JOURNAL OF THE EXPERIMENTAL ANALYSIS OF BEHAVIOR 1975, 23, 223-232 NUMBER 2 (MARCH)

SCHEDULE-INDUCED DRINKING AS A FUNCTION OF PERCENTAGE REINFORCEMENT[1]

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Drinking was recorded in rats while lever pressing was maintained on a series of percentage reinforcement schedules in which the per cent of 1-min fixed intervals terminating with food was 100, 90, 30, 70, 10, 50, and 100%. Intervals in which a pellet was omitted were terminated by brief light flash and click stimuli that were also correlated with food presentations. Drinking failed to develop in five of six subjects following intervals in which the brief stimuli were presented regardless of percentage reinforcement. Postpellet drinking, which followed intervals terminated with pellet delivery, however, increased in both duration and amount ingested per interval as percentage reinforcement was systematically decreased. The increase in postpellet drinking above that produced by 100% reinforcement was interpreted as an analogue of the positive-contrast effect observed with food-reinforced operants.

Schedule-induced drinking is a well-established phenomenon and has been readily obtained in conjunction with a variety of simple time- and ratio-based reinforcement schedules (see Falk's, 1969 review of this literature). Typically, drinking during these schedules is a postpellet phenomenon in that a rat consumes approximately 0.5 ml of water immediately after delivery and ingestion of each food pellet.

Recently, several investigators (Falk, 1971; Porter, Arazie, Holbrook, Cheek, and Allen, *in press;* Rosenblith, 1970) have attempted to isolate those factors surrounding the period of reinforcer delivery that might be responsible for the development and maintenance of schedule-induced drinking. For example, drinking may be induced by the consummatory stimuli (texture, taste) and behaviors (chewing, swallowing) associated with the ingestion of the pellet, or by the discriminative properties of reinforcer delivery that signal a period of low reinforcer probability immediately postpellet, or both. Since simple reinforcement schedules completely confound the effects of consummatory and discriminative properties of the reinforcer in an analysis of drinking, these investigators used second-order reinforcement schedules.

Under a second-order schedule, performance generated by one schedule is treated as a unitary response that is reinforced according to a second schedule of reinforcement (Kelleher, 1966). For example, an animal might be required to complete a series of fixed-interval (FI) schedules, in which the first response after a fixed time has elapsed from completion of the previous interval terminates the present one. Whether or not a reinforcer is delivered at completion of an interval, however, may be determined by a second reinforcement schedule. The second schedule may be arranged so that either a fixed number or a variable number of FIs are required, giving rise to a fixed-ratio (FR) or variable-ratio (VR) second-order schedule, respectively. The variable-ratio second-order schedule has more commonly been denoted a percentage reinforcement schedule (Ferster and Skinner, 1957; Neuringer and Chung, 1967; Zeiler, 1972), since it specifies the per cent of reinforcers, assigned by the FI schedule, that are actually delivered, the remainder being omitted on a random basis. Second-order schedules may also be arranged so that a brief stimulus (light and a click) is paired with pellet delivery and is also presented at completion of intervals for which the reinforcer is withheld. With this arrangement, poststimulus control over the response comes to resemble postpellet control over the response. Namely, a pause at the outset of the

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[1] This study was supported in part by Grant MH 19665-01A1 from NIMH/USPHS to J. D. Allen and by Contract DADA17-73-3007 from the U.S. Army Medical Research and Development Command to B. N. Bunnell, I. S. Bernstein, and J. D. Allen. The authors would like to thank J. W. Holbrook and M. S. Cheek for their assistance in the conduct of this study. Reprints may be obtained from Joseph D. Allen, Department of Psychology, University of Georgia, Athens, Georgia 30602.

next interval is followed by positively accelerated responding (Zeiler, 1972).

Rosenblith (1970) reported that two distinct patterns of drinking emerged during a fixed-ratio second-order schedule in which every completion of an FI 1-min component produced a 2-sec light flash and every third-component completion also produced a food pellet. A high rate of drinking initially appeared after each pellet delivery, and then a lower rate of drinking, which frequently alternated with lever pressing, gradually developed following intervals terminated with the brief stimulus alone. The second type of drinking, that produced by a brief stimulus, has not yet been reported in rats when percentage reinforcement schedules are used (Falk, 1971; Porter *et al.*, *in press*). For example, in the study of Porter *et al.* (*in press*), Experiment 1), lever pressing by rats was initially reinforced on an FI 1-min 100% reinforcement schedule, in which each completed interval was associated with a brief light flash, a click, and a 45-mg pellet. Upon switching to 90% reinforcement, in which 10% of the intervals terminated with light and click alone, water consumption following pellet deliveries increased significantly above that produced by the baseline schedule; however, no drinking followed intervals terminated by the light and click alone.

