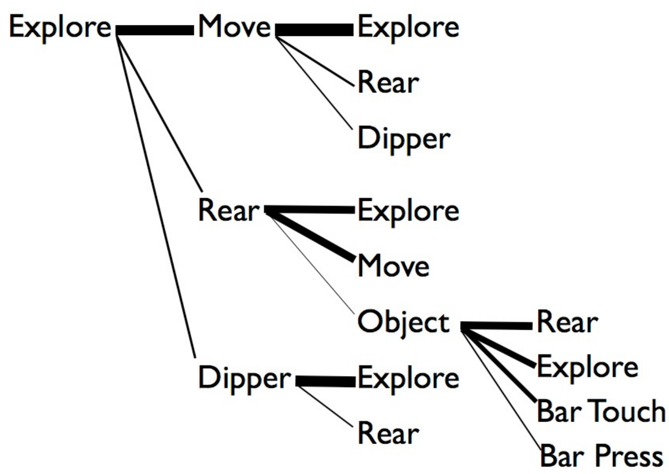


Figure 5. Kinematic Flow Chart illustrating all conditional probabilities greater than .05 for all subjects combined during habituation.

Global Behavioral Organization During Habituation: Behavioral Flow (Velocity) Dynamics

Ray and Brown (1975) also first introduced the idea of measuring the rate at which behavior changes, regardless of what behavioral sequences are involved. Over the years this measure has been referred to either as "behavioral flow rate" (Ray & Brown, 1975) or "behavioral velocity" (Ray & Delprato, 1989). In essence, it is a general inverse reflection of the durational aspects of behavior. When behavioral velocity is high, most behavioral events are relatively short in duration. When behavioral velocity is low, behavioral categories tend to be of a longer duration. Selective behaviors can impact this general measure, of course. For example, grooming tends to be much longer in duration than movements from place to place as well as rearing in upright exploration. As these behaviors change in probability with respect to one another, one also might expect general behavioral velocity to reflect that change. Of course specific behaviors can, and do, also change in relative duration within a category (Ray, Upson, & Henderson, 1977). The average behavioral velocity based on micro-categories for all subjects across each successive 5 minute window is depicted in Figure 6.

Behavioral velocity measures depicted in this graph reveal a gradual decline in the rate of change from behavior to behavior across the session (with the exception of the last 5 min window). Stated another way, behavioral durations are gradually lengthening across the 30 minute session up until the last 5 minute period, at which time velocity increases again. As noted, this is quite possibly due to the fact that the animals increase spatial exploration during this last period. This group of behaviors are typically of shorter duration than self-directed behaviors, such as grooming.

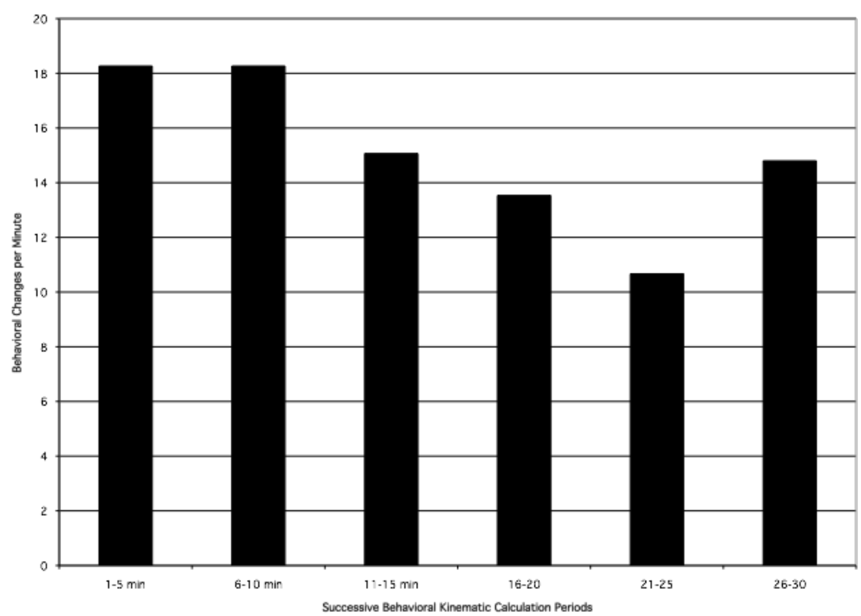


Figure 6. Average behavioral velocity across 30 minutes of habituation to an operant chamber.

Discussion

This Study and *CyberRat* V 2.0. The coding system used in this study was also defined as a general "index" so that it might be used as a general "search" engine for very fine-grained behavioral codes used to edit a new and improved digital video catalog for *CyberRat* V 2.0. In the actual working version of *CyberRat*, directional orientations and place within the chamber must be taken into account. Also, many "behaviors" at the mid-grain level are broken into smaller components. This allows them to be used for micro-behaviors. By video "splicings" into alternative "branches" of behavioral variations, they may then be used to recreate macro categories. Thus a tightly executed "clockwise circle" might actually be made up of an appropriate sequence of "quarter-turns." Initial "quarter-turns" might alternatively branch into "go to dipper" behaviors during a shaping process, wherein reinforcement initially "interrupts" the more complete circle that is eventually being taught. An astute reader will have already caught on to the fact that "turns" aren't even a categorical element of the coding system being reported presently, much less "clockwise" or "counter-clockwise" turns. In the above system, these would all fall under the "move" category.

This ability to "translate" from familial micro categories by collapsing them into "parent" macro categories is, of course, one of the explicit properties of hierarchically defined subsystems within systems theory (Ray et al., 1977). As such, *CyberRat* makes it possible to reconstruct replays using a similar coding scheme as that used in the study reported here. This is the "mechanism" used to implement the new feature in *CyberRat* that allows users to graph cumulative records for such categories as those used in our original studies, thus allowing one to evaluate what is happening to the rate of each category during any time within a session.

