THE TEMPORAL PATTERN OF UNCONSTRAINED DRINKING: RATS' RESPONSES TO INVERSION AND IDENTITY CONSTRAINTS

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Rats obtained all of their water by licking a metal tube during a series of daily 1-hour sessions. When the tube was freely available throughout, each rat showed the classic temporal pattern of unconstrained drinking: As the session progressed, drinking bouts generally grew shorter and pauses grew longer. In subsequent sessions the tube was opened and closed independently of the rat's behavior, on a schedule that gave the rat a chance to duplicate the exact inverse of its unconstrained baseline pattern. Thus, as the inversion session progressed, the opportunities to drink generally grew longer and the enforced pauses grew shorter. When the rats were forced away from their unconstrained patterns of drinking and pausing, their total time spent drinking consistently fell short of previous values, but total licks and volumetric intake remained at previous levels. The same results occurred under an identity schedule, a series of openings and closings that duplicated the unconstrained pattern of drinking and pausing. The results have implications for theories that assume that instrumental performance under schedule constraint derives from the animal's defense of a measured set-point.

Key words: drinking, bouts, pauses, unconstrained pattern, inversion constraint, identity constraint, rats

Numerous regulatory models assume that performance under the constraints of a schedule derives from the animal's defense of some set-point for the kinds of behavior controlled by the schedule (Hanson & Timberlake, 1983; Heth & Warren, 1978; Rachlin & Burkhard, 1978; Staddon, 1979; Timberlake, 1980; Timberlake & Allison, 1974). The set-point is commonly defined in terms of the total amount of responding typically observed in the absence of schedule constraint, in constant-duration sessions that allow unrestricted performance of the kinds of behavior under study. Various tests of the set-point status of a particular behavioral total have been performed or proposed (Allison, 1981, 1983). Some of the tests inspired a round of critical debate and comment (Hursh, Case, Mazur, Fantino, Branch, & Shull, 1984; Staddon, 1983, p. 220; Timberlake, 1984) that has helped crystallize the question posed here: Can we define a particular set-point solely in terms of a behavioral total, or must we also attend to the underlying pattern—the specific path the animal takes as it accumulates that total?

The present paper introduces a method of rearranging the component parts of the unconstrained behavior, while forcing no change within any part. The question is whether the animal, forced out of its unconstrained pattern, will still reproduce the unconstrained total. If it does, then the underlying pattern would seem to be irrelevant. If it does not, then the sequential organization of the behavior would seem to be a pertinent system variable with a set-point of its own.

As a preliminary step, we recorded the unconstrained behavior of the thirsty rat in a series of daily 1-hr sessions of free access to a water tube. These records provided information about the rat's drinking patterns in the absence of external constraint, including total time spent drinking, the duration of each drinking bout and each pause, and the place of each duration in the entire sequence of bouts and pauses.

Next we tested whether the rat would invert its unconstrained sequence of bouts and pauses, if that were the only way it could maintain its total time spent drinking. We did that by presenting the tube intermittently. For example, suppose the rat typically started the free-access session with a 50-s bout of drinking and finished with a 300-s pause. Then the

test session under the *inversion constraint* would start with the water tube closed for 300 s and finish with the tube open for 50 s, the reverse of the unconstrained sequence.

Figure 1, which plots cumulative drink time against cumulative pause time, illustrates the method and a few possible outcomes. Because we treated drinking and pausing as mutually exclusive and exhaustive categories, the rat had to finish each session at some point on the diagonal line on the right: Each point on the diagonal represents a total of 3,600 s, the sum of drink time and pause time. The top staircase line traces the path a rat might follow, given free access to the tube. It shows the classic pattern—a brief pause at the start of the session followed by alternate drinks and pauses, the drinking bouts generally growing shorter and the pauses longer as the session progresses (Allison & Castellan, 1970; Stellar & Hill, 1952).

