Counting in Rats: Its Functional Significance and the Independent Cognitive Processes That Constitute It

E. J. Capaldi and Daniel J. Miller
Department of Psychological Sciences
Purdue University

Four major conclusions were supported in seven runway experiments: Rats count; rats routinely and perhaps automatically count reinforcing events; counting reinforcing events is of importance for understanding instrumental learning and performance; and counting is the result of several independent coordinated cognitive processes. The results suggested counting rather than some simpler numerical ability because (a) they cannot be ascribed to other mechanisms (e.g., an identical–nonidentical discrimination (Experiments 4 and 5) or subitizing (Experiments 1–7); (b) qualitatively different reinforcers were categorized as both similar and different for counting purposes (Experiment 5); (c) the order-irrelevance principle was followed (Experiment 6–7); (d) abstract tags were assigned on the basis of number of events (Experiments 5–7); and (e) assignment occurred according to complex and situationally determined rules that were themselves abstract (Experiments 6–7). Number cues associated with reinforcing events are often valid in learning investigations but are invariably confounded with various, equally valid number and duration cues (related to trials, responses, etc.). Reinforcers were counted when confounded with these other cues (Experiments 1, 2, 3, and 5), which supported the sequential view that rats are highly disposed to using number cues associated with reinforcers and normally do so in instrumental situations. There was some evidence that one or more of the confounded events (unidentified) provided cues that were used by the rat, but this was of minor significance.

To establish both that animals count and that counting is central to understanding many learning phenomena, at least four steps are required. It must be shown that number of events can be used as a discriminative cue; that such use involves the application of distinctive abstract numerical tags to events on a flexible basis; that numerical tag assignment occurs even when, as is almost invariably the case in both laboratory and real-life learning situations, other equally valid cues are simultaneously available to mediate correct responding; and that as an explanatory mechanism, counting is of substantial rather than trivial significance. In available animal counting investigations, researchers have concentrated on the first of these issues, expended some effort on the second, and all but ignored the third and fourth issues except to express various contrary opinions not adequately substantiated by data. We examined all four issues in seven runway investigations reported here. This was possible because in the present counting investigations, unlike in many previous ones, the procedures departed minimally from those used in a variety of conventional instrumental learning investigations. Rats were asked to count, not auditory stimuli or geometrical figures or whatnot, but the number of successively presented food reinforcements. The number of reinforcing events is a valid cue predictive of other reinforcing events in a wide variety of learning situations, and the view that reinforcing events produce internal representations that may motivate

and direct behavior is widely accepted. Given this state of affairs, what remains to be determined is (a) whether animals form representations corresponding to the number of reinforcers, and if so, under what conditions and (b) whether such representations are complex enough to be characterized as counting.

Available counting investigations are, for the most part, discrimination-learning investigations in which animals have been asked to respond differentially on the basis of number of events. Discriminative responding, or successful demonstration of number usage in such investigations, typically has required extensive training or relatively extreme motivational conditions. This has suggested to some that although animals count, they do so only as a last resort, when no other option is available to them (e.g., Davis & Bradford, 1986; Davis & Memmott, 1982, 1983; Salman, 1943). Because in most learning situations, laboratory or real life, number cues are confounded with other cues, it follows from the last-resort hypothesis that counting is of little explanatory significance in general and that animals certainly do not count in conventional instrumental learning investigations.

Slow discrimination learning by animals in counting investigations, though consistent with the last-resort hypothesis, is far from uniquely implied by those data. Not surprisingly, therefore, we suggest a diametrically opposite view, one based mainly on conventional extinction findings that may be more sensitive to counting than discrimination learning data. According to this view, animals are highly disposed to counting reinforcing events and will do so even when other cues are equally predictive of the consequences of responding, as they invariably are. This view is consistent with theoretical treatments strongly indicating that counting reinforcing

This research was supported in part by National Science Foundation Grant BNS-8515831 to E. J. Capaldi.

Correspondence concerning this article should be addressed to E. J. Capaldi, Department of Psychological Sciences, Purdue University, West Lafayette, Indiana 47907.
events may explain a wide variety of instrumental learning phenomena, which are already available in the literature (see especially Capaldi, 1966, 1967, 1985; Capaldi & Verry, 1981; Capaldi, Verry, Nawrocki, & Miller, 1984). This more optimistic view of counting, like the last-resort view, is not adequately supported by data, something that we attempted to remedy in this study.

Consider some differences between explicit counting investigations and conventional instrumental learning investigations. In counting investigations, some number cue and only that number cue is valid as a matter of intention. In conventional learning investigations, number validity is present, but (normally) unintentionally so. In addition, a variety of number cues may be simultaneously valid (related to trials, reinforcers, responses, etc.). Finally, the various valid number cues may be confounded with each other, with still other unintentionally valid cues (most often temporal ones), and with the variable explicitly manipulated by the experimenter. If these conditions prevail in investigations concerned with either consistent reinforcement, various regular schedules of varied reinforcement (e.g., single or double alternation), or serial learning (see e.g., Capaldi et al., 1984) is perhaps too obvious to warrant demonstration.

The attempt to determine whether in conventional learning investigations animals count or fail to count accounts for the experimental strategy employed in Experiments 1, 2, 3, and 5. In an initial training phase in Experiments 1, 2, 3, and 5, reinforcer-related number cues were valid along with other cues duplicating, more or less, the sort of conditions that prevail in many instrumental learning investigations. In a subsequent shift phase, however, only the reinforcer-related number cues continued to be valid, duplicating the conditions that prevail in explicit counting investigations. If responding is undisturbed by the shift, then (a) reinforcer-related number cues, confounded or not, are used as signals in conventional learning investigations, and (b) the last-resort hypothesis of counting is not correct, at least with respect to reinforcer related number cues and possibly in general.

We used the model of counting suggested by Gelman and Gallistel (1978). The model suggests that counting involves applying distinctive tags (internal representations) in one-to-one correspondence to events. Tags (e.g., 1, 2, or 3) should be assigned in the same order over occasions (stable-order principle). Any event may be assigned any tag; thus the order of presenting events is irrelevant (order-irrelevant principle). Clearly, most important and indispensable to any claim of counting is the demonstration that the tags are abstract (abstraction principle). That is, the basis for tag assignment must be number of events, irrespective of other event characteristics such as size, shape, color, taste, and so on.

Although the tags used by the animals are presumably unlike the tags 1, 2, and so on, in being neither conventional nor verbal, they are not thereby prevented from being abstract. Thus children appreciate the abstract character of tags before being adept at using the conventional verbal ones (Gelman & Gallistel, 1978). In our study, the number of successively presented food reinforcements served as signals for the consequences of responding, which were either reinforcement (R) or nonreinforcement (N). Our view is that animals encode two distinct aspects of reinforcers: their abstract number properties and the sort of concrete properties traditionally stressed by various conventional theories—the taste, visual appearance, size, and so forth—of reinforcers. Neither property, we suggest, is more "natural" than the other.

Counting would be impossible in the absence of categorization, which entails identifying the events to be counted, including those events in the count and excluding all other events from the count. For example, depending upon instructions, a person provided with an apple, an orange, and a lemon might count all three items (count fruit), only two of the items (count citrus), only one (count oranges), and so on. To investigate counting in this study, we used four distinctive food reinforcers differing in such concrete properties as taste, visual appearance, and so on: 0.045-g Noyes Pellets, Kellogg's Corn Pops, Kellogg's Honey Smacks, and Kellogg's Cocoa Puffs. Whether rats count items in two different ways simultaneously was addressed in Experiment 5, the first experiment in this report concerned with the use of numerical tags by rats in a manner suggesting categorical flexibility and abstraction. In Experiments 6 and 7, we were concerned with abstraction and order irrelevance. In the shift phase of Experiment 6, the order of presentation of two different reinforcers (Corn Pops and Pellets) was rearranged in such a way that established discriminative responding would continue if abstract number tags were being used in accord with the order-irrelevance principle, but would deteriorate if only the concrete properties of reinforcers were being used. Both arrangements of reinforcers that occurred in Experiment 6, considering initial training and shift, were used in the initial training phase of Experiment 7. Subsequently, a shift occurred to two completely novel reinforcers, thereby removing concrete properties of the former reinforcers. Maintenance of discriminative responding in shift could occur if the rats were using abstract number cues, assigning them in accordance with an abstract rule.