Experiment II: Bar Pressing Dynamics under Continuous Reinforcement Conditions with and without Prior Deprivation of the Reinforcing Stimulus

Skinner (1938) was one of the first to report that animals well exposed to the pairing of primary reinforcement, such as food or water, with the sound of a mechanical delivery device (a "magazine"--establishing a procedure called "magazine training") was sufficient to train rats to press levers for just the magazine sound alone. It might be expected that this "secondary reinforcement" would result in some degree of bar pressing in trained animals, even though they were not deprived of the reinforcement used for their training. Of course this all implies that animals have already been both magazine-trained and also trained to press levers for the primary reinforcing stimuli used. Thus we magazine trained and shaped bar pressing behavior in our 3 rats prior to more parametric investigations of bar pressing dynamics using water as a continuous reinforcing consequential operation for that class of behaviors.

Subsequently, we investigated bar pressing when animals were not water deprived prior to the session, thus allowing us to assess bar pressing and secondary reinforcement dynamics and to establish the expected bar press rate during sessions where no pre-session deprivation (i.e., home-cage ad libitum water availability) of the reinforcer had been applied. Following this experiment, we returned to depriving the animals for 22.5 continuous hours prior to daily sessions using continuous reinforcement (CRF) for each bar press. These sessions enabled us to determine when and how bar pressing rates would decline within (and across) prolonged (60 minute) sessions.

Method and Procedures

Three subjects who had prior bar press training on both CRF and some variable ratio (VR) schedules were taken off of deprivation scheduling and placed on ad-libitum water availability in the home cage for several weeks before running a "pre-session satiation test" session. On their test day, each subject was placed in an operant chamber with continuous water reinforcement available for bar pressing throughout a 60 minute evaluation session. This "pre-session satiation test" offered a baseline "satiety" bar press rate for each well-trained, but not recently practiced nor water deprived, subject which could then be applied as a criterion for that same animal having reached an equivalent “satiety” state/rate in subsequent sessions involving pre-session deprivation.

Returning animals to deprivation schedules also gave us the opportunity to evaluate whether deprivation scheduling across days that include experimental sessions might have any cumulative dynamics. Common laboratory practices often dictate that animals be placed on a deprivation schedule for some time prior to initiating research. The idea is to "get subjects used to the deprivation schedule" or to "stabilize deprivation scheduling effects." We wished to document whether this is a true concern, and thus immediately transferred from our "ad-lib water availability" in the home cages to running 5 successive days of a CRF session using a 22.5 hr schedule of water deprivation prior to the session.

These 5 successive sessions were also used to investigate when satiation was reached in these 60 minute bar press sessions under 22.5 hr deprivation conditions. To operationally define satiety we applied the criterion of a continuous 5 minute period where the average bar press rate within that 5 minute window was at or below the average bar press rate for that same subject as established from that animal’s satiation test session. The time of onset for this 5 minute period was then used as the time at which "satiety" had been reached for that animal, regardless of subsequent bar press rates. However, because we had some subjects who met this criteria before any sustained rates of bar pressing had been established (see discussion below concerning session "warm-up/habituation" phenomena and measures), we specifically excluded this early period by imposing a "prerequisite" criterion that the average rate of bar pressing for the entire session had to be reached and/or exceeded prior to application of the satiation criterion.

Our research on CRF under water deprivation establishing operations also revealed that it may take some time for a subject to "habituate" to being placed in the operant chamber each session, even after significant prior training histories in this environment. This "warm-up" period comes before a steady and sustained rate of bar pressing occurs. We thus calculated the amount of time it took to reach the 5th, 10th, 15th, and finally the 20th bar press to determine the character of this warm-up/habituation period, and these data are reported for the satiation test experiment as well as for subsequent experiments.

Results for Pre-experimental *ad-libitum* Scheduling: Individual Session Data for Each of the Three Subjects

Despite being maintained on an *ad-libitum* schedule of water access, all 3 animals pressed the bar for water between approximately 60 to 90 times across the one hour sessions. Each of the 3 subject's average bar press rates, plus the time elapsed until the 5th, 10th, 15th, and 20th bar press (warm-up period) are reflected in the “inset notes” for each graph in Figures 7, 8, and 9 respectively. Following this session under no deprivation conditions, we re-established deprivation as the establishing operation or setting factor and conducted another series of CRF "maintenance" sessions to assess the rates and rate stability for these same animals. These sessions are reported in the next experiment (Experiment III).

