

Temporal cuing of runs in series of reward events reduces interevent anticipation

RICHARD A. BURNS, LARRY P. WILEY, and TERRI L. PAYNE
Georgia Southwestern College, Americus, Georgia

In Experiment 1, a group of rats were runway trained on each of two reward series for 32 days. The two series consisted of three runs, the first two of which were, respectively, rewarded and nonrewarded; the third run was rewarded in one series but nonrewarded in the other. A 40-min interval separated the two series; the first and second runs within the series were separated by a 10-min interval, whereas the second and third runs were separated by a 30-sec interval. The reward (and nonreward) events and temporal cues of the two series are designated R-NR/R-NN. A second group was similarly trained, with the exception that the 10-min interval separated the second and third runs (RN-R/RN-N). Both groups developed appropriate differential running on the third run of the two series, and the RN-R/RN-N animals ran appropriately (slowly) on the second run of both series. Appropriate Run 2 performance appeared in one half of the R-NR/R-NN animals (depending upon order of series presentation); the remaining half ran faster on Run 2 of the R-NR series than on the same run of the R-NN series, an effect currently termed interevent anticipation. A cue shift phase in which all within-series intervals were 30 sec showed that the temporal intervals were controlling performance before the shift. Experiment 2 showed that interevent anticipation appears when all within-series intervals are either 10 min or 30 sec from the beginning of training, suggesting that the elimination of interevent anticipation in Experiment 1 was due to the differential cuing of runs by the temporal intervals rather than the particular interval duration. The overall findings suggest that the similarity of Run 2 and Run 3 performance termed interevent anticipation may be due to a failure to discriminate the ordinal position of runs within a series.

Runway experiments that employ reward events arranged in two series such that comparably rewarded runs within the series are followed by differently rewarded runs have prompted consideration of the possibility that rats anticipate reward amount on future runs during current runs. Capaldi, Nawrocki, and Verry (1983) have called this "interevent anticipation." In their Experiment 1, rats were trained on the two three-run series 10-0-10 and 10-0-0, each number referring to the number of pellets given as reward on the individual runs of the series. Every rat ran both series, in the same order, each day with a relatively short interval between runs within the series but a longer interval between the two series. Differential performance developed on the third run, which was differentially rewarded, but it also developed on the second run, which was not. Rats ran faster on Run 2 of the 10-0-10 series than on Run 2 of the 10-0-0 series. Similar results have been obtained in a variety of other studies (Burns & Wiley, 1984; Burns, Wiley, & Stephens, 1986; Capaldi & Verry, 1981; Self & Gaffan, 1983).

Capaldi et al. (1983) imagined that the rat formed an internal sensory representation, or serial map, of the reward events in a series. Once training on the series had

clearly established the map, any stimulus in that series would evoke representations of the remaining elements of the map. Retrieving future reward events was assumed to affect performance on current runs. When the rat began Run 2 of the 10-0-10 series, for example, a representation not only of the nonreward of Run 2 but also of the 10-pellet reward of Run 3 would occur, causing the animal to run faster than if only nonreward was retrieved, as in the 10-0-0 series.

One possible alternative to the sensory mapping view of these findings is that the Run 2 performance results from generalization and a failure to discriminate the run stimuli, events correlated with the ordinal position of a run, for Runs 2 and 3. In 10-0-10/10-0-0 training, the rat must distinguish between the two series. This discrimination is indicated by appropriate differential running on Run 3, which is rewarded differently between the two series. In addition, the rat must distinguish the three runs within each series. Run 3 performance should also be affected by this distinction, but so should performance on Runs 1 and 2 which are rewarded differently within but not between series. Running fast on Run 1 and slowly on Run 2 in both series is an indication of the discrimination of runs. The possibility that differential Run 2 performance is due more to a failure to discriminate the position stimuli of Runs 2 and 3 than to elicited sensory representations of future reward events is suggested by the finding in experiments on this problem that as differen-

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tial performance improves, with extended training, on Run 3 it tends to correspondingly reduce on Run 2.

An experiment designed to facilitate the discrimination of position stimuli associated with Runs 2 and 3 by providing visual and tactile cues preceding Run 3 of both the 10-0-0 and the 10-0-10 series (Burns, Wiley, & Stephens, 1986) produced some evidence of a reduction in differential Run 2 performance. Cued rats ran more slowly on Run 2 of the 10-0-10 series than did uncued controls, but both groups ran even more slowly on Run 2 of the 10-0-0 series. The difference in Run 2 performance, called interevent anticipation, was reduced but not eliminated by cuing Run 3.