Experiments 1 and 2

In Experiment 1, each animal received, in irregular order, multiple presentations each day of two slightly different series of trials in a runway. The intertrial interval was 15 s; the interseries interval, about 10–15 min. One series, the three-trial series, consisting of two food-reinforced trials followed by a nonreinforced trial, was RRN. The second series, a four-trial series, was NRRN. Because the two series were presented irregularly, we anticipated, as found, that the rats would run fast and nondifferentially on Trial 1 of each series. Confinement time in the goal box was 60 s on the terminal N trial of each series and 15 s on all other trials. The 60-s confinement time was used to encourage slow running.

Assume that in Experiment 1 the rats come to run more slowly on the terminal N trials than on any other trial, no other difference being significant except perhaps between the terminal N trials themselves. Such discriminative responding could not be fully explained by either counting or summing the durations of any of the following events, either singly or in any combination—responses, trials, intertrial intervals, and goal box confinements—irrespective of nonreinforcement and reinforcement. To consider a representative example, if
the rat either counted goal box confinement or summed their duration and ignored either timing or counting R events, then number and duration stimuli that signal the N trial of the RRN series would signal the second R trial of the NRRN series, and discriminative responding of the sort described above could not occur. In order to correctly anticipate the terminal N trials of each series as described above the animal, whatever else it might or might not do, must attend to the R events. The animal must either count the R events (one R event signals R, two R events signal N) or sum the confinement times of the R events, abbreviated as CTR (15-s CTR signals R; 30-s CTR signals N).

According to the last-resort hypothesis of Davis and Mermott (1982), the animal will use the CTR cue rather than count R events. The sequential view suggests, as it has in the many conventional learning investigations in which CTR and number of R events were completely confounded, that the rat will count R events. A test of these alternatives is easy to arrange. If the animal is timing the R events and not counting them, then established discriminative responding should be disrupted either by increasing CTR from 15 s to 30 s (Experiment 1) or by decreasing CTR from 15 s to 7 s (Experiment 2). In the first shift, the sum of CTR (30 s), which was formerly a cue for the terminal N event of each series, is now a cue for the second R event of each series. In the second shift, the sum of CTR (15 s), which was formerly a cue for the second R event of each series, is now a cue for the terminal N event of each series. If the animal is timing rather than counting, it is most difficult to imagine that one or the other or both of these shifts in CTR would leave discriminative responding undisturbed, even if it is assumed, for example, that two 7-s CTRs are not exactly equivalent to one 15-s CTR. But if the animal is counting rather than summing CTR, a change in CTR either from 15 s to 30 s or from 15 s to 7 s would have no effect upon discriminative responding. This latter result could also be interpreted as indicating that the rat is both counting and timing, but the number of R events is a much more salient or dominant cue than is the sum of CTR. In addition to increasing CTR after discriminative responding developed in Experiment 1, we subsequently increased the intertrial interval from 15 s to 30 s.

**Method**

**Subjects.** The subjects in Experiment 1 were 4 naive male albino rats, 82 days old on arrival at the laboratory, purchased from the Holtzman Co., Madison, Wisconsin.

**Apparatus.** The apparatus in Experiment 1 was a straight gray runway, 208.67 cm long, 10.2 cm wide, and enclosed by 22.75-cm sides covered by a wire-mesh top on a hinged frame. The start box and the goal box were 20.8 cm and 29.7 cm long, respectively, closed off by the metal guillotine doors. Raising the start box door started a silent 0.01-s digital clock, which was stopped when a photobeam located 175.27 cm beyond the start box door and 7.5 cm in front of the goal cup was broken by the rat. Pellets (0.045-g Noyes) could be placed in a goal cup 4.2 cm in diameter and 1.85 cm in depth. Upon interruption of the photobeam, an aluminum guillotine door was lowered, confining the rat to the goal box.

**Pretraining.** On arrival at the laboratory, all rats were caged individually and given ad lib food and water for 36 days. They were then placed on deprivation consisting of 14 g of Wayne Rodent Bna each day (minus any 0.045-g Noyes food pellets consumed). On Days 1–6, each rat was handled for 1 min. On Day 7, after 1 min of handling, each rat received ten pellets in the home cage, followed by the daily ration. On Days 8–10, each rat was given 3 min of exploration of the runway and allowed to eat six pellets scattered throughout (but not in the goal cup). Also, at the 1/2-min mark, the doors were lowered briefly and then raised to acquaint the rat with this noise. Following exploration, the rats were fed their daily ration in the home cage. On Days 11–13, each rat received the series RRN and NRRN, one of each on Day 11 and three of each on Days 12 and 13.

**Experimental training.** This began on Day 14 and lasted 15 days. Each rat received the following two series of reinforced (R) and nonreinforced (N) trials: RRN and NRRN. On R trials, the rats were allowed to eat from the goal cup containing 10 pellets for 15 s. The rats were confined in the empty goal box for 60 s on the terminal N trial of the RRN and NRRN series and for 15 s on the initial N trial of the NRRN series. Each series was presented three times each day. The time interval between the trials within a series was about 15 s. The time interval between series repetitions was about 10–15 min. These intervals were maintained by running the rats in the following manner: A rat received all of the trials of a series before the next rat was run, all rats received their first series of trials before any rat received its second series, and so on, until each rat had received its three repetitions of each series. The order in which the 4 rats were run varied over days. Also, there were four different orders of presenting the RRN (Series A) and NRRN (Series B): ABAB, AABBA, AABBB, and BAAAB. The orders occurred irregularly over days. On Days 14 and 15 of experimental training, confinement duration on R trials was increased from 15 s to 30 s. On Day 15 of experimental training, the intertrial interval within a series was increased from 15 s to 30 s.

A trial began with the placement of the rat in the start box. The start box door was raised about 3 s later. The rat was given a maximum of 60 s to traverse the runway. If the rat had not entered the goal box within 60 s, it was placed there by the experimenter, and it received the outcome scheduled for that trial. A cloth-lined cup was used to bait the goal cup on R trials to eliminate possible noise cues, and an open canister of pellets was placed near the goal box to keep food odor cues constant. The rats were fed their daily ration about 10 min after all animals had completed runway training.

Except for the following differences, Experiment 2 was similar to Experiment 1. The 4 rats of Experiment 2 were 73 days old on arrival from the supplier and were given food and water ad lib for only 16 days before the start of pretraining. The runway used in Experiment 2 was slightly shorter (197.10 cm) and slightly wider (10.1 cm) than that used in Experiment 1 and was enclosed by shorter sides (13.85 cm). The photobeam was located 158.13 cm beyond the start box door and 9.50 cm in front of the goal cup, which was 4.0 cm in diameter and 1.5 cm deep. In Experiment 2 on Day 25 of experimental training, confinement duration of the R trials of the RRN and NRRN series was reduced from 15 s to 7 s.

**Results**

The following comments apply to each experiment reported here. Exact p values are not reported; a difference is said to be significant only if p < .05 or better. Trial 1 of the three-trial series and Trial 1 of the four-trial series were compared in a separate analysis. This difference, as well as any difference involving series, may be assumed to be nonsignificant unless otherwise mentioned. The major analysis in each experiment was over the common trials of the two series. In Experiment
1, for example, these were the RRNs of the two series; the initial N trial of the NRRN series was omitted.

Figure 1 shows running speed on each trial of the RRN and NRRN series on each day of training. In the early training days, the rats showed no tendency to run more slowly on terminal N trials than on R trials. By Day 11, however, a consistent tendency to anticipate the terminal N trials of the series began to appear. By the final days of training, the rats were clearly running slowly on the terminal N trials and running rapidly, and equally so, on all other trials. There is some suggestion in the data (Days 12, 13, and 14) that overall, running was slower on the terminal N trial of the NRRN series than on the terminal N trial of the RRN series. On Day 15, however, this difference was in the other direction.