The staircase line immediately below the top line represents the corresponding inversion constraint. Each horizontal run represents a time period when the tube is closed, a forced pause of the same duration as one of the unforced pauses shown on the top line. Each vertical rise represents a time period when the tube is open for the duration of one of the drinking bouts shown on the top line, a chance for the rat to duplicate that particular bout. The sequence of runs and rises that defines the constraint line is the exact inversion of the unconstrained sequence shown on the top line. Thus, the rat can reproduce its unconstrained total time spent drinking if, and only if, it drinks whenever it can. But if it drinks whenever it can, it will necessarily generate, in temporal detail, the inverted version of its unconstrained pattern of drinking and pausing.

The rat cannot rise above the line of constraint shown in the figure, but can fall below. By way of illustration, the broken line shows the path the rat might follow if it did not fully exploit its final chance to drink. Upon the final opening of the tube the rat continues its pause for several seconds, starts drinking, then stops while the tube stays open; the tube closes during the latter pause, and the session ends several seconds later.

Note that the method described above requires no alien or novel frequency distribution of bout duration or pause duration (cf. Dunham, 1977), for the frequency distribution required under constraint is one the animal has already generated in the absence of constraint. The method thereby allows a relatively pure test of the role of sequential patterning, closely attuned to the individual's normal bout and pause durations.

This general method is easily varied. Although our main concern was the inversion constraint, we also obtained some information on a second kind, the *identity constraint*. Under the identity schedule, openings and closings of the tube would coincide with the unconstrained pattern of drinks and pauses. In the context of Figure 1, the top line would represent both the unconstrained pattern of drinks and pauses and the identity constraint, with the tube closed for the duration of each run, and open for the duration of each rise. Thus, the identity schedule allows a relatively pure test of the role of external constraint as such, because it requires no novel bout or pause durations, and no novel sequence.
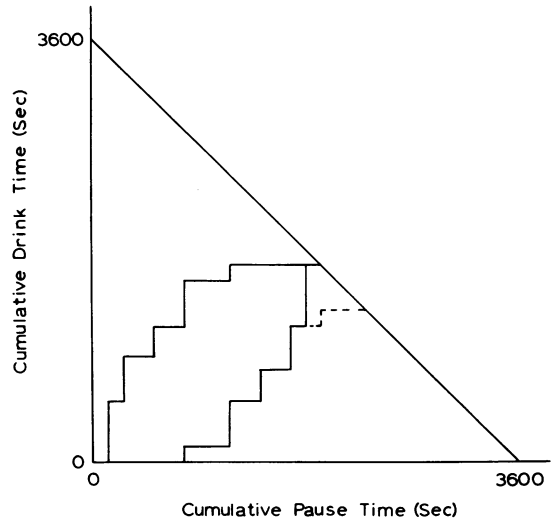

Fig. 1. Cumulative drink time as a function of cumulative pause time. The top line represents a hypothetical performance under the unconstrained baseline condition, the middle line the inversion constraint; the broken line represents a hypothetical performance under the inversion condition.

METHOD

Subjects

Six naive 90-day-old male albino rats, purchased from Laboratory Supply Company (Indianapolis), served as subjects. We discarded 1 of the 6 when it failed to meet our sta-

bility criteria during the test phase of the experiment.

Apparatus

We tested the rats in three identical chambers 26 cm wide, 24 cm deep, and 18.5 cm high, controlled by separate microcomputers. The sheet metal chamber had a front door made of transparent Plexiglas; three stainless steel drinking tubes, with graduated water bottles, were mounted on the outside of the rear wall. The tip of each tube was 7 cm above the floor, and had a 3-mm orifice. Only the right-hand tube, 9 cm from the right wall, was used; apertures to the other two tubes stayed closed throughout the experiment.

The tip of the tube was recessed 5 mm beyond the interior surface of the rear wall. An electric motor opened or closed the aperture that gave access to the tube, by raising or lowering a metal shutter located between the tip of the tube and the outside surface of the wall. An electronic drinkometer registered discrete tongue contacts with the tube.

A rectangular cutout in the right side wall, 5 cm wide and 2.5 cm high, gave access to a food trough filled with powdered laboratory chow. A 15-W bulb in the ceiling lighted the room that housed the chambers, and a noise generator masked extraneous sounds.