One obvious difference between the studies of Rosenblith (1970), Falk (1971), and Porter *et al.* (*in press*) was the per cent of intervals to which food reinforcers were assigned. Drinking produced by paired stimuli alone has been reported in rats when 33% of the intervals terminated with food (Rosenblith, 1970), but not when either 50% (Falk, 1971) or 90% (Porter *et al.*, *in press*) of the intervals have terminated with a pellet. It is possible that poststimulus drinking is a phenomenon occasioned only by relatively low per cent reinforcement schedules. The present study thus sought to identify, in a more precise and systematic fashion, the influence of percentage reinforcement on schedule-induced drinking.

METHOD

Subjects

Six 130-day-old female albino rats of the Holtzman strain had previously served in the first two experiments by Porter *et al.* (*in press*). In Experiment 1, drinking was recorded while the rats responded on 100 and 90% reinforcement schedules for food reinforcers. The data from that experiment have been elaborated and included in the present study as the first 2% of reinforcement conditions. Experiment 2 essentially replicated the procedure in Experiment 1, except that the response lever was retracted during the first half of each fixed interval. The subjects had free access to water at all times, but were reduced to and maintained at approximately 80% of their free-feeding weights during the experiment by daily adjustments in their ration of Purina rat chow.

Apparatus

A Lehigh Valley Electronics (Model 1417) operant conditioning chamber with a sound-attenuated cubicle was used. A retractable response lever (LVE, Model 145OR), requiring approximately 15 g (0.14 N) force to operate, was mounted on the right side of the front panel, 3 cm above the grid floor and 8 cm from the centrally mounted food magazine. A 7-W light with a white jewel cover was powered by 20-V ac and was located directly above the response lever. A Systems Engineering drinking valve (Model LV-100) was mounted 8 cm to the left of the food magazine and 3 cm above the grid floor where the left-hand lever would normally be. The valve, the tip of which barely protruded through a 7.0-cm by 6.3-cm Plexiglas plate mounted on the inside wall, linked with a 250-ml graduated cylinder that was periodically filled with distilled water. Drinking bouts were sensed with a Grason-Stadler drinkometer (Model E4690A) and were converted to a time measure by means of a multivibrator that pulsed a counter at the rate of six per second when the subject's tongue was in contact with the drinking valve.

Food reinforcers were 45-mg Standard Formula Noyes pellets dispensed by a Gerbrands (Model D) dispenser. A second, identical but empty, dispenser was also mounted in the cubicle and provided a click stimulus when intervals without a reinforcer terminated. Except for intermittent offsets, a 7-W houselight, energized by 20-V ac, illuminated the chamber; white masking noise was provided during the session.

Procedure

Following lever-press shaping, the next 75 lever presses each produced a pellet. Three

0.5-hr training sessions followed, during which lever presses were reinforced according to a variable-interval 15-sec food-reinforcement schedule. Then, the session length was increased to 1 hr and subjects received daily sessions in which lever presses were reinforced according to a fixed-interval 1-min schedule. The first response 1 min after the previous reinforcer delivered a pellet, briefly extinguished the houselight, and illuminated the cue light over the response lever for 1 sec. Responses were reinforced according to a 100% schedule for 33 sessions, which was sufficient for drinking to appear following reinforcers and for total session water intake to exhibit no consistent change for at least five sessions. The following percentage reinforcement schedules were then introduced, in which the per cent of 1-min intervals that terminated with a pellet were: 90, 30, 70, 10, 50, and 100. All subjects received 20 sessions with the reinforcement schedule at 90%, and then, following approximately a one-month period during which Experiment 2 of Porter *et al.* (*in press*) was conducted, the remaining series of percentage reinforcement schedules was resumed, with all subjects receiving 10 sessions on each schedule.

For each per cent of reinforcement, the sequence with which intervals terminated with a pellet was randomized over repeating blocks of 30 intervals, using a table of random numbers to determine the sequence; a new sequence was used daily. Intervals terminating without a pellet were still paired with the brief 1-sec visual stimuli, and the empty pellet dispenser was operated to simulate the auditory stimuli of the pellet delivery. Lever presses and drinking time were recorded in consecutive 10-sec periods during each 1-min interval and were recorded separately for intervals that terminated with and without a pellet. Drinking that occurred after the interval had elapsed, but before a reinforcer was produced, was recorded in the sixth period counter. While this arrangement permitted the last period to be stretched beyond 10 sec, drinking time rarely extended to the end of that period, except when the 10% reinforcement schedule was in force. Data consisted of an average of the last five sessions under each schedule.

