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ABSENCE OF ANTICIPATORY CONTRAST IN RATS TRAINED ON MULTIPLE SCHEDULES

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Rats were trained on three- and four-component multiple schedules in which two of the components were correlated with identical reinforcement schedules that remained unchanged throughout training. These target components differed in terms of whether their respective following schedules were either higher or lower in value. Unlike corresponding experiments previously reported with pigeons, higher response rates occurred in the target component followed by a higher valued schedule than in the target component followed by the lower valued schedule. Overall contrast effects occurred independently of these sequential effects, but were inconsistent across subjects. The results suggest that the effects of a following schedule of reinforcement are opposite for pigeons and rats, and that one reason previous studies have often failed to show contrast effects with rats is that the effects of the following schedule in rats are in competition with contrast dynamics.

Key words: behavioral contrast, anticipatory contrast, following schedule of reinforcement, variable-interval schedules, superstitious reinforcement, lever press, nose poke, rats

An important early influence on the development of the "additivity theory" of behavioral contrast (Rachlin, 1973; Schwartz & Gamzu, 1977) was the apparent difference between rats and pigeons in the ease with which contrast effects were obtained. Although contrast occurs routinely with pigeons, several early studies using rats failed to find reliable effects (e.g., Freeman, 1971; Weiss, 1971). Others (e.g., Bradshaw, Szabadi, & Bevan, 1978; Gutman, Sutterer, & Brush, 1975; Nallan & McCoy, 1979) have shown clearly that robust contrast effects can be obtained with rats, but laboratory lore continues to support the belief that rats and pigeons are substantially different with respect to how easily such effects are produced. In my own laboratory, for example, approximately 50% of the rats serving as subjects in a variety of contrast procedures have exhibited contrast, although it should also be noted that some subjects do exhibit large effects, even after repeated reversals of baseline and contrast conditions.

The possibility of species differences is of increased interest in view of analyses that show contrast to be composed of more than a single type of behavioral interaction. On the basis of a variety of data (Williams, 1976, 1979, 1981, 1988), it appears that the effects of reinforcement variation preceding a target component are functionally different from the effects of reinforcement variation following the target component. For example, Williams (1988) demonstrated, with pigeons as subjects, that the effect of the preceding-schedule variation was enhanced by using component stimuli (e.g., two line orientations) similar in character (also see Blough, 1988), whereas that from the following-schedule variation was enhanced by increased stimulus dissimilarity. The two types of contrast effects also appear to be differentially sensitive to the extent of discrimination training; continued training typically decreases the effects of the preceding schedule while increasing those of the following schedule. As a result of these differential effects of stimulus similarity and continued training, the largest portion of steady-state contrast is due to variations in the following schedule ("anticipatory contrast"), at least with pigeons as subjects (Williams, 1981; Williams & Wixted, 1986).

Previous contrast experiments with rats as subjects have not attempted a functional dissociation of the different types of contrast. Such an investigation is of interest because it is possible that the differences in obtaining contrast with different subjects may be due to their

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differential sensitivity to different types of contrast. For example, there is clear evidence that rats are sensitive to the schedule in the preceding component, at least as indexed by response rates at the beginning of the unchanged component, in that large local contrast effects have been obtained (Bernheim & Williams, 1967). Hence, previous demonstrations of contrast with rats may be due in large part to this type of contrast. If rats were also insensitive to anticipatory contrast, thus eliminating it as a component of the overall contrast effect, failures to obtain overall contrast might then be due to conditions that minimize local contrast (e.g., highly dissimilar stimuli or extended periods of training). Thus, it becomes of interest to examine directly the effect of the following schedule of reinforcement in rats to determine whether they are functionally comparable to pigeons.

The primary question addressed by the present experiments was whether the contrast effects that do occur with rats are primarily due to anticipatory contrast, as they have been shown to be with pigeons. The design of Experiment 1 was modeled after that of Williams (1979). A four-component multiple schedule was used in which two target components were correlated with identical variable-interval (VI) schedules. The remaining two components were a richer schedule of variable-time (VT) reinforcement or extinction. The two target components were preceded equally often by these two schedules, but differed with respect to their following schedule. At issue was whether the response rates in the target components would differ systematically as a function of the following rate of reinforcement, as has been shown with pigeons (Williams, 1979, 1981; Wilton & Gay, 1969).