Procedure

Food was freely available in both the test chamber and the home cage throughout the experiment. For several days before the first test session, we handled the rats daily and restricted their home-cage watering to the 1-hr period reserved for their experimental test sessions. On the day before the first test session, we closed the water tube and introduced the rat to its test chamber for 15 min of free exploration. Baseline testing began the next day. From that day on, water was available only during the daily test session.

During the unconstrained baseline phase, the water tube stayed open throughout the session; after each session we recorded total food intake (g) and total water intake (mL). The computer classified each of the 3,600 s as either 1 s of drinking (if the 1-s window showed at least one lick) or 1 s of pausing (if the 1-s window showed no licks). Consecutive seconds of drinking were classified as members of the same drinking bout, and their number measured the duration of the bout in

seconds. The computer also recorded the number of licks in each distinct bout. Consecutive seconds of pausing were classified as members of the same pause, and their number measured the pause duration. During inversion or identity constraint sessions, the computer distinguished forced pauses (when the tube was closed) from unforced pauses (when the tube was open).

In evaluating the stability of individual rats' data we attended to five totals: time spent drinking, number of licks, food intake, water intake, and number of bouts. For each rat, each major test phase was continued until two criteria were met with respect to each of the five totals: three consecutive sessions with no appreciable systematic change, and a standard deviation no greater than 15% of the three-session mean.

To avoid the problems inherent in combining the three final sessions for the calculation of an average temporal pattern, we simply selected one of the three as representative of all measures for that particular rat. Specifically, we selected as the typical session the one that contained the rat's median total time spent drinking.

After the baseline phase, we introduced the inversion-constraint condition by inverting the sequence of bout and pause durations that had occurred during the typical baseline session. Among 4 of the 5 rats, the baseline sequence both started and ended with a pause, so their inversion-constraint sessions both started and ended with the tube closed for specific periods of time. The remaining rat typically started the baseline session by drinking, and ended with a pause; accordingly, its inversion-constraint sessions started with the tube closed, and ended with the tube open. A particular example may remove any confusion about the inversion-constraint condition. One rat's typical baseline session started with a 17-s pause, followed by a 38-s bout; after several additional episodes there was a 9-s bout followed by a 646-s pause, at the end of which the session expired (Rat R-1). Accordingly, we started this rat's inversion sessions by placing the rat into the chamber with the tube closed, and starting the program after a brief delay; 646 s later, the tube opened and stayed open for 9 s, regardless of the rat's behavior; after several additional timed openings and closings we opened the tube, closed it 38 s later, and ended the session 17 s after that final closing.

After its final inversion session, each rat was returned to the baseline condition for one session in an effort to detect any extreme change in features of unconstrained drinking. After that baseline session we tested 3 of the rats under the identity constraint, running each until it met our customary stability criteria. The identity schedule simply reversed the inversion schedule, and thus coincided with the individual's typical baseline pattern.

RESULTS

Inversion Constraint

In the absence of constraint, each rat's drinking showed the classic pattern: Bouts grew shorter and pauses grew longer as the session progressed. We inferred those changes within the baseline session from linear regression analyses that used the ordinal number of the bout or pause as the independent variable. For each of the 5 rats, the analyses revealed both a negative correlation with respect to the duration of the drinking bout and a positive correlation with respect to pause duration.

Some rats' drinking fit the classic pattern more closely than others'. Those differences are evident from a comparison of the five panels of Figure 2, which makes room for all 5 rats by truncating the vertical axis, cumulative time spent drinking. For each rat, the unconstrained baseline pattern appears as the top staircase line in the panel. The line immediately below is the inversion constraint line. On the unconstrained condition, each rat showed a large if idiosyncratic within-session change. Accordingly, in each case the unconstrained baseline and the inversion constraint line follow widely divergent paths between their common starting point and their common end.