RESULTS

The cumulative records of Figure 1 illustrate the major effects of percentage reinforcement upon the pattern of lever pressing and drinking for Subject 16. During the initial 100% condition, a period of no lever pressing occurred at the start of each interval, during which a sustained drinking episode typically occurred. Lever pressing was initiated shortly after each drinking episode terminated, and in most instances continued at either a positively accelerated or steady rate for the remainder of the interval. As the per cent of intervals terminating with food was progressively lowered from 90 to 10, episodes of sustained drinking continued to occur immediately after intervals that terminated with food. Drinking rarely occurred after intervals in which food was omitted; the few instances in which drinking did occur are denoted by an "n" above the event line. Each bout typically consisted of a few licks at the tube, and in most cases closely preceded initiation of lever pressing. The records suggest that the number and duration of these bouts following brief stimulus presentations were not systematically related to the per cent of reinforcement. On the other hand, drinking episodes following pellet delivery appeared to increase in duration as per cent of reinforcement decreased, and often extended beyond the limits of the 1-min interval during the 10% condition.

Subject 16's records were similar to those of every other subject, except Subject 18, with respect to lever pressing, and were also representative of the drinking performance of all subjects, except 17 and 18. Subject 18 developed a low and unstable lever-pressing rate, beginning with the third condition, that continued for the remainder of the experiment, and failed to drink after many pellet deliveries. Drinking rarely occurred after intervals in which food was omitted.

Subject 17 developed a semi-stable drinking performance following brief stimulus presentations. Drinking occurred at all percentage reinforcement conditions below 90% and the drinking pattern was distinctly different from the extended episodes that immediately followed pellet delivery. The drinking produced by the brief stimuli alone usually occurred in a series of short bursts, which often extended throughout the interval and alternated with lever pressing.

Figure 2 depicts the relationship between duration of the drinking episode and per cent of reinforcement. Drinking duration has been expressed in terms of the proportion of the interval time spent drinking and was computed separately for intervals following pellet delivery and following brief stimulus presentations. Proportions were obtained by divding the total number of multivibrator counts accumu-