An analysis of the common trials shown in Figure 1 revealed that the difference due to trials was significant, $F(2, 6) = 8.67$, as was the Trial $\times$ Series $\times$ Days interaction, $F(28, 84) = 1.86$. A breakdown of this interaction by means of Newman-Keuls tests revealed the following. On each of the first 7 days of training, no difference was significant; there was no tendency toward discriminative responding. However, on each of the last 4 days of training, the terminal N trials differed significantly from all other trials; no difference among the other trials was significant. On Days 10 and 13, running was significantly slower on the terminal N trial of the NRRN series than on the terminal N trial of the RRN series; this difference was significant but reversed on Day 15. From these results, it is clear that neither increasing R confinement from 15 s to 30 s (Days 14–15) nor increasing intertrial interval from 15 s to 30 s (Day 15) had much of an effect on established discriminative responding.

The results obtained in Experiment 2 were quite similar to those obtained in Experiment 1. One major difference was that no difference associated with series was significant; there was no tendency for the rats to run more slowly on the terminal N trial of one series than the other. Over the last 3 days of initial training, for example, running speeds on common trials of the two series were practically identical: 113.6, 107.6, and 40.4 (RRN) and 112.9, 111.4, 105.6, and 37.7 (NRRN). Reducing R confinement from 15 s to 7 s on the shift day had virtually no effect on these speeds: 114.2, 111.5, and 40.3 (RRN) and 118.4, 118.6, 102.8, and 32.2 (NRRN). Differences due to trials were significant over the last 3 days of training, $F(2, 6) = 369.95$ and on the shift day, $F(2, 6) = 108.67$. Newman-Keuls tests revealed in both cases that averaged over series, the terminal N trials differed significantly from the R trials but the R trials failed to differ.

**Discussion**

In Experiments 1 and 2, rats manifested discriminative responding by running slowly on the terminal N trials of the RRN and NRRN series and running fast and nondifferentially on all other trials. How differences between the terminal N trials of the RRN and NRRN series are to be interpreted will concern us in the Discussion section of Experiment 3.

Discriminative responding of the sort obtained in Experiments 1 and 2 could not be supported by either counting or summing the durations of any of the following events, either singly or in any combination: goal box confinements, intertrial intervals, trials, or responses. However, in initial training, such discriminative responding could have been supported either by counting R events or summing the duration of CTR. In shift, CTR was either increased from 15 s to 30 s (Experiment 2). If the rats had been summing the duration of CTR rather than counting R events, either one or both shifts should have substantially disrupted discriminative responding. However, neither shift had even a minor effect upon discriminative responding.

Our findings are compatible with one of two conclusions: Either the rats were counting R events rather than summing the duration of CTR or they were doing both, but counting was dominant over timing. This dominance would have to be pronounced because increasing or decreasing CTR had no

![Figure 1](image-url)
discernible effect whatever on discriminative responding. In any event, because the sum of CTR and the number of R events were equally valid cues, and the rats counted R events nevertheless, we may conclude that the results support the sequential view that motivationally significant goal events, when valid, will be counted by animals in instrumental tasks even when confounded with other cues. At the same time, the results of Experiments 1 and 2 are inconsistent with the last-resort hypothesis of Davis and Memmott (1982, 1983), insofar as rats seemed to have counted R events despite the presence of an equally valid time cue, the sum of CTR.

The direct perceptual apprehension of a small number of simultaneously presented events is called subitizing (see, e.g., Mandler & Shebo, 1982). Subitizing is one way in which number of events may be used as a discriminative cue without specifically counting or enumerating the events. In Experiment 1, an increase in intertrial interval from 15 s to 30 s had no effect on discriminative responding. To suggest that animals use the number of events as a discriminative cue by subitizing them when the events are presented successively and separated by 15 s, much less 30 s, is to strain that concept beyond its limits. Therefore, we reject the notion that rats in Experiments 1 and 2 correctly anticipated the terminal N trials of the series by subitizing R events.

Experiment 3

Experiment 3 was conducted in two phases. There were two groups in Phase 1 or initial training. One group received multiple presentations each day of the three-trial series RRN and a single N trial in irregular order. The other group received multiple presentations each day of the four-trial series NRRN and a single R trial, also in irregular order. Trials of the RRN and NRRN series occurred as in Experiment 1. The RRN series and the single N trial were separated by about 10 min, as were the NRRN series and the single R trial. As may be seen in each of the groups, anticipation of the terminal N trial in each series could develop through the use of any number of valid cues, independently or in any combination: Responses could be timed or counted; intertrial intervals could be timed or counted; trials could be timed or counted; goal box confinements could be timed or counted; and finally, R events could be timed or counted. But all of these cues, which were confounded with the number of R events in initial training, were rendered invalid in the shift phase of Experiment 3 because each group now received both series, RRN and NRRN, in irregular order. In early shift trials, only one timing cue was valid along with number of R events, the sum of confinement times for reinforcement, which was shown to be ineffective in Experiments 1 and 2. Nevertheless, in Experiment 3, as in Experiment 1, CTR was subsequently increased in shift from 15 s to 30 s.

Method

The subjects were 4 rats of the same description as those in Experiment 1, about 82 days old on arrival at the laboratory. The apparatus was the same as in Experiment 1. Pretraining was like that in Experiment 1 with two exceptions: (a) It began only 14 days after the rats arrived at the laboratory. (b) On Days 11 and 12, the last 2 days of pretraining, 2 rats received a single RRN series and a single N trial about 10–15 min apart, and 2 rats received a single NRRN series and a single R trial about 10–15 min apart.

In Experiment 3, there were 24 days of initial training followed by 8 shift days. On each of the Days 1–24 of initial training, 2 rats in Group RRN received four presentations daily of the RRN series and N trial (15-s confinement), and an interval of about 15 min separated each of these eight events. The 2 rats of Group NRRN received four presentations daily of the NRRN series and an R trial; each of these eight events also occurred about 15 min apart. Trials of the RRN (A) series were administered as in Experiment 1, as were the trials of the NRRN (B) series. The two types of events were presented according to four different orders administered irregularly in blocks of 4 days: AAABBB, BABBAA, ABBABB, and BAAAAB. On each of the first 6 days of shift, all rats received the RRN and NRRN series, exactly as on Days 1–13 of initial training in Experiment 1. On Days 7 and 8 of shift in Experiment 3, confinement duration on R trials was increased from 15 s to 30 s.

Results

Figure 2 shows speed of running on each trial for Groups RRN and NRRN in blocks of 3 days in initial training and on each day of shift. The single N trial received by Group RRN and the single R trial received by Group NRRN in initial training are the unconnected points shown in Figure 2. In initial training, the tendency to run slowly on the terminal N trial and rapidly on the remaining trials developed with training. On all of the shift days, including the first, both groups showed a strong tendency to run slowly on the terminal N trials of both series and to run about equally rapidly on all other trials. On Day 1 of shift, both groups showed a marked tendency to run more slowly on the terminal N trial of the four-trial series than on that of the three-trial series.

An analysis applied to the common RRN trials of Groups RRN and NRRN in initial training revealed that significant differences were associated with trials, F(2, 4) = 38.97, and with the Trial × Block interaction, F(4, 28) = 12.08. A breakdown of the Trial × Block interaction by means of Newman-Keuls tests revealed that on Blocks 5–8, averaged over groups, running was slower on the terminal N trial than on either R trial, which did not differ. One other difference was significant: On Block 4, averaged over groups, running was slower on the terminal N trial than on the second R trial of the series.