EXPERIMENT 1

METHOD

Subjects

Eight experimentally naive albino rats (Holtzman strain), approximately 4 months of age at the start of training, served. All were maintained in individual cages with water continuously available. The food-deprivation regimen consisted of allowing access to Purina Rat Chow® for 1 hr per day, beginning approximately 5 min after the subjects were removed from the experimental chambers.

Apparatus

Two different chambers were used, one involving lever pressing as the operant response, the other key pressing. The lever chamber consisted of a Plexiglas shell, 19 cm high, 25 cm wide and 25 cm deep, equipped with a grid floor. Three walls and the ceiling were of clear glass; the front wall was painted black. Mounted on the front wall were two nonretractable stainless steel levers, 9 cm apart (edge to edge), each mounted 12 cm above the grid floor. Each lever was 3.2 cm wide, 0.3 cm thick, protruded 1.9 cm into the chamber, and required a minimum force of 0.3 N for operation. Directly between the levers, 1.3 cm above the floor, was mounted a recessed steel opening into which a liquid dipper entered (BRS/LVE® Model SLD-002). The dipper, which nominally contained 0.01 cc of liquid, remained protruded into the chamber until activated, at which time it dropped into a tray of Mazola® corn oil for 0.25 s and then was returned to the up position to allow consumption of the oil. The only light sources in the chamber were three 28-V miniature light bulbs (Sylvania® #28PSB) mounted in a row on the front panel, 3.5 cm above the levers. One of the lights was directly above the right lever, a second was above the left lever, and the third was centered between the other two. For sound attenuation the interior chamber was placed in a larger exterior chamber equipped with a ventilating fan for masking noise.

The key chamber was constructed from a Coulbourn modular shell that included a grid floor, two side walls of clear glass, and ceiling, front, and rear walls of aluminum. The height of the interior chamber was approximately 29 cm, its width was 24 cm, and its depth was 31 cm. The interior chamber was contained in a larger exterior enclosure for sound insulation, which also provided masking noise from a ventilating fan.

Mounted on the middle of the front wall of the interior chamber 2 cm from the floor was a recessed opening into which a liquid dipper could enter. The nominal capacity of the dipper was 0.01 cc. The dipper remained in the raised position at all times except for a brief lowering into the tray containing corn oil whenever the reinforcer was presented. Above the opening to the dipper, and 3 cm below the ceiling, was mounted a shielded 28-V houselight.

Mounted on both the left and right sides of the dipper opening, 2.5 cm above the floor, were standard pigeon keys (Coulbourn Model E21-15), 2.5 cm in diameter, that required a force of approximately 0.12 N for operation. Each key was illuminated from behind by a 28-V IEE in-line stimulus projector. The stimulus projected on the left key, when illuminated, was a diffuse white light with a small dark circle in the middle. The stimulus projected on the right key was a vertical white line on a dark background, 1.0 cm in width and extending the entire diameter of the key.

Procedure

Four subjects were trained in each of the two chambers. Training occurred at different times, so their respective procedures will be described separately.

Lever chamber. All subjects were first trained to eat from the dipper by presenting free oil according to a VT 60-s schedule. After each rat approached the dipper immediately upon its lowering into the oil tray, it was then hand-shaped to press the two levers. Fifty continuously reinforced lever presses were then allowed to each lever. Only one lever produced the reinforcer at any given time; this was indicated by the illuminated light bulb located above the lever.

After lever pressing was established, training was begun on the four-component multiple schedule used for the duration of the experiment. For the left component, the light above the left lever was illuminated and food was available on a VI 1-min schedule. For the right component, the light above the right lever was illuminated and food was available on an identical but independent VI 1-min schedule. During both components, responses to the incorrect lever began a 2-s change over delay (COD), such that responses to the correct lever could not be reinforced until at least 2 s had elapsed since the last response to the incorrect lever. During the VT component, both lights above the levers were extinguished, the center light between the two levers was illuminated, and food was freely presented on a VT 30-s schedule. During the extinction (EXT) component, all lights were extinguished and food was never delivered. Lever presses during the VT and EXT components had no scheduled effect. Component duration was always 1 min.

During Phase 1, the EXT component preceded and followed both the left and right target components. The order of left or right was determined randomly, with the restriction that both had to occur twice in any block of eight components (the other four being EXT presentations). This training continued for a total of 16 sessions. During Phase 2, one half of the EXT components were replaced by VT components. The order of components was such that the left component was always followed by EXT and the right component was followed by the VT, and both the left and right components were preceded half of the time by EXT and half of the time by VT. This order was arranged by treating the left-EXT components and right-VT components as pairs that were randomly interspersed, with the restriction that each pair occur twice in any given block of eight component presentations. A total of 28 training sessions occurred in Phase 2. During Phase 3, the same order was used except that left was now followed by VT and right was followed by EXT. A total of 16 training sessions were presented.

