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Random and fixed two-trial sequences of reward magnitudes

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Albino rats were trained in a straight runway for 110 days, two trials/day, with an intertrial interval of 3-5 min. One trial each day ended in large reward (10 standard Noyes pellets for one group, 1 ml of 30% sucrose solution for another) and the other trial ended with small reward (1 pellet or 3% sucrose). The daily sequence of reward magnitudes, either small-large (SL) or large-small (LS), was determined by pseudorandom orders, so that a block of 8 days contained 4 SL and 4 LS days. For 20 days following this random-sequence training, all rats received fixed sequences, always SL or always LS, with the same reward type (standard pellets or sucrose solutions) as that used during random-sequence training. Differential running for different reward magnitudes (patterning) did not develop during random-sequence training with either reward type. The fixed-sequence training generated patterning on Trial 2 but not on Trial 1. The data are discussed in the light of several possible sources of the stimulus control of patterning, and implications of the data for a sequential account of the successive negative contrast effect are briefly considered.

Two experiments with sucrose rewards (Burns, 1976, Note 1) have shown that rats trained in a runway two trials/day with the fixed reward sequence small-large (SL) or large-small (LS) ran relatively fast on the large-reward trial of each day and relatively slowly on the small-reward trial. When daily sequences are fixed, either SL or LS as a between-subjects treatment, four possible accounts of the differential running (patterning) may be offered.

First, patterning on Trial 2 may be the result of the differential conditioning by large- and small-reward magnitudes of the aftereffects of different Trial 1 outcomes. When the reward sequence is SL, aftereffects from small reward on Trial 1 may be conditioned to the instrumental response by large reward on Trial 2. When the sequence is LS, large-reward aftereffects may be conditioned by small reward. Habit strength, consequently, would be greater on trials following small reward than on trials following large reward (Bloom, Williams, & Metze, 1973; Capaldi & Molina, 1979; Leonard, 1969). To account for patterning on Trial 1, reinstated memorial representations of the Trial 2 outcome from the previous day must be invoked. These memories may be differentially conditioned by different Trial 1 reward magnitudes (Capaldi, 1971, 1972). From this conceptualization, of course, the memory mechanism may work in both massed and spaced trials, while aftereffects, stimulus residuals, or decaying neural traces are presumed to work only in massed trials. No attempt is made in the present treatment to distinguish between aftereffects and recent memories. The term "memory" is used here only when considering reinstated representations of remote events.

A second possible account of SL or LS patterning comes from work on human serial learning (Hulse & Dorsky, 1977, 1979) and consists of the assumption that during ordered reward sequences (monotonically increasing or decreasing) that the rat learns a cognitive rule ("greater than" or "less than") and behaves in the runway according to that rule.

Still another account of the patterning is implicit in the work on odor cues in the runway (e.g., Davis, Prytula, & Voorhees, 1979; Ludvigson & Sytsma, 1967). Some evidence (e.g., Mellgren, Fouts, & Martin, 1973) is available that rats leave odors that are different depending on whether the trial outcome is reward or nonreward. In the fixed LS or SL design, when animals are run in rotation within like sequences, patterning may be controlled by differential odors from small and large reward left by previous animals.

A fourth possibility rests on the assumption that situational stimuli not intentionally manipulated are, nevertheless, different on the two daily trials. Since these trial stimuli are correlated with different reward amounts, differential habit strength associated with the trial stimuli may come to control patterning (Couvillon, Brandon, Woodard, & Bitterman, 1980; Mackintosh, Note 2).

The present experiment examined two-trial sequences of reward magnitudes in a design that controlled for three of the four possible sources of patterning mediation. Reward sequences (SL or LS) varied pseudorandomly (some days SL, some days LS) within subjects, making

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rule learning and trial-stimuli discrimination untenable accounts of patterning should it occur, and the order of running of animals assigned randomly to different pseudorandom sequences of SL or LS was determined randomly each day to make possible odors from previous animals uncorrelated with trial outcome. Futhermore, because liquid sucrose and standard-formula Noyes pellets have produced performance differences in designs employing the single alternation of reward magnitudes (Burns, 1976) and the successive reduction of reward magnitudes (Dunham, 1968), the type of reward (standard pellets or sucrose) was examined as a between-subjects factor.