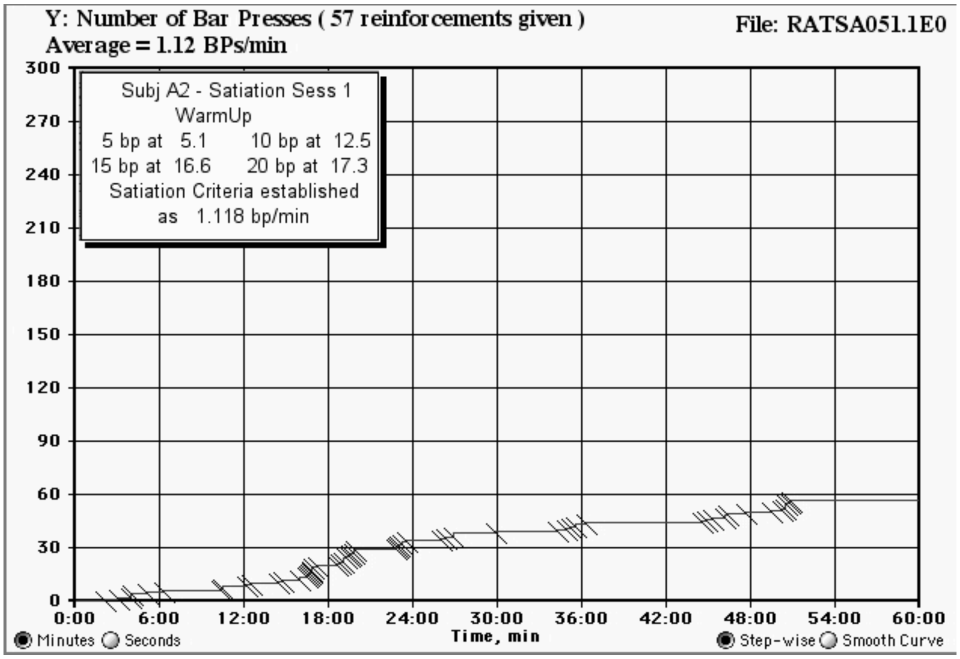


Figure 7. Subject A2: 60 minute "satiety" test session with warmup period.

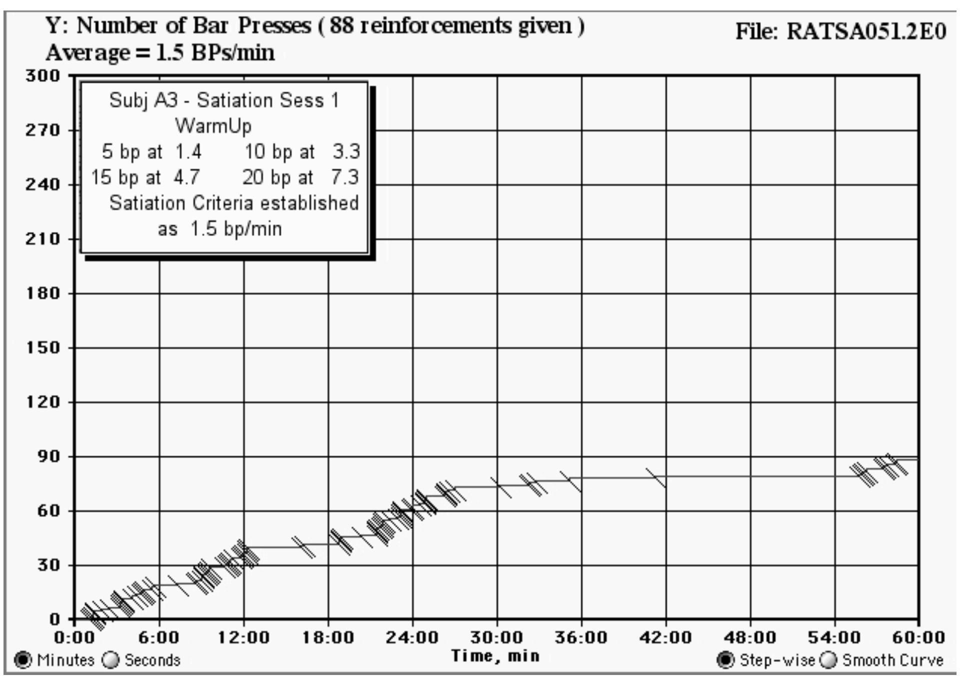


Figure 8. Subject A3: 60 minute "satiety" test session with warmup period.

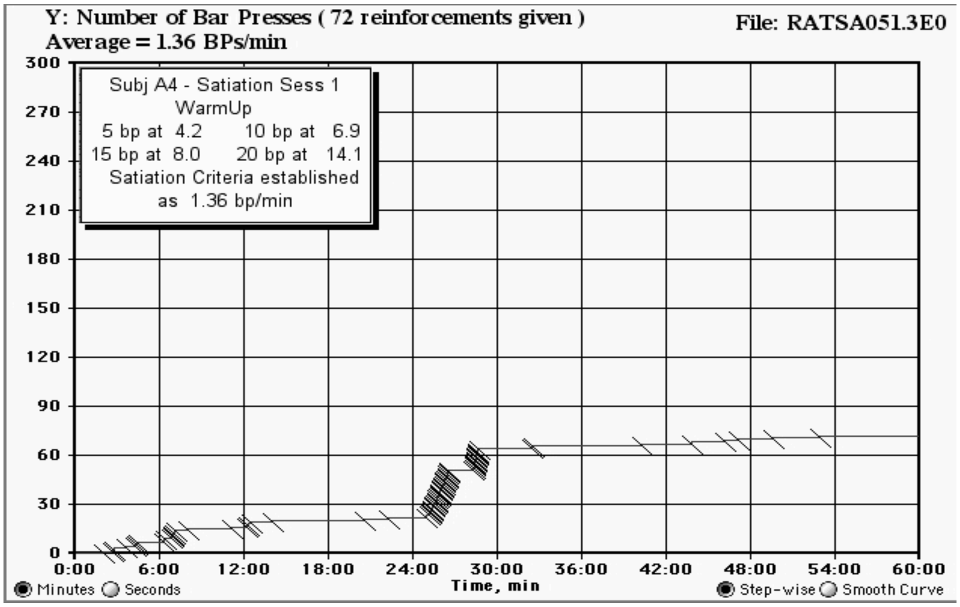


Figure 9. Subject A4: 60 minute "satiety" test session with warmup period.

Results for Deprivation Scheduling: Individual Session Data for Each of the Three Subjects

Subject A2. Cumulative record data collected from subject A2 for each of the 5 sessions following 22.5 hrs of deprivation are shown in the first column of cumulative records depicted in Figure 10. The average time it took for animal A2 to become satiated was 21.4 minutes (*SD* = 5.3)The average number of bar presses that it took A2 to become satiated was 135.2 (*SD* = 69.6). The average maximum sustained bar press rate after the 20th bar press for A2 (see "Warm-up/Habituation Discussion below) and continuing until the satiation criterion was met for this subject was 7.4 bpm.