EXPERIMENT 1

The visual and tactile cues used by Burns, Wiley, and Stephens (1986) did not produce a convincing reduction in interevent anticipation. Other recent experiments on serial pattern learning suggest, however, that temporal cues may control the discriminations in these problems as well as or better than visual (brightness) and spatial cues (Capaldi, Verry, Nawrocki, & Miller, 1984; Fountain, Henne, & Hulse, 1984; Yazawa & Fujita, 1984). In one of the Capaldi et al. (1984) experiments, for example, rats were trained on a single series (10-2-0-10) four times a day with a different interval or different runway brightness cuing the final element of the series. Running time more closely matched reward amount in the temporal cue condition than in the brightness cue condition, and both cued conditions produced more appropriate running than did an uncued control condition.

Experiment 1 was conducted to see if temporal cues for Runs 2 and 3 would reduce differential running on Run 2 with training on the 10-0-10 and 10-0-0 series. Unlike the investigation of Capaldi et al. (1984), the cues were not correlated with reward amount in a single series of reward amounts. They were correlated with the second and third run positions of two series that differed only in the amount of reward on the third run. The assumption was that Run 1 of the two series was already a distinct event, cued by longer intervals (23 h and 40 min) than were the other runs, since no experiment yet reported with these series had shown anything but fast running on Run 1. Distinguishing the position of Run 2 from that of Run 3 with temporal cues should produce better discrimination between Run 2 and Run 3 and reduce Run 2 differences on the two series.

Method

Subjects. The subjects were 12 naive male rats purchased from the Holtzman Company, Madison, Wisconsin. The animals were about 90 days old at the beginning of preliminary training.

Apparatus. The apparatus was a wooden L-shaped runway (233.7 cm long) painted black and covered with hinged clear plastic. Manually operated start and retrace doors were positioned 20.3 and 172.7 cm, respectively, from the beginning of the runway, and three photocells mounted 7.6, 160.0, and 195.6 cm beyond the start

door allowed measurement of start, run, and goal times by Standard electric timers. The right turn was 182.9 cm beyond the start door. A removable floor panel that ran the length of the runway was painted white and covered with 1/2-in. (1.28-cm) hardware cloth to provide brightness and tactile cues.

Preliminary training. Upon arrival, all rats were housed in individual living cages with water freely available. The cages were kept in the room in which the experiment was conducted. After 3 days of free feeding, reduction to 85% of free-feeding body weights was begun and maintained throughout the experiment. During the first 4 days of deprivation, all animals were allowed 15 min each day on a walled exercise table in squads of 6 rats each prior to daily weighing and feeding. The remaining 6 days of preliminary training consisted of goalbox placements. Each rat was taken from its living cage and placed in the goalbox, which was baited with 10 Noyes pellets (.045-g Formula A) delivered in the goal cup, which was a teaspoon. After the pellets were consumed (judged by the experimenter), the animal was placed on the exercise table while the remaining animals were run, after which it was weighed and fed. The order of running of animals during goalbox placements was randomized each day. Half of the animals had the white, rough floor in place on Days 1, 3, and 5; the remaining half had the floor on Days 2, 4, and 6. By the end of the goalbox placements, all rats were consuming the pellets in fewer than 60 sec.

Training. On each day except the first 4 days, every animal was given two three-run reward series which differed only in whether or not the third run of the series was rewarded. For both series, the first and second runs were, respectively, rewarded and non-rewarded. All three runs of a series were administered to every rat before the second series was begun, so the interval between series each day was about 40 min; within the series, however, a random half of the rats were run in such a way that the interval between the first and second runs of a series was about 30 sec whereas the interval between the second and third runs was about 10 min. The series that ended in reward for this group is designated RN-R; the series that ended in nonreward is designated RN-N. The remaining half of the rats had a 10-min interval between Runs 1 and 2 and a 30-sec interval between Runs 2 and 3 (R-NR/R-NN). Whether the first series of the day ended in reward or nonreward was balanced among the animals within the two interval conditions at the outset so that the order of the series on each training day did not vary for a given rat. In addition, the white, rough floor was inserted on runs in the series ending in reward for half of the rats; it was inserted during the series ending in nonreward for the other half. On each of the first 4 days, only one series was administered, so by the end of 4 days each rat had run both series twice in the appropriate order, making the equivalent of 2 training days.