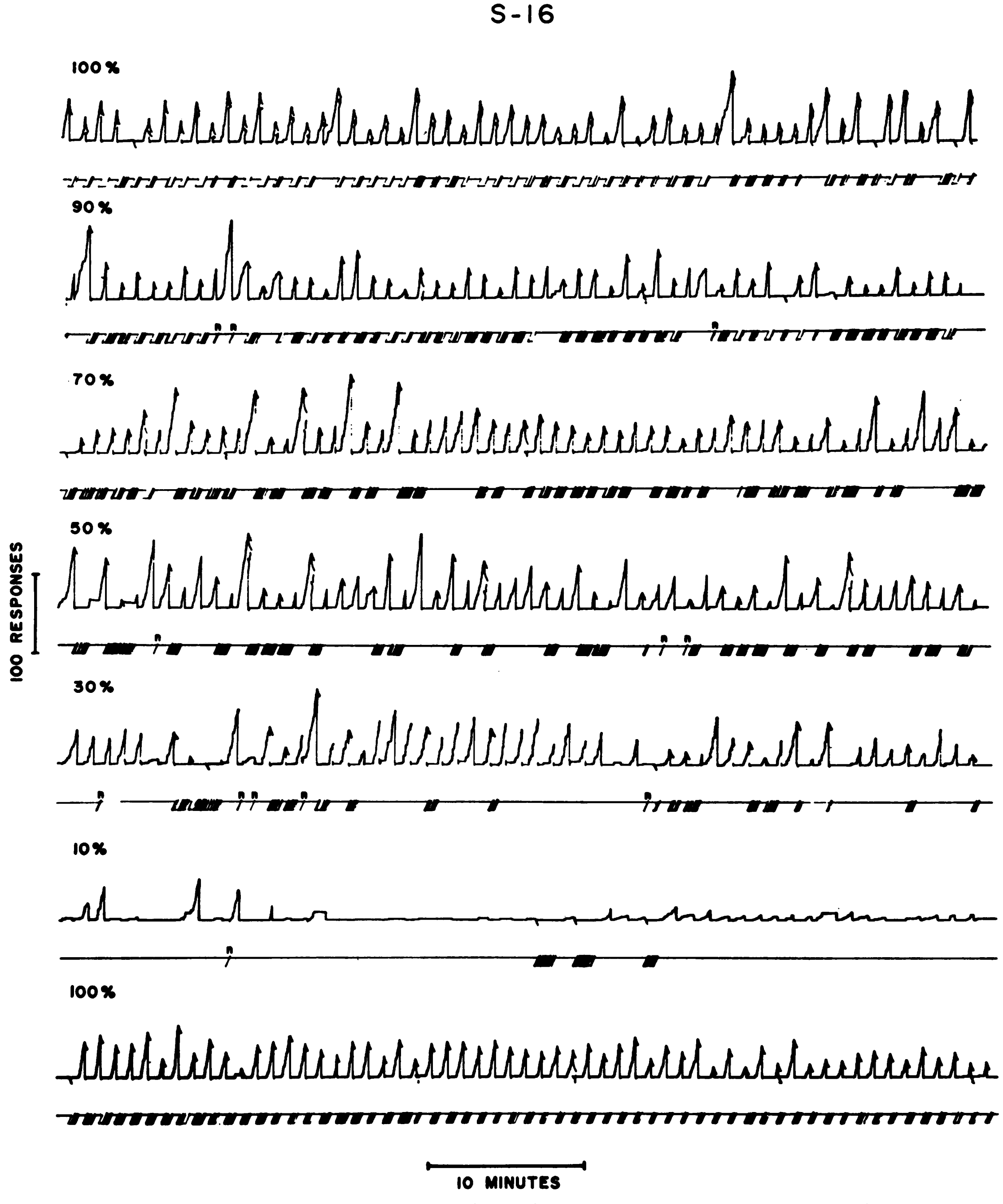

Fig. 1. Cumulative records for Subject 16 of an entire session at each per cent reinforcement. The response pen recorded lever presses and reset at completion of each interval. The oblique hatchmark on the response trace at the end of an interval denotes a pellet delivery. Drinking bouts are recorded by the event marker at the bottom of each record. The event marker was depressed by the first lick in a bout and remained depressed as long as the ensuing licks continued at a rate exceeding approximately three or four licks per second. The "n" over the event trace marks occasional licks that occurred following pellet-omitted intervals.