Subject A3. Individual session records for subject A3 are shown in the second column of cumulative records depicted in Figure 10. The average time it took for animal A3 to become satiated was 21 minutes (*SD* = 7.4 minutes). The average number of bar presses for A3 to become satiated was 222 (*SD* = 99.5), while the average maximum sustained bar press rate after the 20th bar press (see "Warm-up/Habituation Discussion below) and continuing until the satiation criterion was met was 10.7 bpm.

Subject A4. Individual session records for subject A4 are shown in the third column of cumulative records depicted in Figure 10. The average time it took for A4 to become satiated was 8.4 minutes (*SD* = 1.1 minutes). The average number of bar presses that it took for A4 to reach satiety criteria was 104 (*SD* = 30.0). The average maximum sustained bar press rate after the 20th bar press (see "Warm-up/Habituation Discussion below) and continuing until the satiation criterion was met for subject A4 was 14.1 bpm.

Subject A2 **Subject A3** **SubjectA4**

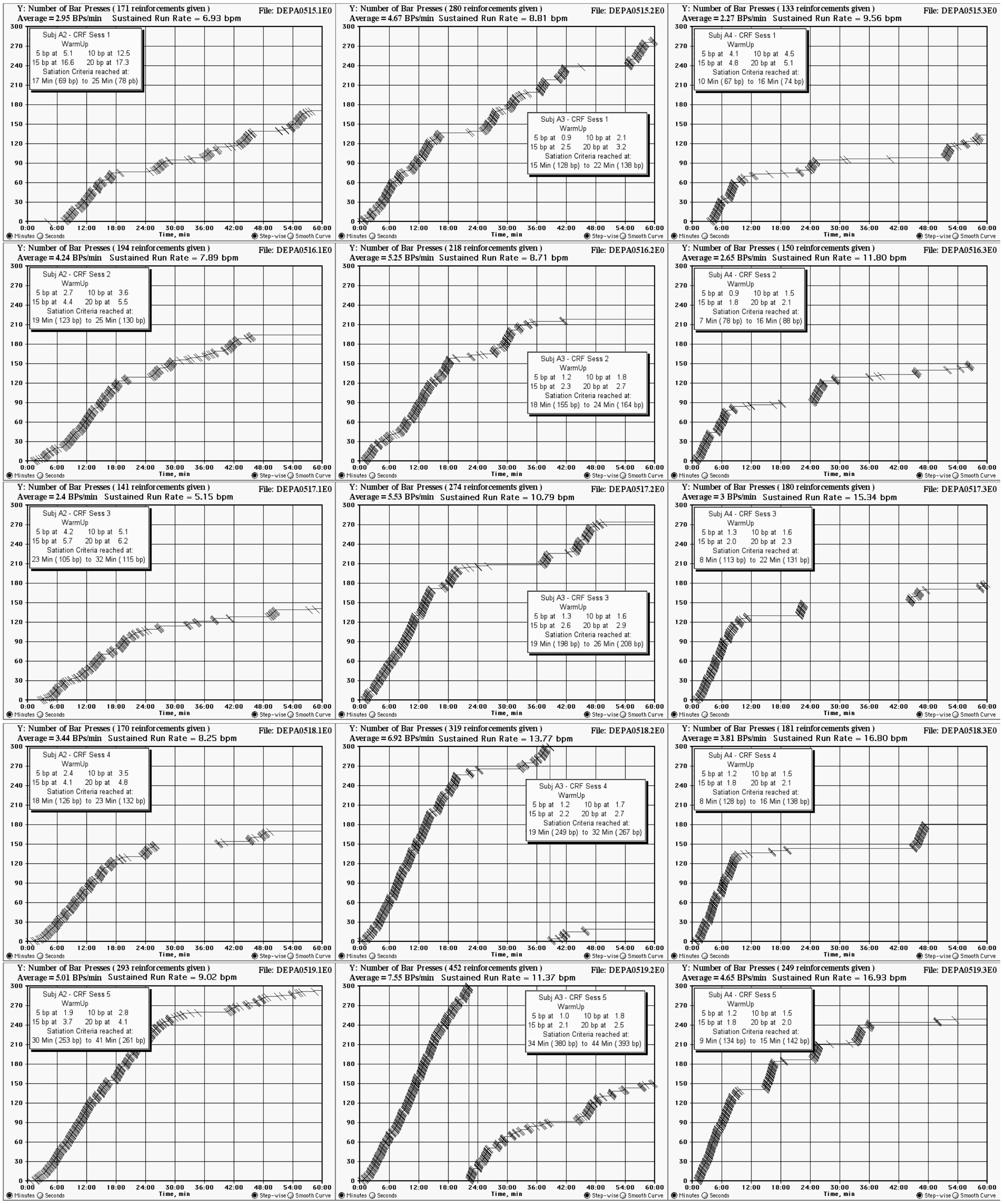


*Figure 10***.** Cumulative records for subjects A2, A3, and A4 across the first 5 successive sessions of CRF maintenance under 22.5 hour deprivation.

Result for All Subjects Analyzed *as a Group* across all 5 Sessions Combined

As illustrated in Table 2, all of the subjects considered as a group across all sessions averaged 16.70 minutes to satiation (*SD* = 7.96 minutes). Table 2 also illustrates that the group averaged 153.73 bar presses to satiation (*SD* = 85.20). The average maximum sustained bar press rate was 10.7 bpm, reached after the 20th bar press (see "Warm-up/Habituation Discussion below) and continuing until the satiety criterion was met for the group.

Table 2
Descriptive Statistics: Satiation During 5 CRF Sessions for All 3 Subjects Combined.