A run began with the opening of the start door about 2 sec after placement of the rat in the start area and ended with the completion of reward (10 pellets) on rewarded runs or after 30 sec confinement in the unbaited goalbox on nonrewarded runs. The retrace door was closed as the rat passed the second photocell. There were two running squads containing 3 rats from each of the two interval conditions. Running a rat twice in succession produced the 30-sec interval, and running 3 rats for two runs and the remaining 2 rats of the squad of 6 for one run produced the 10-min interval. Animals within a squad were run in rotation, and the order of running of squads and animals within squads was determined randomly each day. After a rat completed the last run of its second series, it was placed on the exercise table, where it remained until weighing and feeding took place about 1 h after the running of the last animal.

Cue shift. To evaluate the role played by the 10-min interval as a cue, the running procedure was modified after 32 training days so that all intervals between runs within a series were 30 sec for all rats. This was accomplished by running each animal successively on all three runs of a series before running the next animal. The interval between series remained at about 40 min. This cue-shift training was continued for 4 days (Days 33-36).

Results

All times were subjected to a normalizing transformation, and, because the individual dependent measures (start, run, and goal times) yielded similar results, transformed totals, $10[\ln(\text{start}) + \ln(\text{run}) + \ln(\text{goal})]$, are the basis for the results presented here and in Experiment 2. Results both here and in Experiment 2 will be called significant if $p < .05$; individual probability values will not be reported. Figure 1 is a plot of average daily times for both interval conditions and both series. Times for Run 1 are not presented because rats in nearly all conditions simply developed fast ($M=25.52$) running on that run.

Days 1-32. Rats in the RN-R/RN-N condition developed differential running on the third run with faster times on that run in the RN-R series than in the RN-N series. On Run 2, however, times were slow for both the RN-N and RN-R series. Rats that ran the R-NR and R-NN series also ran differently on the third run, depending on reward amount, but, unlike animals in the alternative interval condition, they showed evidence of differential performance on Run 2, running somewhat faster ($M=36.72$) in the R-NR series than in the R-NN series ($M=45.55$).

We did separate analyses on each run which showed no significant effects, other than days, on Run 1. On Run 2, however, there was a significant main effect of interval [$F(1,8) = 12.90$], showing that on Run 2 the times produced by the RN-R/RN-N condition ($M=65.66$) were slower than those produced by the R-NR/R-NN ($M=41.14$) condition. The apparent differential performance on Run 2 for the R-NR/R-NN condition, but not for the RN-R/RN-N condition, did not find support in an interval \times series interaction [$F(1,8) = 1.33$].

The analysis of Run 3 produced a significant series effect [$F(1,8) = 14.04$], but the interval conditions did not differ and did not interact with the series variable. Rats in both interval conditions ran appropriately for the different Run 3 reward amounts of the two series.

A reliable interval \times order \times series interaction [$F(1,8) = 11.64$] appeared on Run 2 but not on Run 3 ($F < 1$). Figure 2 shows the average times on each of the three runs for animals in the R-NR and R-NN series. Each point is averaged over the 32 days of training, and the figure distinguishes between the two orders of series presentation. These order effects were not apparent in the RN-R/RN-N condition. The Bonferroni t statistic used on