An analysis over the common trials of the groups in shift revealed that significant differences were associated with trials, F(2, 4) = 326.89, and with the Trial × Day interaction, F(14, 28) = 2.55. A breakdown of the interaction by means of Newman-Keuls tests revealed that running on each shift day, averaged over groups, was slower on the terminal N trial of each series than on either R trial, which did not differ. A separate analysis of the common trials of the 1st day of shift produced a significant Trial × Series interaction, F(2, 4) = 8.37, which, when broken down, revealed that, averaged over groups, running was slower on the terminal N trial of the four-trial series than on that of the three-trial series. The separate Trial 1 analysis revealed that in shift, a significant difference was associated with the Trial × Day interaction,
$F(7, 14) = 8.96$. Subsequent Newman-Keuls tests revealed that on Days 1 and 5 of shift, running was faster on Trial 1 of the NRRN series, and on Day 6 it was faster on Trial 1 of the RRN series. The pattern of Trial 1 findings obtained does not seem particularly meaningful and thus is ignored.

**Discussion**

Consider first a specific finding instructive for developing the general implications of the results obtained in Experiment 3. In initial training, Group RRN eventually ran slowly on the terminal N trial of the RRN series and ran rapidly and nondifferentially on all other trials. For purposes of discussion, assume that the discriminative responding shown by Group RRN in initial training was due exclusively either to counting responses or to summing their duration. If that were the case, then in shift, Group RRN should have shown two effects on receiving the NRRN series. First, on the initial presentation of the NRRN series, Group RRN should have run as slowly on Trial 3 of that series as on Trial 3 of the RRN series. Second, discriminative responding in both series should soon have been disrupted because a formerly valid cue for an N event, two responses, was now also a cue for an R event (NRRN series). Neither of these effects was observed in shift. Thus we may conclude that number or duration of responses was not a particularly effective cue regulating discriminative responding in Experiment 3. By the same reasoning, it seems clear that discriminative responding would have suffered in shift if rats in Group RRN had relied exclusively on cues associated with any of the following events: goal box confinements, intertrial intervals, or trials. Whatever else Group RRN rats did in initial training, they must have used R events, either counting them or summing the duration of CTR. That Group RRN rats did the latter rather than the former became clear in shift when an increase in CTR had no effect on discriminative responding, which was the same result as obtained in Experiment 1. What has been suggested for Group RRN applies in all particulars to Group NRRN, if a slightly modified argument is employed.

Although rats seemed to count R events, it is conceivable that they did not do so exclusively in initial training, that one or more of the other valid number and duration cues also exercised some useful signal capacity, but a weak one in comparison with number of R events. In support of this view, one might note that on Day 1 of shift in Experiment 3, both groups ran significantly more slowly on the terminal N trial of the NRRN series than on the terminal N trial of the RRN series. In Experiment 1, a similar tendency manifested itself on some of the initial training days, although the opposite tendency was noted on the final day of initial training.

In the investigations to follow, it will become clear that to the extent that there is a tendency to behave differently in the two series, it is substantially in the direction of running more slowly on the terminal N trial of the longer series. However, this tendency does not manifest itself in all groups, and even in a particular group it may be manifest on some initial training days but not on others, or, failing to be manifest in initial training, it may appear more or less strongly in shift (Experiment 7).

The weight of the evidence, we feel, favors the view that there is a weak but real tendency to run more slowly on the terminal N trials of the longer than of the shorter series. We offer the following potential interpretations of this effect. One possibility is that in addition to counting the R events, the rat learns that nonreinforcement is more likely later on than earlier in the series. Perhaps the rat used some temporal cue. This suggestion is compatible with a popular view of human and animal serial learning that associations are formed between events and cues related to the ordinal position of the events in the series (e.g., Crowder, 1976; Terrace, 1986). A second possibility, suggested to us by Richard Burns (personal communication, November 1986), is that rats may count
trials along with reinforcing events. On this view, when rats receive RRN and NRRN training, three trials is an ambiguous cue for reinforcement, but four trials always predict nonreinforcement. Whatever its origin, the cue (or cues) cannot be identified on the basis of the experiments reported here. In any event, the cue (or cues) must be assumed to have produced here an expectancy that in relation to that produced by counting R events, was both diffuse and weak. It was diffuse because it tended to produce slower running on the terminal N trial of the longer series on an inconsistent basis. It was weak because responding was little affected by operations that could be expected to alter that cue (or cues) drastically—for example, an increase in intertrial interval from 15 s to 30 s, a shift in CTR from 15 s to 30 s or from 15 s to 7 s, and a shift from either an RRN series or an NRRN series to both series NRRN and RRN.

Another noteworthy aspect of Experiment 3 was that the number cues associated with goal box confinements, intertrial intervals, trials, and responses that were valid during initial training either were not used by the rats or exercised minimal control over responding. This, of course, is the sort of result expected according to the last-resort hypothesis. It may be that some number cues, when valid, are more easily deprived of signal capacity than are others. This statement is consistent both with the results reported here and with previous ones in which it appeared that valid number cues associated with auditory events were not overshadowed by valid duration cues (Church & Meck, 1984), and valid number cues associated with shocks were completely overshadowed by valid tone stimuli (Davis & Memmott, 1983). In any event, Experiment 3 supplied additional evidence that valid number cues associated with motivationally significant goal events will be used as a discriminative cue, even when confounded with a variety of equally valid number and duration cues.

**Experiment 4**

Assume, as the last-resort hypothesis suggests, that rats avoid counting whenever possible in favor of using any available alternative solution. Thus it could be that in Experiments 1–3, rats did not count, but rather used the following strategy, which, we suggest without proof, is simpler than counting: Run slow on the current trial if the prior two trials were identical (i.e., RR), and run fast if the trials were nonidentical (i.e., NR, or either R or N not preceded by a trial). How Group RRN of Experiment 3 could have learned this strategy in initial training and thus how this strategy can explain the behavior of Group RRN in shift when it received NRRN and RRN training is far from clear. We are also extremely skeptical that rats use this “slow-if-identical, fast-if-otherwise” strategy on the basis of prior findings that indicate that rats can and do attend to, remember, and use many more than the previous two reinforced events of a series (e.g., Capaldi & Verry, 1981; Yazawa & Fujita, 1984).

In Experiment 4, the series RRN and NRRN were used. If the slow-if-identical, fast-if-otherwise solution were all that rats could use, they would be unable to discriminate between Trials 3 and 4 of the RRN series and between Trials 4 and 5 of the NRRN series.

**Method**

**Subjects.** The subjects were 3 naive rats of the same description as those in Experiment 1; they were 165 days old at the start of the experiment. The apparatus was the same as that in Experiment 2. Pretraining was identical to that in Experiment 2, except that on Days 12 and 13, the rats simply explored the runway, which had pellets scattered throughout.

**Experimental training.** Experimental training was identical to that in initial training in Experiment 1, with the following exceptions: The goal cup contained six 0.045-g Noyes pellets. The series used were RRN and NRRN. On Day 21 of experimental training, the rats received two trial couplets, either RR (A) or RN (B), each presented three times in the order AABA. Each rat received its first couplet before any rat received its second couplet. Couplets were separated by about 10 min, trials of a couplet being about 15 s.

**Results**

Figure 3 shows running speed on each trial of the RRN and NRRN series in blocks of 3 days and on the shift day when the rats received the RR and RN couplets. On Trial Block 1, there was no tendency to run differentially on R and N trials. With training, however, a strong tendency to anticipate the terminal N trials of the series developed. An analysis over the common trials of the two series revealed that the difference due to trials was significant, $F(3, 6) = 21.88$, as was the interaction of Trial $\times$ Block, $F(15,30) = 10.82$. A breakdown of this interaction by means of Newman-Keuls tests revealed that on Blocks 1 and 2, no difference was significant. On each of the Blocks 3, 4, and 5, averaged over series, running was slower on the terminal N trials than on the R trials, the R trials failing to differ. By Block 6, an additional difference was significant: Averaged over series, running was slower on the third R trial than on the first R trial of the series. When shifted to the RR and RN couplets, the animals ran about equally rapidly on all four trials; no difference even approached significance.

**Discussion**

In Experiment 4, running was slower on the terminal N trials of the RRN and NRRN series than on any of the R

![Figure 3](https://example.com/figure3.png)
trials. These results indicate that rats are capable of counting to 3, a conclusion suggested earlier by Davis and Memmott (1982). Discriminative responding of the sort obtained in Experiment 4 could not occur if rats were unable to count R trials and could use only the slow-if-identical, fast-if-non-identical strategy. Moreover, the failure of the rats to run more slowly on Trial 2 of the RN couplets than on Trial 2 of the RR couplets indicates that discriminative responding was not based on extraneous cues (odor cues, auditory cues, etc.) associated with R and N trials at a 15-s intertrial interval.