	M	*SD*
Minutes to Satiation	16.70	7.96
Bar Presses to Satiation	153.73	85.20

Increasing Deprivation Schedule Effects Across Sessions

A close inspection of Figure 10 will reveal that each of the three animals shows increasing bar press rates across successive sessions. Likewise, for each of the animals there is a systematic increase in the amount of time and/or the number of bar presses (and thus the amount of water consumed), or both, prior to satiety from 1st to 5th session. A detailed summary of the descriptive statistics showing the cumulative effects across these 5 successive days of scheduled deprivation prior to 60 min CRF sessions are summarized in Table 3. When the deprivation schedule was first initiated, bar pressing was considerably elevated above the previous day's "satiation" test session, where average bar press rates for the entire session ranged from 1.1 to 1.5 bpm (see Figures 7, 8, and 9). First sessions under deprivation conditions range from 6.93 (A2) to 9.56 (A4) bpm. By the 5th day of CRF testing, rates were up considerably. As Table 3 reveals, rates of bar pressing for A2 went from 6.93 bpm to 9.02 bpm between sessions 1 and 5; A3 went from 8.81 to 11.37 bpm; and A4 went from 9.56 to 16.93 bpm.

Table 3
Bar Presses Per Minute, Minutes to Satiation, and Bar Presses to Satiation for Each Subject Across 5 Successive Sessions.

	A2			A3			A4		
	BPM	Min to Sat	BP to Sat	BPM	Min to Sat	BP to Sat	BPM	Min to Sat	BP to Sat
Session 1	6.93	17	69	8.81	15	128	9.56	10	67
Session 2	7.89	19	123	8.71	18	155	11.80	7	78
Session 3	5.15	23	105	10.79	19	198	15.34	8	113
Session 4	8.25	18	126	13.77	19	249	16.80	8	128
Session 5	9.02	30	253	11.37	34	380	16.93	9	134

The column depicting the number of bar presses until our criteria for satiety was reached also reflects an increasing effect of the deprivation schedule. Thus A2 went from 69 bar presses before reaching satiation criteria in session 1 to 253 bar presses prior to reaching the same criteria in session 5; A3 went from 128 (session 1) to 380 (session 5); and A4 went from 67 to 134 bar presses between session 1 and 5 before reaching satiation criteria.

Results Regarding Warm-Up (Habituation) Periods Prior to the Onset of Bar Pressing for Each Session.

The individual session data illustrated in Figure 11 clearly show that each subject takes varying amounts of time to "warm up" (habituate to being placed into the operant chamber) at the beginning of each session before a steady and sustained rate of bar pressing occurs. We calculated the amount of time it took to reach the 5th, 10th, 15th, and finally the 20th bar press to determine the character of this warm-up/habituation period. The time it took for each rat in each session to get to 20 bar presses is depicted in Figure 11, which illustrates a mean of 2.04 minutes (*SD* = 1.37) for all animals to press the bar 5 times, a mean of 3.04 (*SD* = 2.80)to press 10 times, a mean of 3.81 minutes (*SD* = 3.70) to press 15 times, and finally a mean of 4.32 minutes (*SD* = 3.81 minutes) to reach their 20th press. Inspection of the individual plots in Figure 11 clearly reveals that two or three "outliers" at the 20th press tend to inflate the "average time to-reach 20 press, especially during the first session's 15-20 period, so the median (2.90 minutes) is perhaps a better representative of the true 20-second warm-up time.

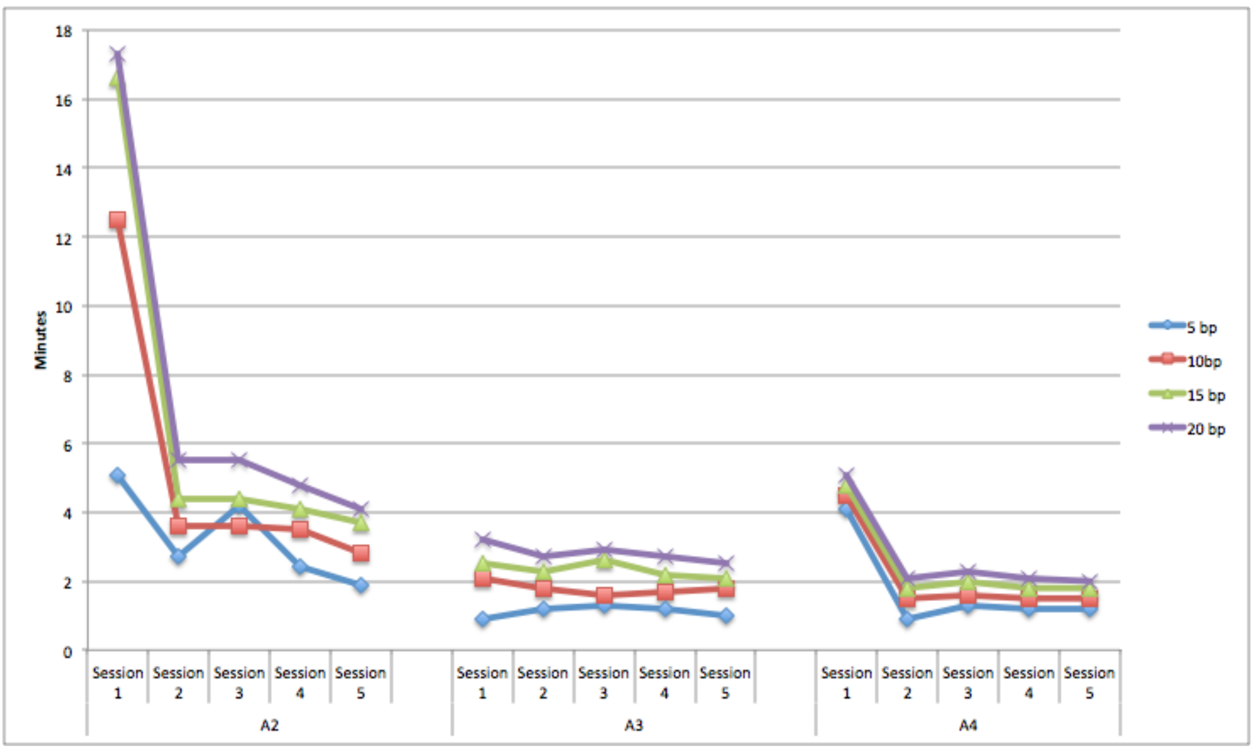


Figure 11. Individual plots of the bar-pressing warm up measures based on the time required to reach the 5th, 10th, 15th, and 20th bar press for each of three subjects, A2, A3, and A4, across successive daily sessions of CRF conditions.