Nose-key chamber. All rats were first dipper trained as in the lever apparatus and were then individually hand shaped to press each of the two response keys with their noses. Fifty continuously reinforced nose presses were then allowed to each key, with the appropriate key cued by the illumination of its respective stimulus. After key pressing was established, training was begun on a four-component schedule like that used in the lever chamber. For the left component, the reinforcer was obtained by presses of the left key according to a VI 1-min schedule; during the right component, right-key responses were reinforced according to an identical but independent VI 1-min schedule. Only the key that produced reinforcement during a given component was illuminated; the other key was darkened and responses to it had no scheduled effect. No COD was used. During the VT component, both keylights were extinguished, the houselight was illuminated, and reinforcers were presented on a VT 30-s schedule. During the EXT component, all lights were extinguished and no food was presented. The duration of all components was always 1 min.

During Phase 1, both the left and right components were preceded and followed by EXT. For a given opportunity, whether left or right occurred was determined randomly, with the

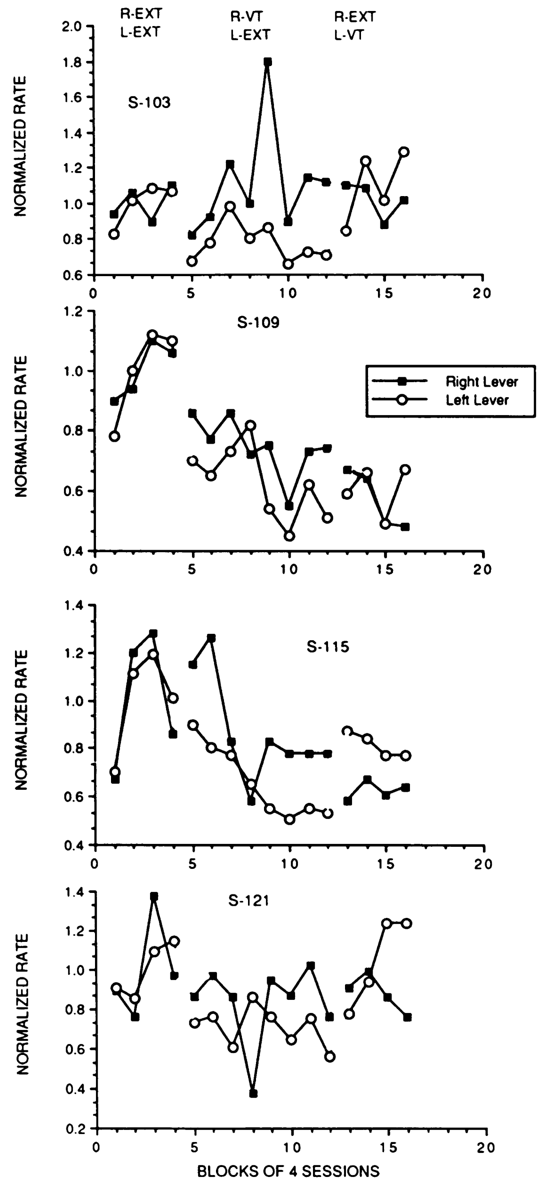

Fig. 1. Normalized response rates during the two target components from the lever apparatus of Experiment 1. The designations at the top indicate which schedule followed which target component.

Table 1

Response rates (responses per minute) for individual subjects during the last four sessions of each condition of Experiment 1 for subjects trained with the lever-press apparatus.

	Phase 1	Phase 2	Phase 3
S-103			
Right	5.5	5.6	5.1
Left	6.3	4.2	7.6
S-109			
Right	10.4	7.3	4.7
Left	10.7	5.0	8.3
S-115			
Right	11.1	10.1	8.3
Left	13.3	7.2	10.2
S-121			
Right	5.9	4.6	4.6
Left	9.8	4.8	10.5

restriction that both had to occur twice in any block of eight components (the other four being EXT presentations). Training in Phase 1 continued for 12 sessions. During Phase 2 one half of the EXT components were changed to VT components, which always occurred following a right component, whereas EXT always followed the left component. The order of components was arranged as in the lever chamber. Training in Phase 2 continued for 20 sessions. During Phase 3, the VT schedule followed the left component and EXT followed the right component. Training continued for 16 sessions. Phase 4 reinstated the conditions of Phase 1 and continued for 16 sessions. Phase 5 reinstated the conditions of Phase 3 (left followed by VT) but with the addition of a 15-s blackout between successive components. During this blackout, all lights in the chamber were extinguished and responding had no scheduled effect. Training in Phase 5 continued for 20 sessions.