METHOD

Subjects

The subjects were 10 experimentally naive female Dublin Sprague-Dawley rats approximately 90 days old at the beginning of preliminary training. The rats were obtained from Flow Laboratories, Dublin, Virginia.

Apparatus

The apparatus was a wooden runway, 15.2 cm high, with start (20.3 x 15.2 cm) and alley (182.9 x 10.2 cm) sections painted flat black and goalbox (30.5 x 15.2 cm) painted white and positioned at a 90-deg angle. The entire runway was covered with hinged Plexiglas, and photocell logic to two Standard electric timers allowed measurement of start and run times in units of .01 sec. Start and retrace doors were manually operated.

Preliminary Training

Upon arrival, animals were placed in individual living cages with free access to food and water for 3 days. Beginning on Day 4 all rats were systematically reduced to 85% of their ad-lib body weights (the average of Days 1-3) and maintained at those weights throughout the experiment by feeding a calculated ration approximately 10 min after each training session. After weight reduction (5 days), 7 days of goalbox placements were administered which consisted of two placements with the reward amount and type to be used throughout the experiment. For one group (standard: n = 5) large reward was 10 standard-formula 45-mg Noyes pellets and small reward was 1 pellet. For another group (sucrose; n = 5) the rewards were 1 ml of either 30% or 3% sucrose solution mixed by weight in tap water. On placement days each animal received one large-reward placement and one small-reward placement in the goalbox, with the retrace door closed and reward delivered in a removable goal cup that was fashioned from a teaspoon. Animals were removed from the goalbox immediately after reward was consumed (<30 sec by the end of placements). During the entire experiment, animals were run in squads of five (a random composition of both groups) and in rotation, producing an average intertrial interval of 3-5 min that was spent in the living cage with water available. The order of running of squads and animals within squads was determined randomly each day. During goalbox placements and random-sequence training, whether the daily two-trial sequence was LS or SL was determined by two pseudorandom orders, and a random one-half of the rats were assigned to each of the orders. The orders were constructed so that a block of 8 days contained 4 LS days and 4 SL days, with the restriction that a given sequence could occur on no more than 2 successive days.

Random-Sequence Training

All rats received 110 days of random-sequence training with the same reward conditions and running arrangements that were in effect during goalbox training, with two exceptions: A trial began with the opening of the startbox door 2 sec following placement in the startbox, and the retrace door was closed as the rat entered the goalbox.

Fixed-Sequence Training

For a within-subjects comparison with random-sequence performance, during the 20 days following random-sequence training three of the five animals (chosen randomly) in each group (standard and sucrose) received the SL sequence every day. The remaining animals received the LS sequence every day. All conditions, except sequences, remained the same as in random-sequence training.

RESULTS

Times for both start and run measures were transformed [$10 \cdot \ln(x + 1)$] for analysis. Plotted in Figure 1 are the mean transformed run times for the two reward magnitudes in blocks of 8 days (except Dayblock 14, which contained 6 days) for random-sequence training and in blocks of 4 days for fixed-sequence training. The Trial 1 times are shown only for fixed sequences, and all data points are pooled over reward types. Analysis of both measures during random-sequence training produced only one reliable effect, dayblocks, in each measure [start: $F(13,104) = 23.02$, $p < .01$; run: $F(13,104) = 11.16$, $p < .01$]. There was a tendency for animals to run faster on Trial 2 (mean = 9.78) than on Trial 1 (mean = 10.33), as well as a tendency to run faster on small-reward trials (mean = 9.88) than on large-reward trials (mean = 10.22), but neither effect was significant [trials: $F(1,8) = 3.53$, $p > .05$; magnitude: $F(1,8) = 3.89$, $p > .05$]. The failure to discriminate reward magnitude was not dependent upon trials (magnitude by trials: $F < 1$). During the 20 days of fixed-sequence training, however, the Trial 2 times slowed considerably when reward was small. The Trial 2 data for the fixed sequences were subjected to a 2 x 2 factorial analysis combining the two levels of magnitude with the two reward types over blocks of 4 days. The run measure in