Descriptive statistics for all animals considered as a group for each of these four 5-minute "windows" are presented in corresponding rows of data in Table 4 below (Row 1 = Time to First 5 Presses, Row 2 = Time to 10th press, etc.).

Table 4
Descriptive Statistics: Time to Reach 5th, 10th, 15th, & 20th Bar Presses

	M	*SD*
5th Bar Press	2.04	1.37
10th Bar Press	3.04	2.80
15th Bar Press	3.81	3.70
20th Bar Press	4.32	3.81

Experiment III: Bar Press Extinction Dynamics Following Continuous Reinforcement Conditions

Following 10 experimental sessions of CRF reinforcement as described above for Experiment 2, we changed experimental operations by introducing extinction conditions--i.e., conditions where no reinforcements were available as consequences for any behavior.

Method and Procedures

Subjects had prior training involving 10 sessions of continuous reinforcement for bar pressing. Those 10 sessions were followed by three successive days of a single 60 minute session with no reinforcement available for any behavior (extinction).

Results for Extinction Sessions

Individual session data for each of three subjects for successive sessions of extinction are depicted in Figure 12. The first column of cumulative records depict Subject A2, the center column depicts A3, and the last column depicts A4. Little bar pressing occurred after the first 20 minutes of session 1 for any of the animals, although animal A4 was the most persistent and showed small bursts even late in the 60 minute session. Total bar presses for the hour varied from approximately 30 for A3 to nearly 110 bar presses for A4. Session 2, administered the following day, reveals relatively weak amounts of spontaneous recovery from Session 1 extinction. By session 3 on the third day, extinction appears nearly total.

Subject A2 **Subject A3** **Subject A4**

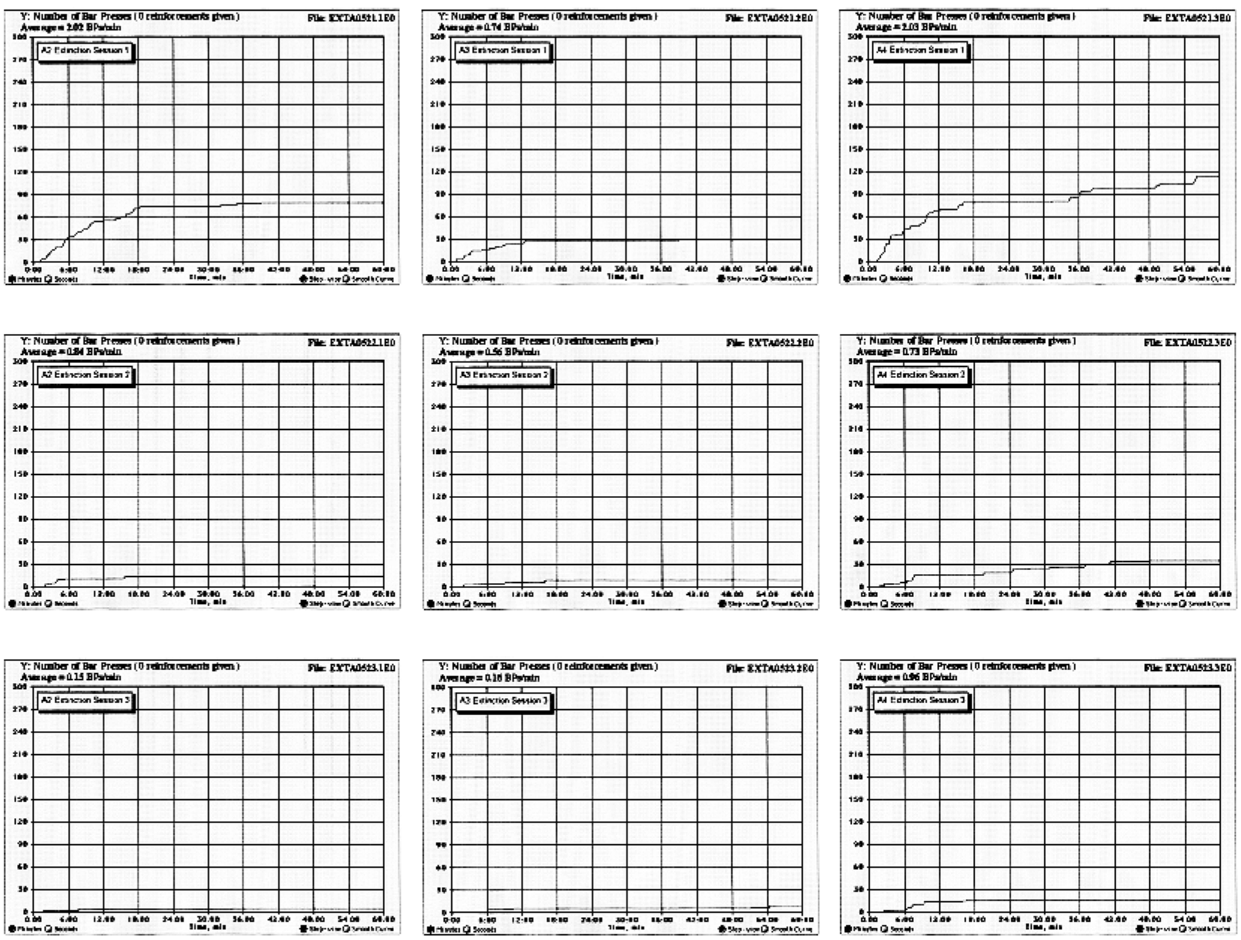


Figure 12. Cumulative records for individual sessions for each of three subjects, A2, A3, and A4, across successive daily sessions of extinction conditions.