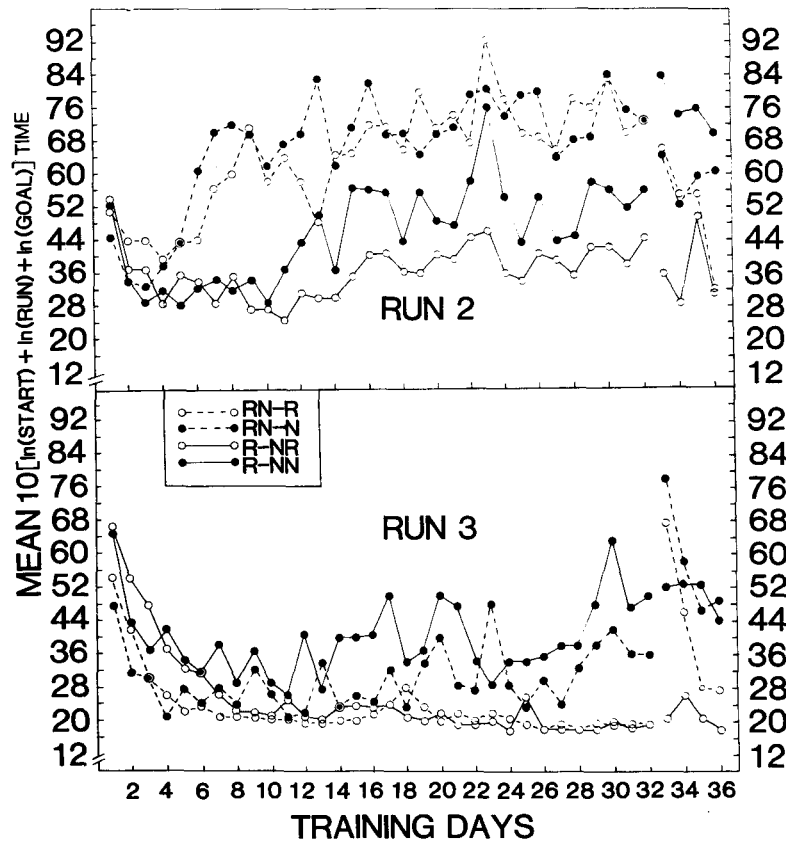


Figure 1. Average daily running times for Runs 2 and 3 of both reward series for both interval conditions in Experiment 1. In the legend, an "R" refers to a rewarded run and an "N" to a nonrewarded run. The dash designates a 10-min interval between runs, and letters joined without the dash designate a 30-sec interval between runs. The break of continuity at Day 33 represents the beginning of the shift to 30-sec cues throughout the series.

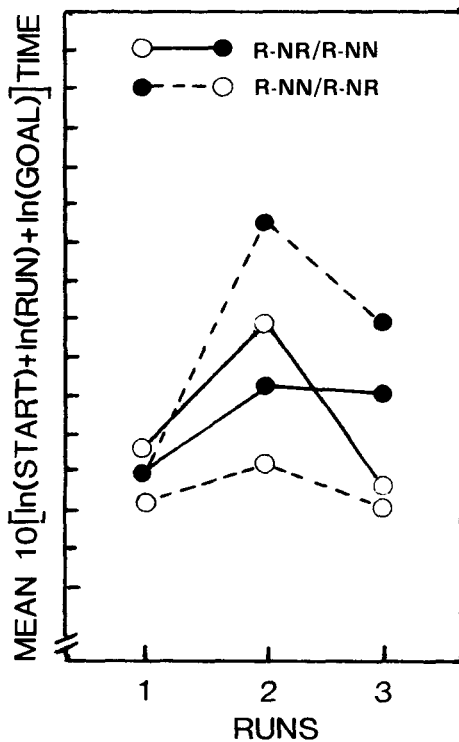


Figure 2. Running times averaged over Days 1-32 of Experiment 1 for each of the three runs in the group given the 30-sec cue for Run 3. The figure distinguishes between the two orders of series presentation.

the Run 2 interaction means showed that rats that received the R-NN series first on each training day differed significantly in their Run 2 performance in the two series, but that rats that received the R-NR series first each day did not.

Days 33-36. When all 10-min intervals were shifted to 30 sec, there was evidence, suggested in Figure 1, that the intervals were controlling performance before the shift. Rats trained with 30 sec as a cue for Run 3 showed an increase in differential Run 2 performance, and rats trained with 10 min as a cue for Run 3 reduced, initially, their Run 3 differentiation by running more slowly in both series. Separate analyses for each run showed that animals previously trained with a 10-min Run 2 cue ran more slowly ($M=26.88$) on Run 1 than did animals in the alternative interval training condition ($M=20.84$) [$F(1,8) = 5.68$]. Subsequent analysis of a significant interval \times series interaction [$F(1,8) = 15.14$] with the Bonferroni t showed that the series discrimination was reliable for animals previously trained on the R-NR/R-NN series, but not for those trained in the alternative interval condition. Order effects seen in R-NR/R-NN rats on Run 2 but not on Run 3 during original training were not present after the shift to 30-sec cues ($F < 1$). All 6 of those rats showed the differential performance on Run 2.