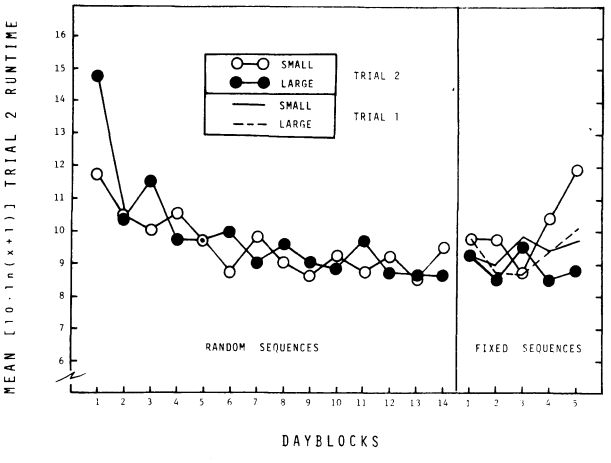

Figure 1. Mean transformed run times in blocks of 8 days (except Dayblock 14, which contained 6 days) for random-sequence training (left panel) and in blocks of 4 days for fixed-sequence training (right panel). The means are pooled over reward type (standard and sucrose).

this analysis yielded reliable interactions of Type by Dayblocks [$F(4,24) = 3.21$, $p < .05$], Magnitude by Dayblocks [$F(4,24) = 3.06$, $p < .05$], and Type by Magnitude by Dayblocks [$F(4,24) = 4.96$, $p < .01$]. The two- and three-way interactions were relatively unsystematic regarding reward type, but reward magnitude yielded systematic effects indicating patterning that developed over dayblocks. The start measure proved more sensitive to the change from random sequences, with patterning developing earlier and remaining stable [magnitude: $F(1,6) = 6.93$, $p < .05$; magnitude by dayblocks: $F < 1$]. Separate factorial analysis of the last dayblock showed that animals were running slower when Trial 2 ended with small reward (mean = 10.12) than when it ended with large [mean = 8.94; $F(1,6) = 8.53$, $p < .05$]. Yet when Trial 1 times were considered, no reliable differences appeared in the run measure. The mean Trial 1 run times for small and large reward were 9.53 and 9.60, respectively ($F < 1$). Factorial analysis of Trial 1 start times yielded significant interactions of Type by Dayblocks [$F(4,24) = 2.88$, $p < .05$], Magnitude by Dayblocks [$F(4,24) = 5.33$, $p < .01$], and Type by Magnitude by Dayblocks [$F(4,24) = 5.07$, $p < .01$], but all were due primarily to an unusually large mean for large-sucrose reward on the third dayblock.

DISCUSSION

In the two experiments in which patterning was reported with fixed sequences of sucrose rewards (SL or LS) at two trials per day (Burns, 1976, Note 1), patterning was well developed by the 24th training day (the 48th trial). In the present experiment employing the same procedures and apparatus but with random sequences, 110 training days (220 trials) were not sufficient to establish patterned running. Odors were controlled by randomizing running order in only one of the two earlier studies, yet patterning appeared in both. Of course, patterning was not obtained with random sequences in the present study, which controlled odor, while it was obtained in fixed sequences. The role of possible differential odor cues for large and small rewards, therefore, should be considered minimal at best. The failure to obtain patterning with extensive random-sequence training in the present study—when aftereffects may have been the only relevant cue—compared with the early success in the previous studies—when aftereffects, memories, trial stimuli, and rule learning were all possibilities—might be taken as evidence that the earlier patterning was controlled primarily by either trial stimuli or rule learning and not by aftereffects. The tentativeness of this conclusion is underscored, of course, by the need for comparisons among experiments, of which the general problems associated with acceptance of the null hypothesis and trials-to-criterion comparisons are, in this case, a subset.

Futhermore, it could be argued that a Trial 2 discrimination based on aftereffects, in the random-sequence design is more complex than in the fixed-sequence design involving the discrimination of two different reward aftereffects rather than the development of a simple habit based on a single aftereffect. But when patterning on both daily trials, as in the earlier experiments, is considered, the problem seems to be of equivalent complexity, at least with regard to the number of relevant stimuli (two) that are differentially reinforced. Consider the fixed sequence, LS, for example. An aftereffect account of patterning on both trials would invoke the discrimination of the large-reward aftereffect from Trial 1, which is 3-5 min old and conditioned to running by small reward, and the small-reward memory from Trial 2 of the previous day, which is 24 h old and conditioned by large reward. The theory holds that the age of the aftereffect or memory makes it distinctive, just as the reward magnitude that produced it (Capaldi, Leonard, & Ksir, 1968). In the random-sequence design, on the other hand, the relevant stimuli would be the Trial 1 aftereffects of large and small reward, which are conditioned by small and large reward, respectively. The memories of the Trial 2 outcomes from the previous day are irrelevant (uncorrelated with reward amount) in the random-sequence design, and Trial 1 patterning would not be expected.