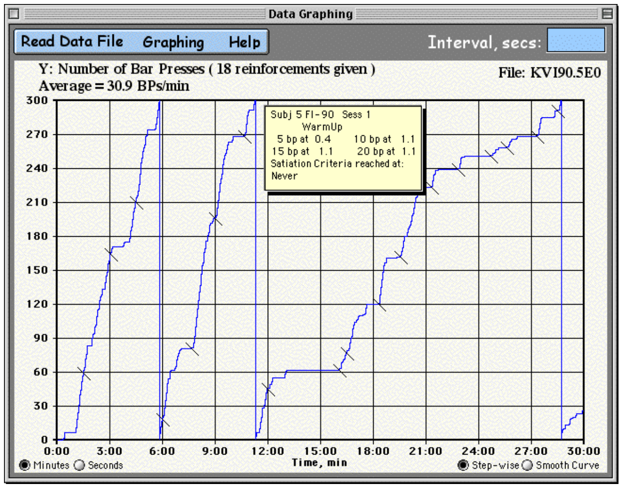
Experiment IV: Intermittent Reinforcement Schedules and Associated Response Rate Patterns

In a 50-year retrospective reflection on the discovery and significance of Skinner's pioneering work on schedules of reinforcement (Skinner, 1956), Morgan (2010) suggests that the defining book on the topic was Ferster and Skinner's (1957) *Schedules of Reinforcement*, but that it was "…dominated not by verbiage but by volumes of cumulative records, portraying response characteristics across a wide array of schedule types and parameters…." (p. 153). Nevertheless, these "volumes of cumulative records" offered very little guidance as to the specific values and timing that should be incorporated when modeling rats pressing levers for water reinforcement. While general patterns in responding are similar from species-to-species and from type of reinforcers used, there are far too many prior reports based solely on pigeons and food-as-reinforcement to warrant generalization in modeling specific values in *CyberRat*. But to duplicate Ferster and Skinner's varieties of cumulative records just to learn about the species/stimulus differences was far beyond reasonable aspirations. Thus we simply sampled some fundamental schedules for reproduction and investigation, with an intent to consider this sample as sufficient for guiding reasonable reproductions of well known scheduled-associated response patterns. Such patterns include the breaks that occur after reinforcement in fixed ratio (FR) and fixed interval (FI) schedules, as well as the scalloped patterns of FI schedules. Further, current space and purpose is far too limited here to report each session for each animal under each alternative schedule even from our limited samples, so only a few of details will be provided for real animals and *CyberRat* simulations. And because most of our data reproduce schedule transitions, only the last session under any schedule will be used to represent stabilized patterns.

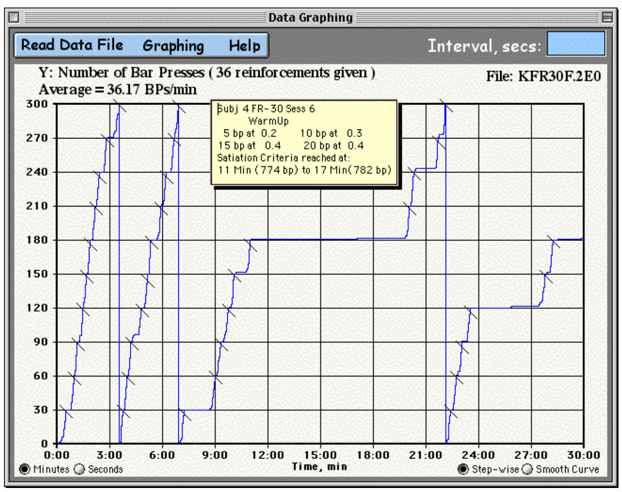
Method & Procedures

The following procedures were used to generate our sample of parameters that guided the modeling of intermittent water reinforcement schedule effects on bar-press patterning with rats. The project started with determining CRF response characteristics, including those already described regarding warm up and satiation, as well as determining consistent and sustained-rate values. Subsequent to these 10 sessions for 3 animals using CRF, we shifted to the investigations of FI reinforcement based on unlimited holds and an interval of 2 seconds. We followed with a session using an interval of 90 seconds. This was suggested to be a feasible schedule by Skinner's (1938) description of FI schedule performances, and we wanted to verify that the subjects would make such a transition without schedule-induced extinction (sometimes referred to as *ratio-strain*). Subjects were exposed to one session of FI 2 seconds on an automated schedule involving unlimited hold periods providing reinforcement for the first response following each 2 seconds non-reinforcement interval. Following that session, a second session used the same rules, except a FI 90 seconds interval replaced the 2 seconds non-reinforcement interval of the first session.