Interestingly, by the last block of training trials, running was slower to the third than to the first R event of the series. This slowdown may indicate that the rats had a little difficulty in determining if they had received two R events (run fast) or three R events (run slow). Perhaps rats have some difficulty in discriminating between tags corresponding to two R events (run fast) and three R events (run slow). Or perhaps memory lapse was involved; the R events to be counted were presented successively over a long time. In any event, the speed decrease to the third R event of each series was small in relation to the speed decrease to the terminal N events of the series. This fact suggests that although the rat may have suffered some minor confusion in discriminating between one, two, and three R events, its ability to discriminate among these events is nevertheless quite considerable.

**Experiment 5**

The results obtained in Experiment 4 indicate that rats are not limited to the slow-if-identical, fast-if-otherwise strategy, assuming rats employ that strategy at all. We performed Experiment 5 to answer the following question: If rats are given a choice between counting and using the slow-if-identical, fast-if-otherwise strategy, will they nevertheless count? If the last-resort hypothesis is to be regarded as correct in general and more particularly as an alternative explanation of the results obtained in Experiments 1–3, the rats of Experiment 5 must use the slow-if-identical, fast-if-otherwise strategy while simultaneously eschewing counting. However, according to our view, the rats of Experiment 5 should count.

Evidence of counting in Experiment 5 was expected to be of interest for another reason as well. In order to count in the preshift phase of Experiment 5, rats had to categorize two different food events, Kellogg's Corn Pops and 0.045-g Noyes pellets, both as different (Corn Pops vs. pellets) and as similar (food items). Categorizing a given event in two or more different ways simultaneously may be said to indicate *categorical flexibility*. Categorical flexibility seems to be an indispensable component of any numerical ability that deserves to be called counting.

Experiment 5 was conducted in two phases. In Phase 1, or initial training, the rats received multiple presentations each day of the four-trial series R'RRN (R' = Kellogg's Corn Pops; R = pellets) and a single N trial, the four-trial series and the single N trial being about 10 min apart. In Experiment 5 we ask, Can a rat presented with the events R' and R categorize them as both different and alike, much as a person presented with, say, an apple and two oranges can categorize them as two oranges or three pieces of fruit? To determine this, there were two conditions in shift; Rats were shifted either to the series RRN and NRRN (count to 2) or to the series RRNN and NRRN (count to 3). If rats in both conditions quickly performed appropriately under their respective series (i.e., count), it would be extremely difficult to supply some alternative interpretation of the present findings.

By way of example, assume along with the last-resort hypothesis that rats avoid counting whenever possible and use instead some other supposedly simpler strategy such as running slowly if the previous two trials were identical and running fast otherwise. That strategy in the initial training phase of Experiment 5 could be used to anticipate the terminal N trial of the R'RRN series. If only that strategy were used in initial training, then in shift the animals that received RRN and NRRN should not master their series in the absence of extensive training because those series violate considerably the strategy of running slowly if the previous two trials were identical and running fast otherwise. But if in the initial training the animals learned that two successive pellet trials (RR) signaled nonreward and that three successive food events (R'RR) signaled nonreward, then rapid mastery in shift of both the RRN and NRRN series and the RRN and NRRN series may be expected.

If rats in the shift phase in both the RRN and NRRN condition and the RRNN and NRRN condition rapidly mastered their series, a variety of other alternatives to counting may also be ruled out. One possibility, for example, is that rats in Experiments 1–4 trained under either the RRN and NRRN series or the RRN and NRRN series ran slowly after ingesting a certain amount of food. If this were the case in Experiment 5, shift to RRN and NRRN should have disrupted performance because these series involved less food before nonreward than did the R'RRN series used in initial training. Good transfer in Experiment 5 would also rule out various timing hypotheses. If animals that received R RRN training begin timing with either the R' event or the first R event, they could not show good transfer performance when shifted to all of the transfer series used in Experiment 5.

**Method**

The subjects were 5 rats of the same description as in Experiment 1, ranging in age from 75 to 90 days on arrival at the laboratory. Pretraining was like that used in Experiment 1, with the following exceptions: It began about 2 weeks after the arrival of the rats at the laboratory. Rats received two different reinforcing events, one piece of Kellogg's Corn Pops (R') and six 0.045-g Noyes pellets (R). Corn Pops vary in size but weigh about 0.25 g. On Days 7–9 of alley exploration, Corn Pops and pellets were scattered about the runway, and the rats received three Corn Pops and six pellets in the home cage. On Days 10–12 of pretraining, rats were given the four-trial series R'RRN and a single N trial. On Day 13, the four-trial series was given twice, as was the single N trial. One rat, assigned to Group 3, received an additional day of pretraining (R'RRN and N events occurred twice each day), and it started experimental training 2 days behind the other rats. That rat simply received 2 fewer days of initial training than the other rats, and its Day 1 data of initial training were included with the Day 3 data of the other rats, and so on.

In Experiment 5 we used 44 days of initial training followed by 3 shift days. On each day of initial training, the rats received the series R'RRN (A event) four times and a single N trial (B' event) four times. The trials of the R'RRN series occurred exactly as did the
RRN and NRRN series of Experiment 1, except that R' replaced the initial N. The A event, the R'R'RN series, and the B event, the N trial, occurred about 10 min apart. The A and B events were presented according to four different irregularly presented orders in original training, each presented equally often: AABBAAB, BBAABAA, ABABAB, and BABABAA.

Two groups were formed in the shift phase, which lasted 3 days. Two rats were given three presentations each day of each of the series RRN (A series) and NRRN (B series) as in Experiment 1 (Group 2). Three rats were similarly trained except that they received the series RRRN (A series) and NRRRN (B series) (Group 3). The R event, of course, was six 0.045-gram Noyes pellets. The order of presenting the two series on each of the 3 shift days was, respectively, ABABAAB, BBAABAA, and ABABAB.

Results

By the end of initial training, all 5 rats were performing more or less similarly, anticipating all reinforcing events correctly. Figure 4 shows running speed on each trial of the R'R'RN series in initial training in blocks of 4 days and on each of the 3 days of shift for Group 2 and Group 3 on each of their two series. The single N trials received in initial training are the unconnected points in Figure 4. In initial training, the tendency to run slowly on the terminal N trials and fast on all other trials developed with training. By the last two blocks of trials in initial training, this tendency was extremely well developed. On each of the 3 days of shift, as may be seen, each group, despite some understandable disruption, showed a strong tendency to run fast on the R trials and slow on the terminal N trials of both series.

An analysis over the initial training trials (R'R'RN series) indicated that significant differences were associated with trials, F(3, 12) = 55.16, and with the Trial × Block interaction, F(30, 120) = 11.29. A breakdown of the Trial × Block interaction revealed that although no differences were significant on Blocks 1 and 2, speeds on the terminal N trial of the R'R'RN series by Blocks 10 and 11, for example, were significantly lower than on any other trial. No other difference between trials were significant.

The shift data indicate that Group 2 performed somewhat better than Group 3; Group 2 ran quite slowly on its terminal N trials. Two comments are in order. First, our concern is with counting by each group rather than with differences between groups, which did not concern us at all. Second, on the assumption that in initial training the rats counted to both 2 and 3, it is clear that in shift, Group 3 had a more difficult or ambiguous problem than did Group 2. Group 2 merely had to run slowly after two R trials. Group 3 had to suppress the tendency to run slowly after two R trials in favor of counting to 3. In any event, despite the absolute differences appearing in shift, we could find no statistical evidence that the two groups differed. For example, an analysis over the terminal N trials of the two groups produced an F ratio smaller than 1 for both the group main effect and the group × day interaction. It may well be that adding more subjects to each group, and thus more power to the statistical analysis, would produce differences between the groups.