The conclusion that the earlier fixed-sequence patterning was controlled primarily by either trial stimuli or rule learning would have important implications for an idea first entertained by Capaldi (1967) and later by Likely, Little, and Mackintosh (1971) and Mackintosh (1974). Sucrose reward reduction has consistently failed to generate the successive negative contrast effect (SuNCE), a temporary disruption in the performance of downshifted animals relative to unshifted controls (Burns & Burns, 1978; Burns, Dupree, & Lorig, 1978; Flaherty, Riley, & Spear, 1973; Homzie & Ross, 1962; Rosen, 1966), while reductions in standard Noyes pellets reliably generate the effect (cf. Black, 1968; Dunham, 1968). The idea is that sucrose rewards may produce nondifferentiable aftereffects relative to standard pellet rewards. One theory to account for the massed-trials SuNCE when it occurs (Capaldi & Lynch, 1967) proposes that the SuNCE is the consequence of generalization decrement engendered by a change from large- to small-reward aftereffects. If large and small sucrose aftereffects were somehow nondifferentiable, it would follow that sucrose reward reduction would not generate the SuNCE, but if the fixed-sequence patterning was mediated by aftereffects of sucrose rather than trial stimuli, for example, the idea that sucrose aftereffects are nondifferentiable would not be plausible (Burns, 1976).

The shift in the present experiment from random to fixed sequences generated reliable patterning in 16-20 days, a result suggestive of the influence of trial stimuli, memories, or cognitive rules that were made relevant by the shift. Yet reliable patterning appeared only on Trial 2; trial stimuli and rule learning accounts would predict patterning on both trials. An account based on aftereffects and memories, to the contrary, would predict the initial development of patterning on the second but not on the first trial; Trial 1 patterning should develop only after extended training. The account would be as follows: During the 110 days of random-sequence training, the small- and large-reward memories that were 24 h old were nondifferentially reinforced; only 3- to 5-min aftereffects were differentially reinforced. On the assumption that nondifferential reinforcement weakens the salience of a cue and differential reinforcement strengthens it (Sutherland & Mackintosh, 1971), the 3- to 5-min cue would be salient relative to the 24-h cue during fixed-sequence training following random-sequence training, but not necessarily in fixed-sequence training with naive animals. Because for each animal in fixed-preceded-by-random training there is only one relevant and salient cue, the 3- to 5-min aftereffect of a single reward magnitude, patterning acquisition is relatively rapid involving a simple habit based on a single aftereffect. The other cue, the 24-h memory, is now relevant but not salient, and Trial 1 patterning, as a consequence, does not occur without extended training. It should also be noted that, in the random-sequence training, trial stimuli and cognitive rules are irrelevant, and while they may be salient when training begins with fixed sequences, they should not be salient following random sequences even though they are made relevant.

Although the picture is far from being clear, the data to now imply that the fixed-sequence patterning obtained earlier (Burns, 1976, Note 1) may have been mediated by several relevant cues (aftereffects, memories, trial stimuli, or cognitive rules) that produced relatively rapid acquisition of patterned running, aided perhaps by cue additivity (e.g., Eninger, 1952; Warren, 1953). When aftereffects alone are made relevant, as in the de novo

random-sequence training, patterning must be extremely slow in coming, presumably taking longer than the training period in the present study. The fixed-sequence patterning in the present investigation may have been mediated by aftereffects, but the limited numbers of subjects during that phase of training make judgments concerning the relative contributions of standard pellets and sucrose solutions of little value. It does, nevertheless, seem prudent to reexamine the notion that the failure to obtain the SuNCE with sucrose rewards is the consequence of relatively nondifferentiable sucrose aftereffects.

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