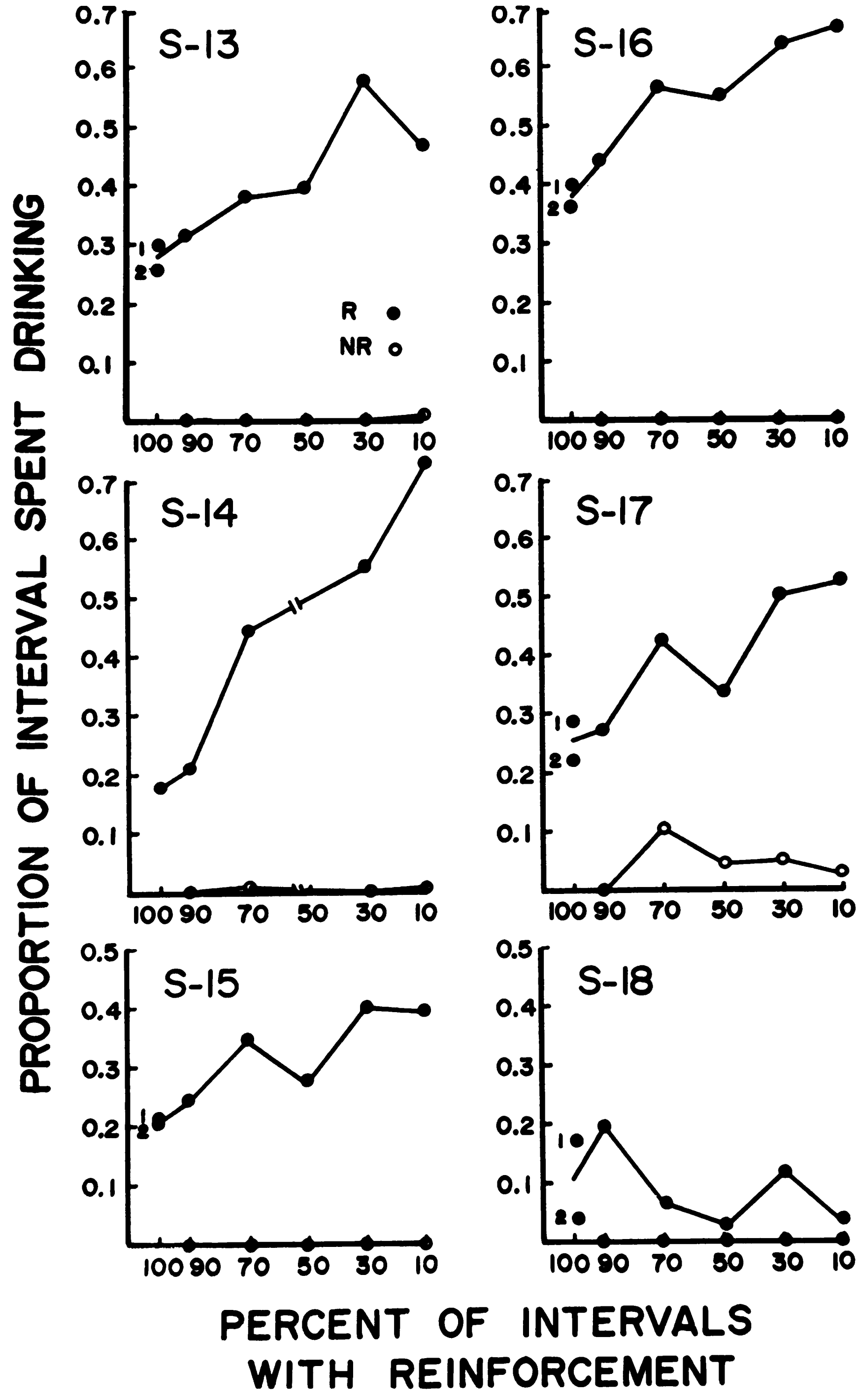

Fig. 2. Proportion of the 1-min interval spent drinking as a function of the per cent of intervals with reinforcement. Drinking functions for intervals following pellet delivery (R) and pellet-omission (NR) are presented separately. At 100% reinforcement, the function originates at the mean of the ordinate values obtained during the initial 100% condition (1) and the recaptured 100% condition (2). Data are not available for Subject 14 during the 50% and recaptured 100% conditions, since it had developed the behavior of depressing the nozzle on the water valve with its paws for extended periods of time during these sessions.

lated over the last five sessions by the total accumulated interval time expressed as multivibrator counts (*i.e.*, total number of intervals × 360 counts per interval). In general, drinking duration following food increased systematically as per cent of reinforcement was lowered. Drinking following brief stimulus presentations was negligible for all subjects except Subject 17, whose drinking varied unsystematically about a mean of 0.06 of the interval time for reinforcement percentages below 90.

In Figure 3, separate functions describe changes in the distribution of drinking time among consecutive 10-sec periods of each interval as the probability of reinforcement delivery was changed. Each data point represents the proportion of each 10-sec period consumed by drinking. Proportions were averaged over five days and for intervals following food delivery only. Several features recurred among most subjects. Drinking time reached a maximum during the second 10-sec period following a pellet and then fell in either a negatively accelerated or inverse S-shaped fashion over the remaining periods of the interval. At both the initial and recaptured 100% conditions, drinking was confined to the first 30 sec of the interval but spread systematically to later periods of the interval with successive decreases in per cent of reinforcement, so that at 30% the functions were concave downward. At 10% reinforcement, the drinking functions were decidedly flatter or even inverted (see Subject 13). Drinking occurred with a stable frequency throughout intervals followed by a pellet and often extended beyond the limits of the 1-min fixed interval.

Though not presented here, the Index of Curvature (Fry, Kelleher, and Cook, 1960) was calculated separately on lever-press rates during intervals initiated with and without pellet delivery. With six periods, the Index of Curvature may range between −0.83 and +0.83, where the former value is produced when all responses occur in the first period of the interval, a value of 0.0 is produced when responses are equally distributed throughout the inter-