On Run 3, a main effect of interval [$F(1,8) = 7.76$] and an interval \times days interaction [$F(3,24) = 6.72$] resulted from the slower running of animals from the

RN-R/RN-N condition on Day 33 (Bonferroni t). Subsequent Bonferroni values based on the significant interval \times series interaction [$F(1,8) = 11.48$] showed that the series discrimination on Run 3 was smaller in the RN-R/RN-N animals than in the R-NR/R-NN animals but was significant in both groups.

Discussion

There was no evidence of differential Run 2 performance in rats for which Runs 2 and 3 were, respectively, cued by 30-sec and 10-min intervals, and 3 of the 6 rats (those getting R-NR first each day) for which the 30-sec cue signaled Run 3 and the 10-min interval cued Run 2 also did not show differential Run 2 performance. These findings show that interevent anticipation can be eliminated with differential temporal cuing for the positions of Runs 2 and 3 in the three-run reward series typically used to study the effect. That the different intervals controlled performance is further suggested by the initial effects of shifting the 10-min intervals to 30 sec. When the cue for Run 3 was 30 sec, the novel appearance of that interval prior to Run 2 increased the similarity of performance on Run 2 to that on Run 3 in R-NR/R-NN animals. In like fashion, the novel appearance of the Run 2 cue prior to Run 3 increased the similarity of performance on Run 3 to that on Run 2 in RN-R/RN-N animals.

Overall, the findings suggest to us that interevent anticipation may be due more to a failure to discriminate one run position from another than to a serial mapping of represented reward events for the different runs and consequent anticipation of upcoming rewards. We do not, of course, mean to suggest that internal representations of reward events do not occur at all, only that they may not play the dominant role in the designs currently employed to study anticipation.

All three rats that received the two series in the order R-NN followed by R-NR ran significantly faster on Run 2 of the R-NR series than on Run 2 of the R-NN series. These were the only animals that showed differential Run 2 performance prior to the interval shift. Failing to discriminate the positions of Runs 2 and 3, if the two series are discriminated, results in appropriate Run 2 performance only in the series ending in nonreward because Run 2 is always nonrewarded. Yet, inappropriate (faster) running is the consequence of the same discrimination failure in the series ending with reward. One possibility is simply that, due to proactive interference, the failure to discriminate Runs 2 and 3 is more likely in the second daily series than in the first. In an earlier study (Burns & Wiley, 1984), as described in Experiment 2 of this report, we found that under conditions that reliably produce Run 2 differences, the differences are greater when the series ending in nonreward is presented first each day.

EXPERIMENT 2

Though the findings of Experiment 1 suggest that the absence of interevent anticipation seen in Experiment 1

is the result of improved discrimination of run position stimuli, the possibility that anticipation was reduced, at least in part, simply by the temporal separation of events must be considered. The most dramatic reduction of anticipation seen in Experiment 1 was in animals trained with a 10-min separation of the events of Runs 2 and 3. It could be that sensory representations of reward events are formed in such a way that future events are temporally tagged so that distant events are anticipated less than imminent events. An interval of 30 sec between Runs 2 and 3 should, by this thinking, produce more interevent anticipation than an interval of 10 min.

In Experiment 2, we simply compared the performance of rats trained with 10-min intervals between all runs within a series with that of controls trained with 30-sec intervals.

Method

Subjects and Apparatus. The subjects were 12 naive rats of the same description as in Experiment 1 and trained in the apparatus used in Experiment 1.

Training. The training methods were similar to those of Experiment 1. The only important change involved the running procedure. The rats were reduced to 85% of their free-feeding weights

and given 6 days of goalbox placements before runway training began. This was followed by 30 days of training in which a random half of the animals had about 10 min between each of the runs in the two series designated R-N-R/R-N-N. The remaining half had 30 sec between each run (RNR/RNN). As in Experiment 1, the series were separated by an interval of about 40 min, and the order of running of animals was randomized daily. Whether the first series ended in reward or nonreward was balanced over groups and remained fixed over days. The white, rough floor was again used as an additional series cue.

Results and Discussion

Times were transformed, as in Experiment 1, and the total measure is the basis for presentation. Figure 3 is a plot of average total times for each of the two series over the 30 days of training. The figure shows daily averages for both interval conditions on Runs 2 and 3. Clearly, differential performance developed on both runs, and the differences did not depend upon whether the interval between runs was 10 min or 30 sec.