The central issue of Experiment 5 was counting by each group in the shift phase. Separate analyses over the common trials of the two series for each group on Day 1 of shift and over the 3 days of shift indicated that each group correctly anticipated its terminal N trials but failed to differ on any of the R trials. Thus for Group 2, differences due to trials were significant on Day 1 of shift, F(2, 2) = 22.08, and over all 3 days of shift, F(2, 2) = 33.47; no other difference was significant. Subsequent Newman-Keuls tests indicated that terminal N trial speeds were significantly slower than on either R trial; the two R trials failed to differ. Exactly the same pattern of results was obtained for Group 3. On Day 1, F(3, 6) = 5.07, and over all 3 days of shift, F(3, 6) = 11.73. The only significant difference between trials for Group 3 was slower running on the terminal N trial than on any R trial.

Discussion

The shift findings of Experiment 5 indicate that rats will count reinforcing events despite the simultaneous availability of numerous other solutions. Note first that the shift findings of Experiment 5 rule out all of the alternatives ruled out by
the shift findings of Experiment 3. Moreover, the results of Experiment 5 rule out still additional alternatives. Most notably, if, as the last-resort hypothesis suggests, rats avoid counting whenever possible, then in the initial training phase of Experiment 5 when training was R'RRN and N, the rats could have eschewed counting in favor of using the supposedly simpler strategy of running slowly if the previous two trials were identical and running fast if otherwise. Had only that supposedly simpler strategy been used, appropriate anticipatory responding in the early shift trials would have been manifested by the animals that received RRN and NRRR trainings, but not by the animals that received RRRN and NRRRN training. But, of course, all animals showed appropriate responding indicative of counting in the early shift trials. Thus the shift results indicate that despite the availability of the strategy run slow if the previous two trials were identical and fast if otherwise, the rats nevertheless opted to count, conceptualizing the events R'RRN simultaneously either in a more or less particular fashion as two R events (RR) or in a more abstract fashion as three food events (R'RR being similar to RRRR). As the shift results indicate, the rats were prepared to use either of these conceptualizations, depending upon what was required of them. We may assume, therefore, that when rats receive RRN and NRRRN training as in Experiments 1–3, they will count. That is to say, animals appear highly disposed to counting and will do so despite the availability of other solutions. This suggests that counting is a highly prepared, perhaps automatic activity in rats.

As already indicated, the shift findings of Experiment 5 rule out still other alternative interpretations of the present findings. To cite a prominent example, the rats in Experiments 1–4 that received either RRN and NRRRN training or RRN and NRRRN training may have learned to run slowly after ingesting a particular amount of food. The shift results of Experiment 5 also support those of Experiments 1–3 in suggesting that it is implausible to assume that a temporal discrimination of some sort can explain our results.

Experiment 6

An abstract number tag corresponds to the number of events independently of any other characteristics of those events. In Experiment 5, rats showed evidence of employing abstract number tags. Rats that were shifted from auditory to visual cues also showed some evidence of possessing abstract number tags (Church & Meek, 1984). Whether rats employ abstract number tags was the major concern of Experiments 6 and 7. In Experiment 6, Group R (for rearranged reinforcers) was reinforced with 0.045-g Noyes pellets (R) and Kellogg's Corn Pops (R'). Group R was trained initially under the two series RRRN and RRN. After discriminative responding was well established, reinforcer relations were suddenly rearranged so that Group R was now trained RR'R'N and R'R'N. Continued discriminative responding in shift depends upon the animal's using abstract number tags and appreciating the order-relevance principle. However, if the rats were using only the concrete properties of reinforcers, discriminative responding in shift would deteriorate completely. Note that the shift is expected to produce some disruption because the animals must also be attending to the concrete properties of R and R'. If they were not, if the difference between R' and R were disregarded, they could not run slowly on the terminal N trials of both series, R'RRN and RRN. This is so because there would be no differential cue to indicate when the third event of a series was to be R or N. After the initial shift just described, Group R was shifted to N series (NRRN and RRN), and pellets were used as the reinforcer. Confinement time on R trials was 15 s on the first 2 days of this training and 7 s on the last day.

Method

Subjects. The subjects were 4 rats of the same description as those in Experiment 5; they were 73 days old on arrival from the supplier and 89 days old at the start of the experiment. The single group used in Experiment 6, Group R, received one piece of Kellogg's Corn Pops (P) and six pellets (P₆) as reinforcers. Two rats in Experiment 6 received P₆,PPN and PPN training. and 2 others received P₆,N and P₆,N training. Taken together, these subgroups may be represented as R'RRN and RRN. Pretraining was the same as in Experiment 5; Corn Pops and pellets were scattered about the alley on exploration days and on each of the last 2 days of pretraining. Each rat received its three-trial series once.

Experimental training. Experimental training was as in Experiment 5 with the following exceptions: Over Days 1 and 2 combined, each rat received each series three times; thereafter, each series was given three times each day, as in Experiment 1. After Day 16 of initial training, each rat had its reinforcers rearranged so that, for example, a rat that had received P₆,PPN and PPN training now received P₆,N and P₆,N training. Such rearrangement occurred on each of the six series of Day 17. This training continued for 5 additional days. On Days 7–9 of shift, all rats received RRN and NRRRN training, in which R was pellets. On Days 7 and 8 of shift, confinement on R trials was 15 s, and on Day 7 it was reduced to 7 s.

Results

Figure 5 shows mean running speeds on each trial of each of the two series for Group R during initial training and on each of the 9 days of shift. On the first 6 days of shift, the reinforcers were rearranged (R'RR to RR'R'), and on the last 3 days of shift, the rats received the RRN and NRRN series, (R = exposure to pellets) for either 15 s (Days 7–8) or 7 s (Day 9). Early in training, running was equally rapid on all trials. With training the tendency developed to run slowly on the terminal N trials of each series; running was about equally rapid on the other trials. An analysis applied to the common trials of initial training revealed that significant differences were associated with trials, F(2, 4) = 29.94, the Trial × Block interaction, F(8, 16) = 9.46, and the Trial × Block × Series interaction, F(8, 16) = 3.18. A breakdown of the triple interaction by means of Newman-Keuls posttests revealed the following. On Blocks 1 and 2 of initial training, no differences were significant. On Blocks 3 and 4 of initial training, running was slower on the terminal N trials of a series than on any other trial; no other difference was significant. An additional difference was significant on Block 5: Running was slower on the terminal N trial of the four-trial series than on that of the three-trial series.

Although there was some tendency for the performance of the animals to be disrupted by the shift, the tendency to run
more slowly on the terminal N trials of the series than on the other trials was pronounced even on the first shift day. An analysis applied to the common trial in shift revealed that significant differences were associated with trials, F(2, 4) = 35.33, and the Trial X Day interaction, F(16, 32) = 3.83. A breakdown of this interaction by means of Newman-Keuls test revealed the following. On each day, averaged over series, running was slower on the terminal N trials than on either R trial. On Day 5 of shift, an additional difference was significant: Averaged over series, running was slower on the second than on the first R trial of the series.

The analysis applied to Trial 1 in shift revealed that the interaction of Trial 1 and day was significant, F(8, 16) = 3.34. A breakdown of this interaction revealed that differences were significant only on Days 2, 3, and 9. We are unable to attach any importance to these differences. On Days 2 and 3, Trial 1 was reinforced in both series, and although running was faster on Trial 1 of the four-trial series on Days 2 of shift, it was slower on Trial 1 of the four-trial series on Day 3 of shift. On Day 9 of shift, running was faster on Trial 1 of the four-trial series (nonreinforced) than on Trial 1 of the three-trial series (reinforced).

Discussion

In shift, Group R continued to run slowly on the terminal N trials of each series, manifesting only minimal disruption. Such behavior, considering the situation that prevailed in initial training, strongly suggests that rats use abstract number tags. In initial training, the rats discriminated between R and R'; otherwise, they would not have run slowly on the terminal N trials of the RRN and R'RRN series. Note also that R' was a signal for R and was not a signal for N. The signal for N was RR. Yet, on being shifted to R'RRN and RRR'N, the animals immediately anticipated the terminal N events. This discriminative responding could not have been based on any similarity between one and two R' events because, as indicated above, R' was a signal for R, not N. Thus concrete cues associated with R' had to be ignored. To behave as they did in shift, the rats had to recognize that two R' events were similar to two R events. The basis of this similarity, what two R' events and two R events have in common, is an abstract number tag, a tag corresponding to two events irrespective of their concrete properties, a tag that would be applied to any two food events of the same kind, either R'R' or RR, and perhaps other food events, a matter investigated in Experiment 7.