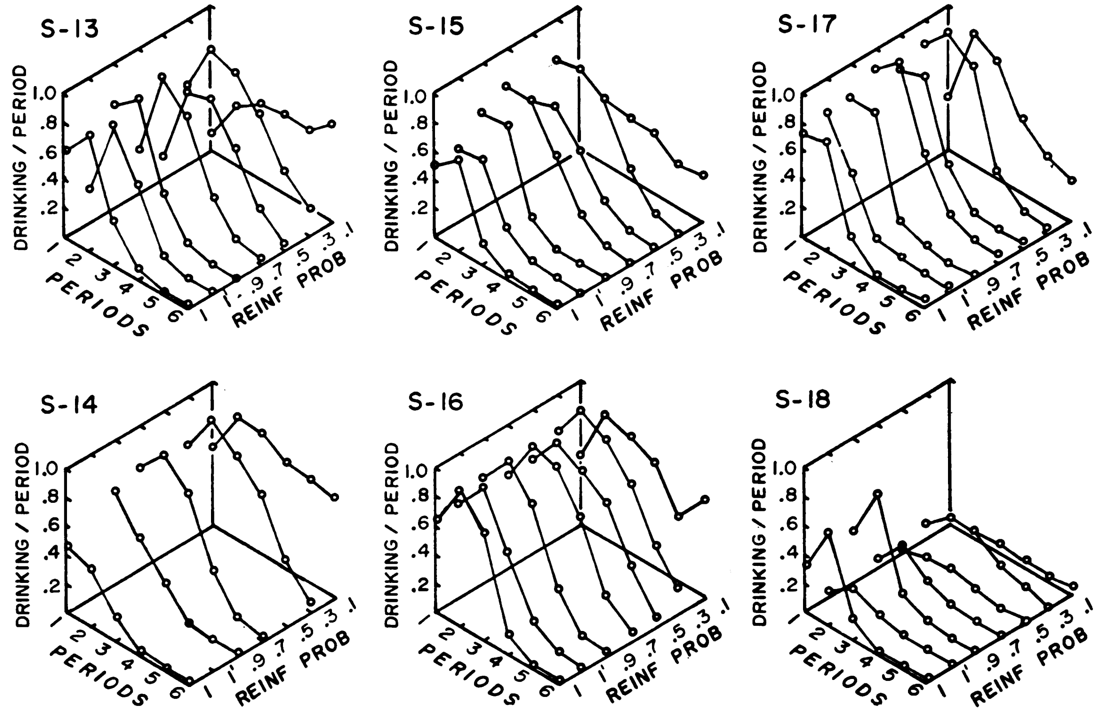

Fig. 3. The proportion of each 10-sec period spent drinking (drinking/period) during intervals following pellet delivery is plotted as a function of consecutive sixths of the interval (periods). A family of curves relating this function to decreasing per cent of reinforcement (expressed as reinf. prob.) is arrayed from front to back. The recaptured 100% function is denoted as 1′. Proportions of drinking time were calculated separately for each 10-sec period and therefore do not necessarily sum to 1.0 over the entire interval.