The broken lines in Figure 2, beneath the inversion constraint lines, show the paths the rats followed during the typical inversion session. Each of the 5 rats fell short of its baseline time spent drinking. Given the scale of Figure 2, some of the shortfalls are so small that they can hardly be seen, but all are evident in Table 1. As shown in the table, the group mean was 815 s of drinking in baseline (23% of the session), and 762 s under the inversion constraint (21% of the session). Although no rat spent as much time drinking under constraint as it had during baseline, some rats
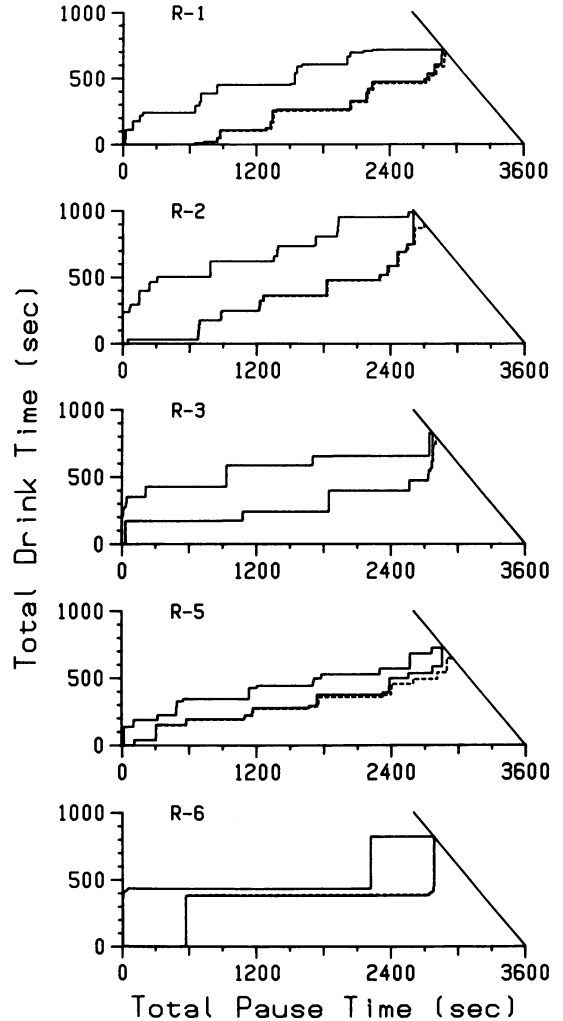

Fig. 2. Cumulative drink time as a function of cumulative pause time for 5 individual rats; the top line represents performance during the typical unconstrained baseline session, the middle line the inversion constraint; the broken line represents performance during the typical inversion session.

came close; they ranged from 89% to 96% of baseline values, with a mean of 93%.

Several different analyses showed that the rats spent significantly less time drinking under the inversion condition than under the baseline condition. One of the analyses compared values from the three final inversion sessions with the two lowest values among the three final baseline sessions. After removing the highest baseline value, we had two sets of data with identical ceilings, such that the inversion mean could have been greater than,

Table 1

Individual totals and group means.

Rat	Condition	Sessions	Drink time (s)	Licks	Water intake (mL)	Food intake (g)	Drink bouts	Pauses
R-1	Baseline	12	712	3,904	20	8.3	17	18
	Inversion	6	685	3,864	20	2.7	19	20
	Identity	7	534	3,001	20	9.0	18	19
R-2	Baseline	9	990	4,552	20	4.9	20	21
	Inversion	8	894	4,359	20	3.0	24	25
	Identity	7	806	3,952	24	5.9	31	32
R-3	Baseline	11	827	3,728	21	4.3	10	11
	Inversion	10	789	3,992	22	3.0	16	17
	Identity	—	—	—	—	—	—	—
R-5	Baseline	7	725	3,162	19	2.2	15	16
	Inversion	12	648	2,833	16	6.4	16	17
	Identity	—	—	—	—	—	—	—
R-6	Baseline	10	823	3,891	24	6.3	9	9
	Inversion	9	793	4,297	18	7.1	10	11
	Identity	6	808	4,126	22	2.6	10	11
Mean[a]	Baseline	10	815	3,847	21	5.2	14	15
	Inversion	9	762	3,869	19	4.4	17	18
	Identity	—	—	—	—	—	—	—
Mean[b]	Baseline	10	842	4,116	21	6.5	15	16
	Inversion	8	791	4,173	21	4.3	18	19
	Identity	7	716	3,693	22	5.8	20	21

[a] All 5 rats.
[b] Rats R-1, R-2, and R-6.

equal to, or less than the baseline mean. But for each rat, the analysis revealed less drinking time under the inversion condition than in the baseline condition, Wilcoxon $T = 0$, $z = 2.02$, $p = .04$, two-tailed.