In Experiment 6, then, rats learned the following. The abstract number tag corresponding to one event, either R or R', was a signal for R, and the abstract number tag corresponding to two R events, either RR or R'R', was a signal for N. As indicated, the rats, in addition to using these abstract number tags, attended to the concrete characteristics of R and R'. Presumably such relatively minor response disruptions, as were observed in shift, were due to the concrete characteristics of the R' now signaling R and N, whereas in initial training the R' had signaled only R. In any counting situation, concrete and abstract characteristics of events must be used simultaneously. If they were not, it would not be known what specific events had been counted.

When shifted to the series NRBN and RNN, the rats continued to count. The significance of this behavior will be considered in the Discussion section of Experiment 7. In Experiment 6, reducing confinement time on R trials from 15 s to 7 s failed to disrupt counting. The implications of this
were discussed earlier in the Discussion section of Experiment 1.

Experiment 7

In Experiment 7 we attempted to provide still additional evidence that animals use abstract tags corresponding to number of events. Four different reinforcing events were employed in Experiment 7: 0.045-g Noyes pellets (R), Kellogg's Corn Pops (R'), Kellogg's Honey Smacks (r), and Kellogg's Cocoa Puffs (r'). Group BA (for both arrangements), in its initial training phase, received both reinforcer relations that Group R of Experiment 6 received in its initial and transfer phases: the series R'RRN and RRN on odd days and the series RR'R'N and R'R'N on even days. In Experiment 7 we attempted to provide new information concerning abstract number tags by the following procedures: After discriminative responding was well established, Group BA was shifted to the novel reinforcers, Honey Smacks and Cocoa Puffs; they received r'r'N and rrN training on odd days and rr'r'N and r'r'N training on even days. If the rats were using only the concrete properties of reinforcers, discriminative responding would deteriorate in shift. However, if the rats were using abstract number tags, discriminative responding would be maintained in shift. After the initial shift, Group BA was shifted to the series RRN and NRRN, in which pellets were used as the reinforcer. Finally, confinement time on R trials was decreased from 15 s to 7 s.

Method

Subjects. All aspects of Experiment 7, including the type of subjects used, were identical to those of Experiment 6, with the following exceptions: Scattered throughout the runway on exploration days were four reinforcers: Kellogg's Corn Pops (P), Kellogg's Honey Smacks (S), Kellogg's Cocoa Puffs (C), and Noyes pellets (P'). Initial training lasted 17 days. On odd days, each rat received PPN and P'PPN training; on even days, it received PPSPN and P'P'P'N training. This training may be represented as R'RRN and RRN (odd days) and RR'R'N and R'R'N (even days). On Day 17, the last day of initial training, each rat was fed Cocoa Puffs (C) and Honey Smacks (S) in the home cage; the daily ration was reduced somewhat to compensate for such consumption. In shift, each rat was trained on SCCN and CCN (odd days) and on CSSN and SSN (even days). Day 18, the first day of shift being counted as an even day. This training may be represented as r'r'N and rrN (odd days) and rr'r'N and r'r'N (even days). There were 5 days of such shift training. Subsequently, the rats of Experiment 7 were trained exactly as were the rats of Experiment 6 (i.e., they were shifted to NRRN and RRN, R being 15-s access to pellets on Days 6 and 7 of shift and 7-s access on Day 8 of shift).

Results

Figure 6 shows mean running speed on each trial of each of the two series for Group BA during initial training and on each of the 8 days of shift. On each of the first 5 days of shift, the rats received novel reinforcers (r'r'N and rrN on odd days, rr'r'N and r'r'N on even days). On the last 3 days of shift, the animals received the series RRN and NRRN, R being exposure to 0.045-g pellets for either 15 s (Days 6 and 7) or 7 s (Day 8).

Early in initial training, there was no tendency toward discriminative responding. Over the last two blocks of trials, however, the rats were clearly running more slowly on the terminal N trials of each series than on any of the remaining trials. A comparison of Figure 6 with Figure 5 shows that in initial training, discriminative responding in Experiment 7,
in which the rats received R'RRRN and RRN training (odd days) and RR'R'N and R'R'N training (even days), was considerably poorer than in Experiment 6 (R'RRN and RRN training) primarily because on the terminal N trials, running was faster in Experiment 7 than in Experiment 6.

An analysis applied to the common trials of initial training shown in Figure 6 revealed that significant differences were associated with trials, \( F(2, 4) = 8.03 \), and with the Trial \( \times \) Block interaction, \( F(14, 24) = 3.60 \). A breakdown of the Trial \( \times \) Block interaction by means of Newman-Keuls posttests revealed that on Blocks 1–5, no difference was significant. However, on each of the Blocks 6–8, averaged over series, running was slower on the terminal N trials than on the R trials, the R trials failing to differ.

Even on the initial day of postshift, the rats performed more or less as they had in initial training, running slowly on the terminal N trials of the series. An analysis applied to the common trials of postshift revealed that differences attributable to trials were significant. \( F(2, 4) = 47.21 \), as was the Trial \( \times \) Day interaction, \( F(14, 28) = 2.78 \). No difference associated with series was significant, despite the tendency of the animals, apparent in Figure 6, to run more slowly on an absolute basis on the terminal N trial of the four-trial series than on the terminal N trial of the three-trial series. A breakdown of the Trial \( \times \) Day interaction by means of Newman-Keuls posttests revealed that on each of the shift days, averaged over series, running was slower on the terminal N trials than on either of the R trials. On Days 3 and 5, an additional difference was significant: Averaged over series, running was slower on the second than on the first R trial of the series. The major reason for this was that running was relatively slow on the second R trial of the four-trial series.

**Discussion**

In initial training, Group BA learned to run slowly on the terminal N trials of four series (R'RRN, RRN, RR'R'N, and R'R'N) and rapidly and nondifferentially on all other trials. This behavior was maintained with only slight disruption when Group BA was shifted to new series constructed from the different food events, \( r \) and \( r' \): these new series were \( r'r'r'N, r'r'N, r'r'N, \) and \( r'r'N \). Given the results reported in Experiments 6 and 7, as well as the internal evidence supplied in Experiment 7, the maintenance of discriminative responding in shift by Group BA cannot be ascribed to a failure to discriminate among the events R, R', r, and \( r' \).

One may understand the performance of Group BA in initial training and shift by assuming that abstract number tags were applied to the events R, R', r, and \( r' \), regardless of the order in which these items were presented. But something more was involved. Tags were assigned according to a rule appropriate to the counting problem presented in Experiment 7, a *same–different* rule. This rule, which is essentially a method for assigning tags, should not be confused with the hypothesis rejected in Experiment 5, the rather simplistic slow-if-identical, fast-if-otherwise hypothesis, which, of course, is not at all a method for assigning tags. Our interpretation of the results obtained in Experiment 7 is as follows: On being provided with an initial food event of any kind (R, R', r, or \( r' \), or, presumably, any other), rats in Group BA were prepared as a result of the training that they received to assign to it an abstract number tag corresponding to one event. On being provided with a second food event, rats in Group BA were prepared to do one of two things: If the second food event differed from the first, they withdrew the tag assigned to the first event and applied the tag corresponding to 1 to the second food event. But if the second food event was the same as the first, they assigned to it the tag corresponding to 2. According to this analysis, Group BA used number cues at an abstract level in two quite different senses. First, tags were assigned to events in accord with the abstract *same–different* rule described earlier, a problem-solving strategy. Second, the tags assigned to events on the basis of the *same–different* rule were abstract.