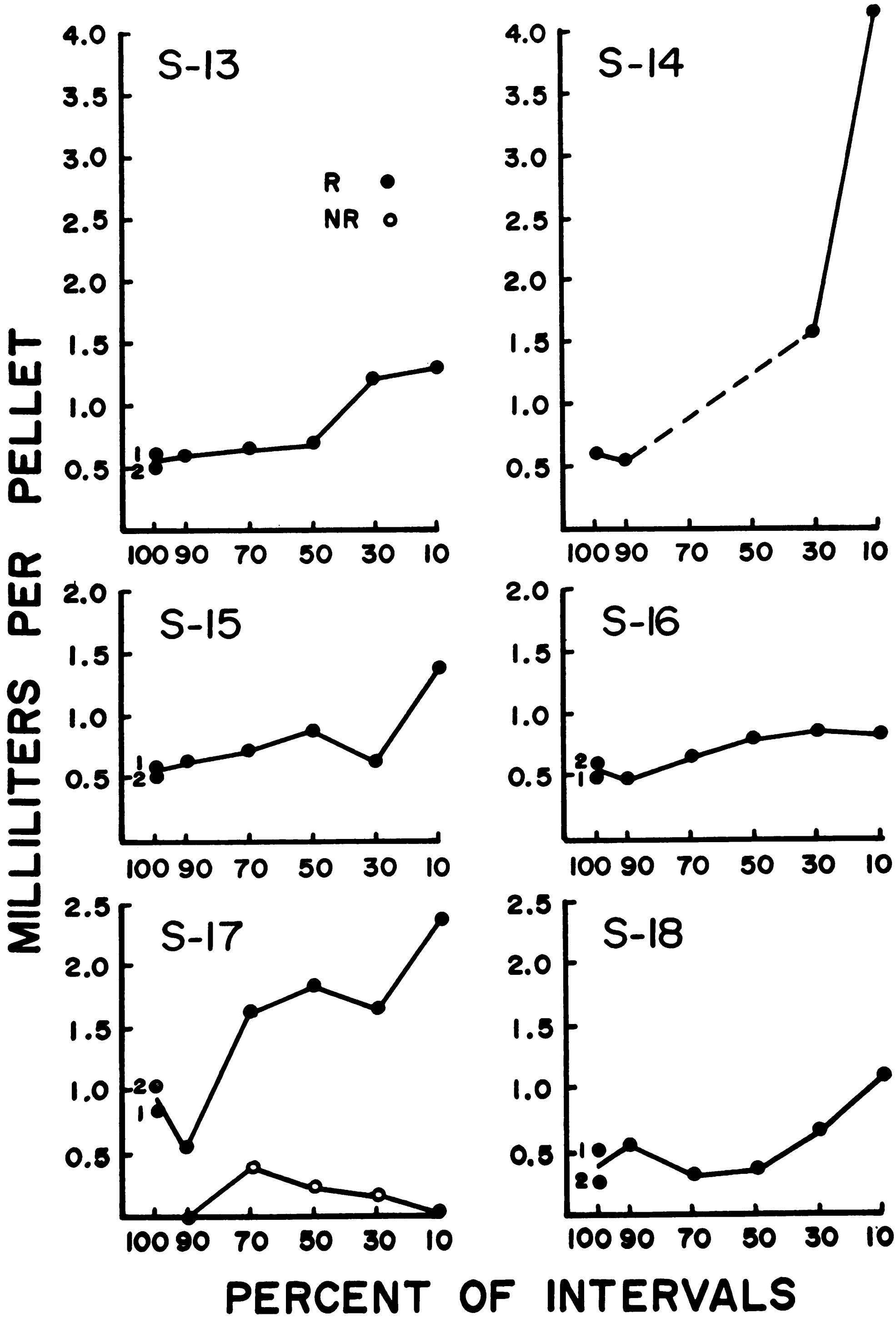

Fig. 4. Mean water intake (ml) per pellet as a function of the per cent of intervals with reinforcement. To obtain these points, the session water-intake values in Table 1 were divided by the number of pellets delivered during the session. For Subject 17, water intakes were separately computed for intervals following pellet delivery (R) and pellet omission (NR).

val, and the latter value is produced when all responses occur in the last period of the interval. In general, the Index during intervals following a reinforcer increased systematically from 0.4 to 0.7 as per cent of reinforcement declined from 100 to 10, reflecting mainly the direct effect of an expanding drinking episode upon the pause length. Index measures during intervals following brief stimulus presentation remained fairly constant between values of 0.4 to 0.5, and showed little interaction with changes in the reinforcement schedule.

Table 1

Mean session water intake in milliliters. Data are based on the last five sessions in each condition.

	Session Intake (ml)					
Reinf. %	*S13*	*S14*	*S15*	*S16*	*S17*	*S18*
100	32.4	36.2	34.8	30.0	46.2	30.2
100-Recap	28.8	—	31.2	35.2	60.4	13.6
90	28.8	28.0	33.2	25.6	29.2	27.6
70	26.4	—	28.8	26.0	69.5	11.6
50	19.6	—	24.8	21.2	57.2	9.6
30	20.4	26.8	10.4	13.2	32.0	10.4
10	6.0	21.6	7.2	4.4	12.8	6.0

—Data are omitted for Subject 17 due to the development of a persistent nozzle-holding response that drained excessive amounts of water from the reservoir during these sessions.

Total session water intake under each reinforcement condition is presented in Table 1. Session water intake was generally greatest in the 100% conditions and dropped fairly systematically as per cent of reinforcement decreased. The decrease in water intake was most probably due to the corresponding reduction in number of pellets delivered per session. Nevertheless, water consumption per pellet increased systematically as per cent of reinforcement was lowered throughout the entire range. These functions are reproduced in Figure 4.

DISCUSSION

Rosenblith (1970) reported that two types of drinking developed on a second-order schedule: "a high-rate drinking occurring after delivery of a pellet and a drinking frequently interrupted for bar pressing after intervals terminated by a light flash and click alone (p. 144)." In contrast, only one subject (Subject 17) of six in the present study developed a sustained drinking rate after brief-stimulus presentations that was comparable to those of Rosenblith's subjects in magnitude or patterning.