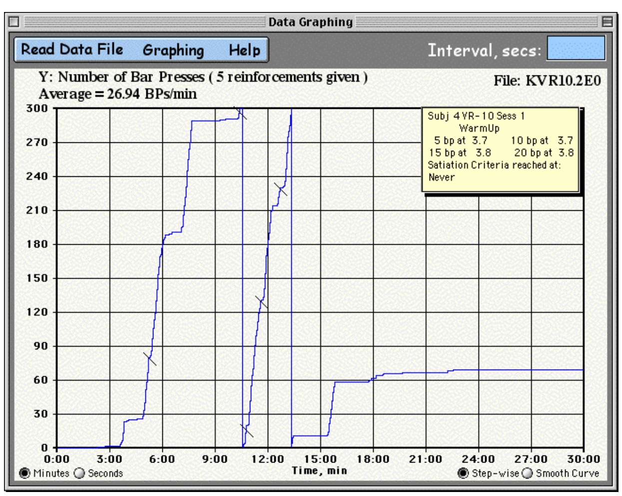
In our next experimental phase we shifted from the FI reinforcement used in the prior two sessions to the application of FR schedules of reinforcement based on 5, then 10, then 30 responses per reinforcement. These sessions were conducted in the following manner: Three successive daily sessions of FR 5 were followed by another three (subject 4 and 5) to five sessions (subject 6) using FR 10. These sessions were, themselves, followed by either six successive sessions of FR 30 (subjects 4 and 5) or by four successive sessions of FR 30 (subject 6). Following these sessions, two successive daily sessions of variable ration (VR), based on a VR 5, were administered followed by one session of VR 10 on a subsequent day. Subjects were then exposed to two successive sessions of variable interval (VI) 90 seconds schedule training. Representative data from these various conditions are illustrated in Figures 13a (FI 90), 13b (FR 30); 13c (VR 10); and 13d (VI 90).



a. (FI 90 sec)

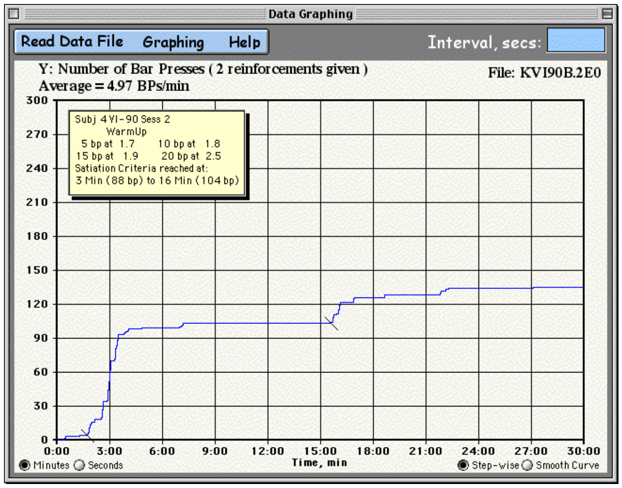


b. (FR 30:1 ratio)



c. (VR 10:1 ratio)

d. (VI 90 sec)



Figures 13a, 13b, 13c, and 13d. Representative live animal data from the experimental series investigating response rates and pattern characteristics for rats pressing for water under various intermittent schedules. Graph 13a is for animal 5 in Session 1 of an FI 90 sec schedule series; Graph 13b is for animal 4 in Session 6 of a FR 30:1 ratio schedule series; Graph 13c is for animal 4 in Session 1 of a VR 10:1 average ratio schedule series; and Graph 13d is for animal 4 in Session 2 of a VI 90 sec schedule series. Graph 13d suggests the effects of schedule-strain generated from moving to a very lean schedule and thus resulting in extinction—an effect observed in all 3 animals when moved to this schedule from their previous VR 10:1 averaged ratio schedule.

References

Bakeman, R., & Gottman, J. M. (1997). *Observing interaction: An introduction to sequential analysis (2nd ed)*. New York, NY: Cambridge University Press.

CyberRat (Version 1.0) [Computer software]. Winter Park, FL: AI2 Inc.

CyberRat (Version 2.0) [Computer software]. Winter Park, FL: AI2 Inc.

CyberRat (Version 3.0) [Computer software]. Winter Park, FL: AI2 Inc.

Ferster, C. B., & Skinner, B. F. (1957). *Schedules of reinforcement*. New York, NY: Appleton-Century-Crofts.

Morgan, D. L. (2010). Schedules of Reinforcement at 50: A retrospective appreciation. *Psychological Record*, *60*, 151-172.

Ray, R. D. (1992). Interbehavioral methodology: Lessons from simulation. In T. Sharpe & A. Hawkins (Monograph Eds.) Field systems analysis: An alternative strategy for the study of teaching expertise. Special monograph of the *Journal of Teaching Physical Education, 12*(1), 105-114.

Ray, R. D. (1996). *CyberRat: Methodological lessons learned from designing an interactive digital video laboratory simulation for operant conditioning*. Invited Address, Association for Behavior Analysis, San Francisco.

Ray, R. D., & Brown, D. A. (1975). A systems approach to behavior. *Psychological Record*, *25*, 459-478.

Ray, R. D., & Brown, D. A. (1976). The behavioral specificity of stimulation: A systems approach to procedural distinctions of classical and instrumental conditioning. *Pavlovian Journal of Biological Sciences*, *11*, 3-23.

Ray, R. D., & Delprato, D. J. (1989). Behavioral systems analysis: Methodological strategies and tactics. *Behavioral Science*, *34*, 81-27.

Ray, R. D., & Mitchell, N. L. (1993). Good-bye scientific journals: Tomorrow's scientific communications. J*ournal of Medical Education Technologies, 3*(3), 47-50.

Ray, R. D., & Ray, M. R. (1976). A systems approach to behavior II: The ecological description and analysis of human behavior dynamics. *Psychological Record*, *26*, 147-180.

Ray, R. D., Upson, J. D., & Henderson, B. J. (1977). A systems approach to behavior III: Organismic pace and complexity in time-space fields. *Psychological Record*, *27*, 649-682.

Skinner, B. F. (1938). *The behavior of organisms: An experimental analysis*. Oxford, England: Appleton-Century.

Skinner, B. F. (1956). A case history in scientific method. *American Psychologist*, *11*, 221-233.