The rats of Experiments 6 and 7 continued to count when shifted to the series RRN and NRRN. This indicates that when the first and second event of a series differed, the rats were prepared to disregard the first event no matter what it might be, whether it was a different reinforcer or an N event.

**General Discussion**

In conventional discrete-trial, instrumental learning investigations, number cues associated with reinforcing events are often valid. By assuming that these valid cues are used as signals for the consequences of responding, researchers have explained a wide variety of diverse findings ranging from various reinforcement schedule effects to discrimination learning (e.g., Capaldi, 1966, 1967, 1985; Capaldi & Verry, 1981; Capaldi et al. 1984). Demonstrations to this effect, however, have a major drawback. In conventional learning investigations, valid reinforcer-related number cues are typically confounded with a variety of other cues of equal validity. These include number cues associated with other events, various temporal cues, and, often, the variable explicitly manipulated by the investigator. Thus the possibility exists that some or all of these other valid cues come to serve as signals for appropriate responding rather than, or in addition to, the valid reinforcer-related number cues. In this connection, our investigations, when taken collectively, support a variety of novel conclusions.

First, we provided data indicating that valid reinforcer-related number cues acquired very considerable signal capacity when confounded with a variety of other equally valid cues, a fact suggesting that counting is a highly prepared, perhaps automatic activity in rats. The confounded cues consisted of a variety of duration cues and other number cues, associated with trials, intertrial intervals, responding, goal box confinement, CTR (Experiments 1–3), and other strategies (Experiment 5). The present results suggest that when reinforcer-related number cues are valid, they often are in many types of instrumental learning investigations, they acquire strong signal capacity despite the presence of other valid cues or strategies. We suggest, therefore, that rats and, by implication, higher animals in general are highly disposed to counting reinforcing events and do so routinely, perhaps automatically. According to this view, rats abandon counting only when it is entirely unpredictable. Also, rats may count even when only one event is available to be counted. To be
specific, we think it is likely that rats which have learned to run fast on the reinforced trials and slowly on the nonreinforced trials of a single alternating schedule of reinforced and nonreinforced trials count to 1; one reinforced trial is a signal for a nonreinforced trial and vice versa (see, e.g., Capaldi, 1967).

The assumption that animals count automatically and as a first resort is useful for understanding why various reinforcement schedule effects, which may be attributed to counting, can be obtained not only after extensive training but after minimal training—as little as two, three, or four runway trials—as well (e.g., Capaldi, Lanier, & Godbout, 1968). In any case, there was evidence that in addition to counting reinforcing events, rats also used some other cue (or cues) related possibly to the ordinal position of events in the series or counting trials. But, as shown earlier, this tendency was diffuse rather than precise, and it was, on the whole, rather weak and variable. Of course, these other cues may require much stronger signal capacity when they alone are valid, or more particularly, when reinforcer-related number cues are not simultaneously valid.

The conclusion that reinforcer-related number cues acquired strong signal capacity when a variety of duration cues and other number cues were equally valid has a variety of implications. The conclusion suggests, in accordance with the sequential approach, that a variety of diverse results obtained in conventional instrumental learning investigations may be explained in terms of the propensity of rats to count reinforcing events (e.g., Capaldi, 1966, 1967, 1985; Capaldi & Verry, 1981; Capaldi et al., 1984). The conclusion is inconsistent with the last-resort hypothesis of Davis and Memmott (1982), the view that animals count only when no other means of solving a problem is available and, in consequence, that counting is of little explanatory significance. Although our data suggest that the last-resort view is not correct as applied to reinforcing events, it may largely be correct when applied to various other events, such as the other number and duration cues that were valid in our study. At best, one or more of the those cues, as shown earlier, acquired only weak signal capacity. Perhaps these other cues would have acquired greater signal capacity if reinforcer-related number cues were not valid.

What does it mean to suggest that successively presented food reinforcers were counted in our investigations? It means, on the one hand, that number cues were not used along with some other mechanism such as subtitizing; that was ruled out in all of our investigations. Nor was a slow-if-identical, fast-if-nonidentical discrimination used; that was ruled out in Experiments 4 and 5. It means, on the other hand, that reinforcer-related number cues were used in accord with four principles (see Gelman & Gallistel, 1978). These are one-to-one correspondence, stable-order, order irrelevance, and abstraction. In the absence of the first two principles, the accurate anticipation of R and N events exhibited in our seven experiments would have been impossible. Order irrelevance was exhibited in Experiments 6 and 7, abstraction in Experiments 5–7. Abstraction means that animals assign tags to reinforcers on the basis of their number alone, irrespective of such concrete properties as their taste, visual appearance, size, and so on. Of course, these concrete properties of reinforcers are used as signals too, but as we judge on the basis of data obtained here, no more readily than the abstract properties of reinforcers. In line with this thought, consider that in the shift phase of Experiment 6, concrete and abstract properties of reinforcers were opposed. This opposition was such that counting would deteriorate if only concrete properties were used and would be maintained if abstract properties were used. In the shift phase of Experiment 7, new reinforcers with new concrete properties were introduced while the validity of abstract number cues was maintained. In the shift phases of Experiments 6 and 7, reinforcers continued to be counted with only slight disruption, which indicates that the rats applied abstract number tags to the reinforcers.

The shift findings of Experiments 5, 6, and 7 do not accommodate the view that the concrete properties of reinforcers are used more readily or more easily by animals than are the abstract number properties of reinforcers. In saying this, we are by no means attempting to minimize the importance of the concrete properties of reinforcers. Rather, our intention is to suggest that rats assign abstract number tags to reinforcers readily, easily, and under most, if not all, circumstances. In any event, it appears that the shift results obtained in Experiments 5, 6, and 7 are resistant to any interpretation that does not assume that qualitatively different and discriminantly different reinforcers share identical representations that are based upon their number, irrespective of other characteristics, including the order in which they are presented. We know of no currently available alternative to counting capable of explaining the shift findings of Experiments 5, 6, and 7.

In Experiment 7, as indicated, rats assigned tags to events on the basis of a same–different rule. We suggest that assigning tags to events on the basis of some rule is as indispensable to counting as is categorial flexibility. According to this view, in other investigations reported here, rules for assigning tags to events were used. As one example, a long interval between events, such as occurred between series, was a signal to withdraw previously assigned tags and to begin the count anew. In addition to the use of various rules of this sort, memory, as alluded to previously, was important in this study because events were presented successively over a long time. To elaborate a bit, at each point in each series, the animal had to remember how many R events it had received at the short (15-s or 30-s) interval; that is, the animal had to remember which tags it had already assigned and then assign the next tag in the series to the current R event. Then the animal had to learn the relation between each tag and the consequences of responding, running rapidly when a tag signaled reinforcement and slowly when a tag signaled nonreinforcement. From these brief remarks, it is perhaps obvious that counting is not a unitary activity. Rather, counting is composed of a variety of coordinated cognitive activities, some in themselves complex. These activities include (a) appreciating the four counting principles described earlier, (b) categorizing in a flexible manner the events to be counted and counting only those events, (c) applying abstract number tags according to situationally determined rules that are themselves abstract, (d) memorizing, and, as a result of all this, (e) learning the relation between a particular number tag and the conse-
quences of responding—reinforcement or nonreinforcement—and thereupon running appropriately, either fast or slow.

References


Received March 23, 1987
Revision received April 23, 1987
Accepted May 27, 1987

---

**Call for Nominations for JEP: General**

The Publications and Communications Board has opened nominations for the editorship of the *Journal of Experimental Psychology: General* for the years 1990-1995. Sam Glucksberg is the incumbent editor. Candidates must be members of APA and should be available to start receiving manuscripts in early 1989 to prepare for issues published in 1990. Please note that the P & C Board encourages more participation by women and ethnic minority men and women in the publication process, and would particularly welcome such nominees. To nominate candidates, prepare a statement of one page or less in support of each candidate. Submit nominations no later than February 1, 1988, to

Donald J. Foss  
Department of Psychology  
University of Texas  
Austin, Texas 78712

Other members of the search committee are James J. Jenkins, Jean Mandler, J. E. R. Staddon, and Saul Sternberg.

---