Separate analyses performed on each run showed that the series ending in reward produced faster running than did the series ending in nonreward on Run 2 [$F(1,8) = 56.13$] and Run 3 [$F(1,8) = 50.50$], but not on Run 1

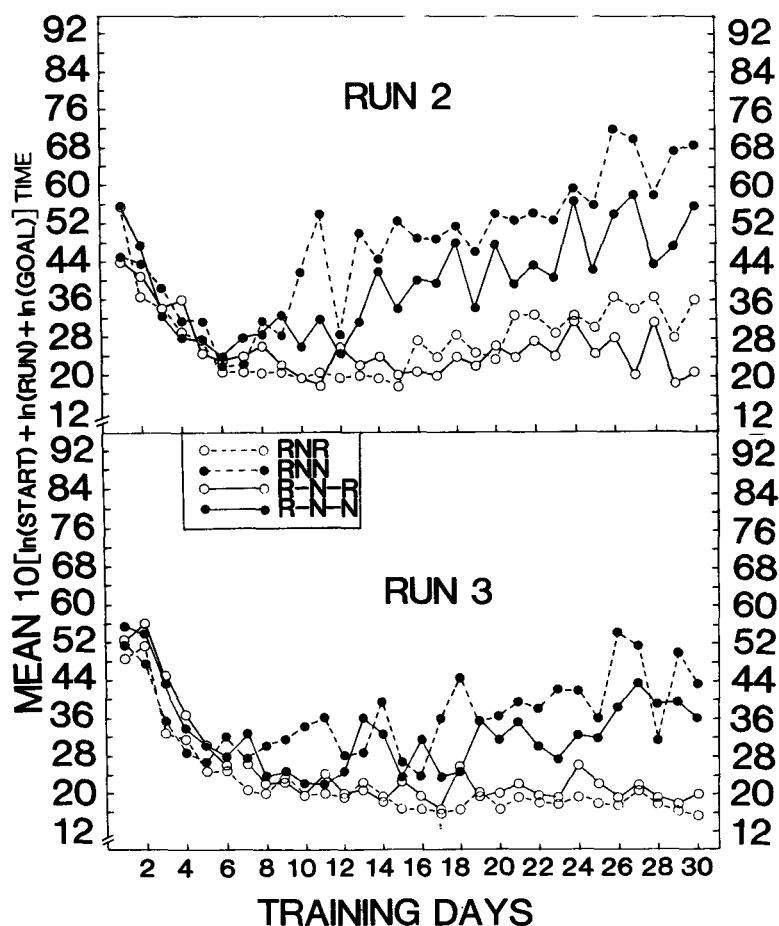


Figure 3. Average daily running for Experiment 2. The figure was constructed in the same manner as Figure 1.

[$F(1,8) = 1.63$]. In no case did the series effects interact with the interval variable. As in Experiment 1, there was a significant interaction of order \times run \times series [$F(2,16) = 13.80$], but the interval variable did not interact with these effects ($F < 1$). Performance on Run 2 paralleled that on Run 3 more precisely in animals trained with the series ending in nonreward appearing first each day whether the intervals between runs in the series were 10 min or 30 sec. Bonferroni t values showed, however, that the Run 2 differences were significant in both presentation orders.

The elimination of differential Run 2 performance seen in Experiment 1 when a 10-min interval separated Runs 2 and 3 did not appear in Experiment 2 when the same interval was used. The difference, of course, between Experiments 1 and 2 is that the interval differentially signaled the Run 3 position in Experiment 1 but non-differentially signaled both Run 2 and Run 3 in Experiment 2. These procedural differences suggest that the elimination of differential Run 2 performance in Experiment 1 was not caused by weaker anticipation of distant than of imminent events.