In the context of Figure 2, to achieve its baseline drinking time under the inversion constraint the rat would have had to drink whenever it could. On many occasions each rat showed itself capable of exploiting the chance to drink to the fullest extent possible, defined as N s of drinking during an N-s opening. Those frequent successes tend to exclude methodological artifact as the cause of the general shortfall. Figure 3 shows the extent to which each individual made use of each opportunity to drink. The lower curve shows the duration of each tube opening, scaled on the right-hand axis; the upper curve shows the percentage of time spent drinking, scaled on the left-hand axis. Note that each upper curve shows many points against the ceiling— occasions where the rat drank for 100% of the time it could have spent drinking. One rat's drinking was at the ceiling level on four oc-

casions out of nine opportunities (4/9); the others were at the ceiling level on 5/10 opportunities, 4/15, 4/17, and 14/20.

Regression analyses of the data in Figure 3 revealed no consistent relation between the percentage of time spent drinking and the ordinal number of the tube opening, the duration of the opening, or cumulative time spent drinking. The most nearly consistent relation was this: All but one of the rats (R-1) typically exploited the early opportunities more fully than the later ones—a relation that might be indicative of satiation.

Perhaps the numerous shortfalls shown in Figure 3 resulted from late starts: If a rat had strayed from the tube, or was engaged in eating or other competing behavior at the moment the tube opened, it might miss the first few seconds of an opportunity to drink. Each rat's record revealed several late starts, but they alone could not account for the shortfall: When we added each rat's late-start time to its total drink time, the sum still fell short of the baseline time spent drinking. As a percentage of the baseline total, the sum ranged
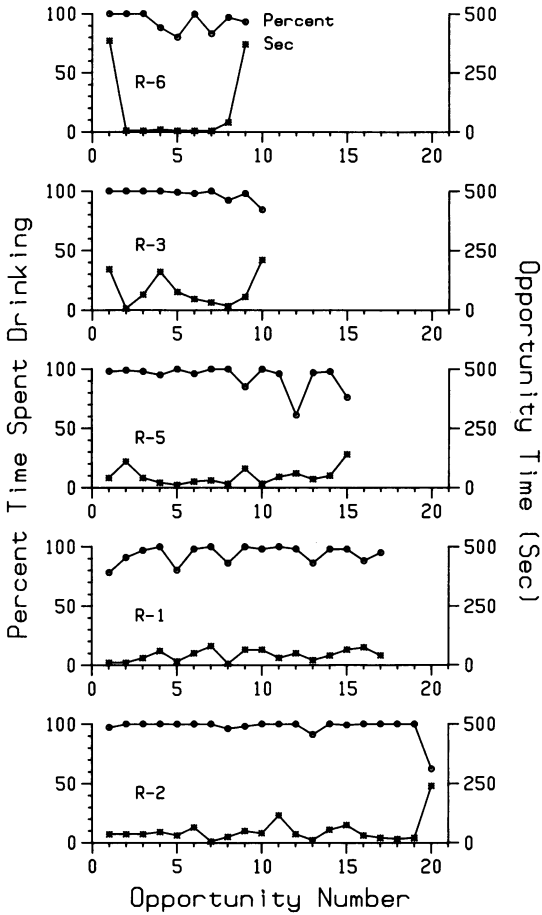
Fig. 3.   Percentage of time spent drinking and opportunity time as functions of the ordinal number of the opportunity to drink for each of 5 rats during their typical inversion sessions.
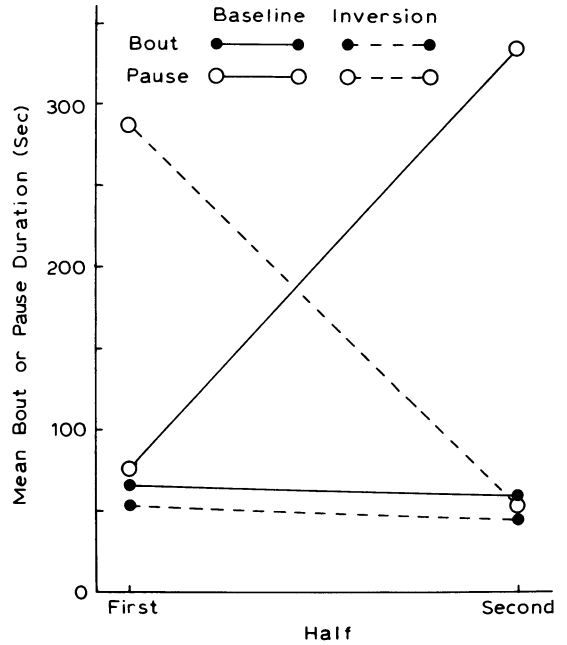