Various procedural differences between the present study and Rosenblith's might have been responsible for the absence of poststimulus drinking here. Among them were (a) session length (1 hr *versus* 2.5 hr); (b) pairing relations between the brief stimuli and pellet delivery (simultaneous presentation of a 1-sec light and pellet *versus* a 2-sec delay between onset of the light and pellet delivery); (c) reinforcement schedule (variable-ratio *versus* fixed-ratio second-order schedule); and (d) position of the water spout (to the side of the food magazine away from the response lever *versus* between the food magazine and the lever). Of these differences, the first (a) would not appear to be crucial, since psychogenic drinking in Rosenblith's study, once it developed, was displayed at the beginning of each session. Also, systematic variations of the next two factors (b and c) have not resulted in marked changes in the controlling relations exerted by a variety of second-order schedules on within-component response patterning (Stubbs, 1971; Stubbs and Cohen, 1972), and it is therefore difficult to understand why drinking would be affected. The importance of the position of the water spout (d) has been argued recently by Wuttke and Innis (1972), who suggested that arranging the drinking spout between the lever and the food magazine may have facilitated the alternating pattern between licking and bar pressing. As they state: "Often rats alternate between bar-pressing and approaching the feeder on interval schedules, and to do so in this situation entailed passing the drinking spout. If the water bottle were in a less convenient location, drinking might not have reoccurred once bar-pressing started (p. 132)." The location of the drinking tube might also account for a recent finding of poststimulus drinking by rhesus monkeys on an 80% reinforcement schedule (Porter and Kenshalo, 1974). In their study, the drinking tube was conveniently located directly above the food hopper. Such an explanation, if experimentally verified, would suggest that the control over drinking by stimuli that are paired with the termination of a component or that signal a period of low reinforcer probability is, at best, indirect. Careful inspection of the cumulative records in Figure 1 reveals that the controlling relations between the stimuli terminating an interval and the onset of lever pressing in the subsequent interval were similar for intervals terminating with and without a pellet; a substantial pause in lever pressing was correlated with each. Nevertheless, drinking was restricted to intervals following pellet delivery. These considerations would suggest that proximity of the source of water to the normal route of the subject within the chamber be systematically investigated as a determinant of schedule-induced drinking.

Of greater significance in this study was the relationship between postpellet drinking and per cent of reinforcement. Both duration and amount of drinking during the intervals following pellet delivery increased systematically as per cent of reinforcement was lowered from 100 to 10. The increase in drinking resembled the positive contrast effect observed with food-reinforced operants.

Typically, contrast effects have been observed with multiple (*mult*) schedules, whereby two equivalent but independent food-reinforcement schedules are presented sequentially to the subject, each in the presence of a different stimulus. When one of the schedules is changed to extinction, response rate in that schedule decreases, while response rate in the unchanged schedule increases (Reynolds, 1961). Recently, Jacquet (1972) demonstrated that schedule-induced drinking maintained by a *mult* VI 1-min VI 1-min food reinforcement schedule increased in a similar fashion when reinforcers were subsequently withheld, and thus drinking was absent from the extinction schedule. A similar effect might well have operated in the present study. The 100% reinforcement schedule used initially arranged a sequence of identical FI components, all of which terminated with a reinforcer that induced postpellet drinking. Upon switching to lower reinforcement percentages, some of the FIs were, in effect, changed to extinction components that did not support any postinterval drinking. Therefore, increased postpellet drinking would be expected as a manifestation of positive contrast.

The systematic increase in magnitude of positive contrast as percentage reinforcement was lowered, or equivalently as the proportion of extinction components was increased, has not yet been explored using operant behaviors reinforced on multiple schedules. But the effect might be expected on purely theoretical grounds. Recent theories attribute behavioral contrast either to the response suppression produced by the changed schedule (Terrace, 1972), or to the degree by which the changed schedule is rendered less preferred than the unchanged schedule (Bloomfeld, 1969). Increasing the proportion of extinction components assigned by a schedule would serve to increase the proportion of the session time during which responses would be suppressed, and would most likely render the extinction components progressively less favorable than the remaining unchanged components. By either account, an increasing magnitude of positive contrast would be predicted. In the present study, increased drinking in intervals following pellet delivery may have resulted from the absence or suppression of drinking during intervals following pellet omission.

An alternative explanation for these results might propose that the successive shifts in per cent of reinforcement merely effected more efficient reinforcement frequencies for the production of schedule-induced drinking. Many studies have confirmed that the milliliters of water consumed per pellet on simple interval schedules varies as a bitonic function of the interpellet interval (Falk, 1966, Flory, 1971, Hawkins, Short, Githens, and Everett, 1972), typically ascending to a maximum at an interpellet interval of 2 min and then descending again at longer intervals. However, if the milliliters-per-pellet values in Figure 4 were replotted as a function of the average interpellet interval obtained on the various percentage-reinforcement schedules, no instance of a bitonic relation would be suggested. It is evident that the functions would increase monotonically as the average interpellet interval increased from 1 min, with the 100% schedule, to over 10 min, with the 10% schedule. The data therefore support a contrast, rather than a simple reinforcement frequency interpretation of the present phenomenon. Thus, it would appear that schedule-induced drinking shows behavioral interactions that are similar to those seen with food-reinforced behaviors; this raises some questions regarding the clarity of the distinctions that Falk (1971) made between adjunctive behaviors, to which schedule-induced drinking has been assigned, and that class of behaviors called operants.

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Received 20 May 1974.
(*Final Acceptance 22 October 1974.*)