GENERAL DISCUSSION

The idea that anticipation may involve generalization is, of course, nothing new, nor is the view that discrimination among elements in a series plays a major role in patterned responding (e.g., Capaldi & Molina, 1979; Capaldi, Verry, & Davidson, 1980) that might otherwise be attributed to cognitive processes (Hulse & Dorsky, 1977, 1979). Plausible to us is the possibility that run times appropriately match reward amounts in a series of reward amounts in part because stimuli correlated with the ordinal position of runs in the series are conditioned to instrumental behavior by the different reward amounts associated with each of the run stimuli. These run stimuli may arise from memory of the number of runs preceding a run within a daily session, or memory tied to the time elapsing since the first run of the day. They might also arise from unintentional run-to-run differences in procedure, or from intentional cues provided to differentiate runs, as in Experiment 1. The extent to which the position stimuli are differentially associated with response strength that is a function of the reward amount on a particular run should determine how appropriately running matches reward. When generalization across run stimuli occurs, performance is appropriate only when reward amount on different runs is the same. Inappropriate running is the consequence of run stimulus generalization when reward amounts are different, and when the generalization is from the second to the first of two runs in a series, it may be called interevent anticipation. Yet, if run position stimuli were conditioned directly to instrumental behavior by reward, the term, anticipation, need not be used at all to describe differential Run 2 performance that results from generalization of those stimuli.

Run (or trial) position stimuli have been relied upon only occasionally to explain performance in animal experiments with patterns of reward (Burns, DeHart, & McRae, 1980; Capaldi & Morris, 1974; Couvillon, Brandon, Woodard, & Bitterman, 1980; Straub & Terrace, 1981). Position hypotheses have, however, played a role in the analysis of human serial learning (Bower, 1971; Ebenholtz, 1972). We suggest that position cues may be a powerful source of control in many situations involving reward series with animals. Consider, for example, experiments that examine extinction following training with different reward series. Wike and King (1973) trained rats with increasing, decreasing, or random three-run series of reward magnitudes in a runway. Clear patterning, appropriate running for the reward amount of a particular run, developed in both groups for which reward was correlated with runs. That run stimuli rather than memories of previous reward amounts were controlling performance is suggested by the results of a 12-day extinction period also run three runs per day with the same temporal intervals used in acquisition. The increasing and decreasing patterns of responding were maintained throughout extinction in spite of the fact that memory cues for the different reward magnitudes in the series would all have been changed to those of nonreward. Other investigations of extinction following patterned reward have shown similar results (e.g., Burns, 1976; Capaldi et al., 1984).

Although we think that the results of Experiments 1 and 2 can reasonably be imagined as the consequence of position stimulus conditioning and generalization, we do not necessarily take them as clear evidence against the sensory mapping explanation. One possible interpretation—derived from the analysis of experiments in which selected reward amounts in a single series were cued (Capaldi et al., 1984; Capaldi, Nawrocki, Miller, & Verry, 1986)—of our Experiment 1 results is that the salient temporal cues employed here overshadowed associations among the sensory representations of reward for Runs 2 and 3. If that were happening, the series of represented reward events retrieved on Run 2 would not include the events of Run 3 and interevent anticipation on Run 2 would not occur. In fact, there are aspects of the findings in Experiment 1 that are not easily accommodated by the position stimuli idea. Differential performance did appear in Experiment 1 on Run 2 of the R-NR/R-NN series when the series ending in nonreward was always presented first in the day. Although the order effects may be imagined in terms of proactive interference with run stimuli, as discussed following Experiment 1, it should be noted that interevent anticipation did not appear at all in animals trained in the RN-R/RN-N condition, no matter what the order. If the different temporal intervals were doing nothing more than differentially signaling the position of runs within a series, then interevent anticipation should not have appeared in any condition. Furthermore, the rats in the R-NR/R-NN condition that did not show anticipation

ran faster than the rats in the other condition which also did not show it.

The 10-min and 30-sec intervals seemed to be doing more than simply differentially cuing runs, but the possibility that a 10-min interval was sufficient to eliminate anticipation by making the upcoming event distant rather than imminent was itself eliminated by the results of Experiment 2. Suggested in the experiments of Capaldi and Verry (1981) is the possibility that memory of a series of past reward events—and perhaps, expectation of multiple future events—might be “forged into a single unit” or chunked, the more so when events are separated by short, rather than long, temporal intervals. When Runs 2 and 3 in Experiment 1 were separated by a 30-sec interval, rats showed a greater tendency to respond similarly to the events of those runs even when the events were different. They did not show such a tendency when Runs 2 and 3 were separated by a 10-min interval. That the 30-sec interval provoked a tendency to combine or chunk the events of Runs 2 and 3 that was incompletely countered by differential cuing of the runs with different temporal signals is a possible explanation for the differences in cue effectiveness of the long and short intervals used in Experiment 1. Of course, the additional necessary assumption that chunking blurs the distinction among items is not always made (Miller, 1956), and that makes a semantic distinction between chunking and generalization questionable.

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