Fig. 4.   Mean durations of the first and second half of the bouts and pauses during the typical baseline and inversion sessions (group means, $n = 5$).

from 91% to 99% with a mean of 95%. Thus, if we remove that part of the shortfall that might be attributable to imperfect stimulus control by the presentation of the tube, some shortfall remains.

Further analyses of pauses in the presence of the open tube showed that each rat accrued its general shortfall from every kind of pause but one. Specifically, there were no *complete misses*; each rat made some use of each chance to drink, never less than 60% of the time it could have spent drinking (see Figure 3). But each rat's record of unforced pauses showed one or more examples of the *late start*, defined above. Each record showed one or more examples of the *break*, defined as a pause between bouts during the same opportunity to

drink. And each record showed at least one example of the *early stop*, where the rat stopped drinking and the tube closed during the ensuing pause. The late start occurred most frequently but was usually shorter than the other two kinds, seldom more than 1 s in duration. The early stop usually lasted longer than the other two, but occurred least often. The net effect was that the three kinds that did occur contributed about equally to the general shortfall in time spent drinking. Thus, although some of the shortfall occurred because the rat did not start drinking as soon as it could (late starts), much of the shortfall occurred because the rat stopped drinking prematurely (breaks and early stops).

To match the baseline amount of time spent drinking while under the inversion constraint, the rat had to reverse its baseline sequence of pause and bout durations. From the analyses presented thus far, it is clear that none of the rats effected the necessary reversal. Additional analyses revealed change in both features, but suggested that bouts were more resistant to change than were pauses. A summary of one such analysis appears in Figure 4 (group means). The figure compares, in terms of mean durations, the first half of the total number of
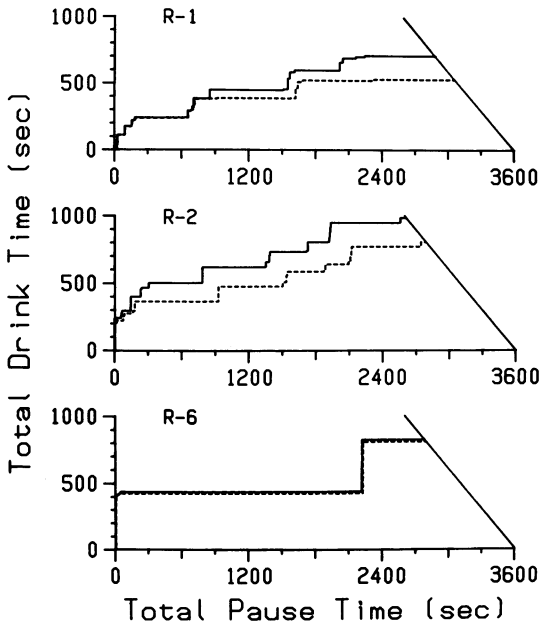
Fig. 5. Cumulative drink time as a function of cumulative pause time; the top line represents both performance during the typical baseline session and the identity constraint; the broken line represents performance during the typical identity session.

bouts and pauses with the second half. Pauses were relatively compliant with the inversion constraint: For each rat, the earlier pauses were shorter under the baseline condition, but longer under the inversion condition. In contrast, bout durations revealed no interaction between half and condition ($F < 1$); the earlier bouts were consistently longer, $F(1, 4) = 8.12$, $p < .05$. But bouts were significantly shorter under the inversion condition than the baseline condition, $F(1, 4) = 8.25$, $p < .05$.

Although each of the 5 rats fell short of its baseline time spent drinking, there was no consistent change in total licks, water intake, or food intake for the sessions of inversion constraint (see Table 1). As a consequence, there was no statistically significant difference on any of those three measures between the typical baseline and inversion sessions. Three rats showed a drop in the total number of licks, but only 1 of those 3 showed a concordant drop in water intake; the other 2 showed no change in water intake. The 2 remaining rats increased their lick totals; 1 showed a concordant increase in water intake, the other a decrease. Thus, in the face of the inversion constraint, the rats as a group maintained all

of the basepoints we measured *except* for total time spent drinking, but showed much individual variation. The baseline session conducted after the final inversion session revealed no significant difference from any of the original baseline measures.

Identity Constraint

The 3 rats tested under the identity constraint all fell short of the baseline time spent drinking (see Figure 5). They showed no consistent change in total licks, water intake, or food intake (see Table 1: R-1, R-2, and R-6). Our analysis of unforced pauses showed that each of the 3 rats accrued most of its shortfall from a kind of event never seen in the typical inversion session, the complete miss. Late starts and breaks appeared in all three records, early stops in two of the three.

The differential occurrence of the complete miss is apparent in Figure 6, which plots the duration of each tube opening (asterisks) and the percentage of time spent drinking (triangles) against the ordinal number of the opportunity to drink afforded by the identity schedule. To aid comparison, each rat's performance under the inversion condition is presented as circles connected by broken lines; the same inversion data appear in Figure 3, in reverse of the order shown in Figure 6. Each of the three identity records shows two or more occasions during which the rat drank for the longest time possible. But each also shows at least one opportunity that the rat missed completely in the identity sequence, but not in the inversion sequence.

DISCUSSION

In planning the experiment, we fancied the inversion constraint as a major perturbation, likely to deflect the rat from its unconstrained total time spent drinking. Although the results plainly revealed a deflection, the disturbance was generally smaller than expected. We were not prepared to see the rats approach the unconstrained total as closely as some of them did, or to see the group maintain total licks and total water intake.

A different kind of surprise came from our preconception of the identity constraint as at most a minor perturbation. Contrarily, the identity constraint proved about as effective as the inversion constraint. Thus, the disruptions
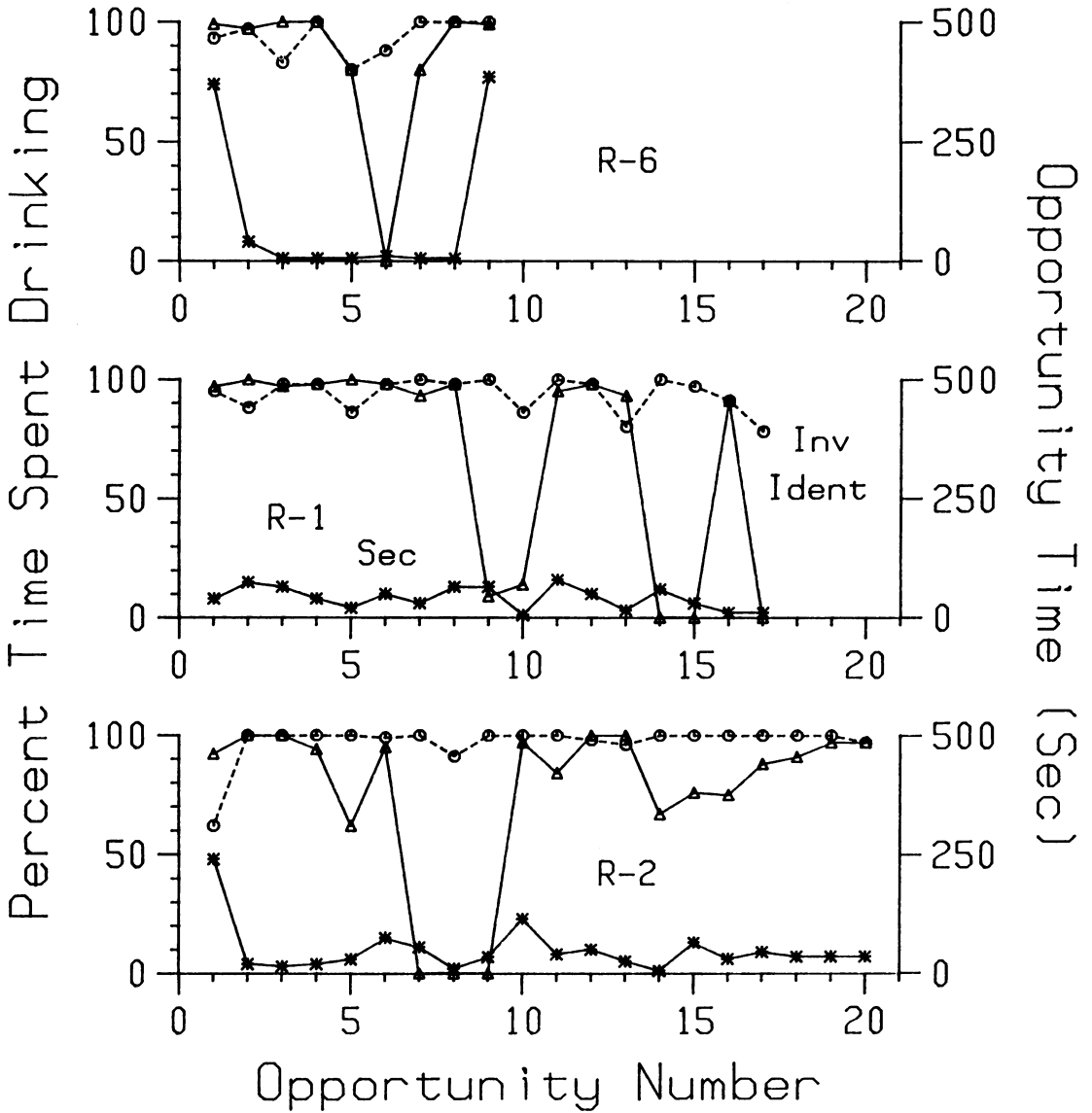
Fig. 6.   Percentage of time spent drinking and opportunity time as functions of the ordinal number of the opportunity to drink for each of 3 rats during their typical identity sessions; the broken line shows performance during the typical inversion session.

of time spent drinking seem to have resulted more from the necessity of drinking whenever external circumstance allowed than from the necessity of following some alien temporal path to the basepoint.

We also found it provocative that number of licks and amount of water intake would be affected so much less than time spent drinking. That contrast makes more interesting the methodological task of securing closer relations among drink time, licks, and water in-

take. Imagine an experimental arrangement different from ours, one that made it more difficult for the rat to maintain one aspect of drinking without also maintaining the others. Under that arrangement, our inversion and identity schedules might deflect the rat's behavior from each of the three basepoints, or from none of the three.

The results have several general implications for the supposition that instrumental performance under the constraints of a con-

tingency schedule may derive from the defense of a particular measured set-point. First, the results show that the animal may not maintain a particular unconstrained total, even when it seems well within the animal's ability to do so. In the present experiment, total time spent drinking was the unconstrained quantity that the rats could have maintained, but did not maintain. Second, the animal may defend some measures of a particular type of behavior more closely than others. In the present experiment, licks and volumetric intake were less disrupted than time spent drinking. Third, although time may be a convenient measure, applicable in principle to every different type of behavior (Premack, 1971), it may not be suited to a role as universal system variable in regulatory models of behavior. Time may sometimes function as the key system variable, but it played no such role in our experiment. Finally, the temporal patterning typically displayed in the absence of external constraint may seem more important than it is (cf. Dunham, 1977). If we force the animal to follow an alien path, what appears to be a major disturbance of the organization of the behavior may cause a surprisingly small deflection from the unconstrained total. Further use of our method may show that organizational disturbance affects some kinds of behavior more readily than others.

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