RESULTS

Lever Chamber

Figure 1 shows the results from individual subjects across the three phases of training. Only the response rates to the lever appropriate to food in a given component are shown; occasional responses to the incorrect lever did occur but were generally low in frequency and uninformative. Different response rates occurred to the two levers even during Phase 1 in which both were preceded and followed by the same EXT schedule. To remove this response bias, the response rates throughout training were normalized relative to those occurring in the first condition. This was done by averaging the response rates across all sessions of training during Phase 1, with this average rate for each lever then assigned a value of 1.0. Values less than 1.0 in Phases 2 and 3 thus reflect negative contrast effects caused by changing one of the EXT schedules to the VT.

The overall degree of negative contrast can be assessed by comparing the response rates during the last four sessions of Phase 1 with those of Phases 2 and 3 (Table 1). Averaged over subjects and both responses, the mean response rate during Phase 1 was 9.1 responses per minute, and the mean of Phases 2 and 3 was 6.6. As assessed by a one-tailed t test, this difference was statistically significant, $t(3) = 2.61, p < .05$.

As shown in Phases 2 and 3, the occurrence of negative contrast differed depending upon the location of the VT schedule in the sequence. The pattern of differences was consistent for all subjects, although the overall level of responding was variable across subjects. During Phase 2, higher response rates (less negative contrast) occurred to the right lever, which was followed by the VT schedule, than to the left lever, which was followed by EXT. Then during Phase 3, when the sequence was changed so that the VT schedule followed the left lever and EXT followed the right lever, the pattern of response rates reversed, with higher response rates to the left lever for all subjects by the end of Phase 3 training. For some subjects (S-109 and S-115), response rates to both levers were below those during Phase 1, whereas for subjects S-103 and S-121 a decrease in rate occurred to the lever followed by EXT, and either no change or an increase in rate occurred to the lever followed by the VT schedule. Thus, negative contrast was shown clearly for the component followed by EXT but was inconsistent for the component followed by the VT schedule.

The absolute response rates averaged over the last four sessions of each condition are shown in Table 1. To support the observations noted above with statistical analysis, a two-way ANOVA (Component × Following Schedule) was conducted on the data from the last four sessions from Phases 2 and 3. The effect of component was not significant ($F < 1$), indicating that the bias toward one or the other lever was not consistent across subjects. The effect of the following schedule was significant, $F(1, 3) = 90.3, p < .05$. Thus, the higher response rate in the target component followed by the richer schedule was a reliable effect. Relative to the response rates in Phase 1, in which both target components were followed by EXT, the rates during Phases 2 and 3 for the components followed by EXT were reliably reduced, $t(3) = 3.83, p < .05$, but the rates for the components followed by VT were not, $t(3) = 1.39, p > .05$. Thus, reliable negative contrast occurred only in the former case.

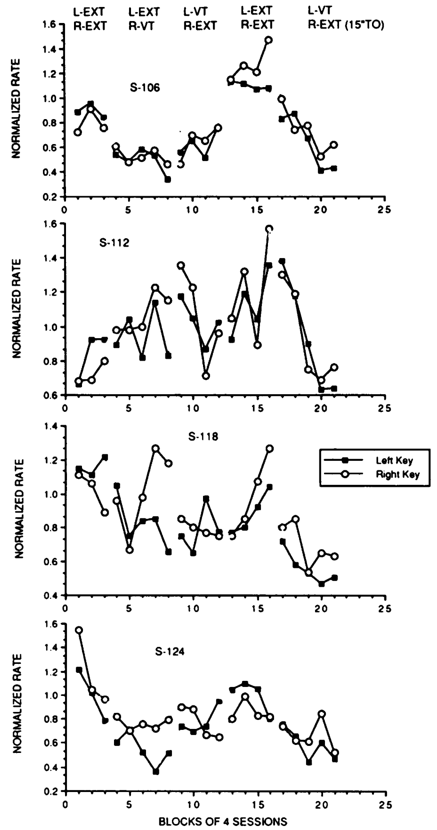

Fig. 2. Normalized response rates during the two target components from the nose-key apparatus of Experiment 1. The designations at the top indicate which schedule followed which target component. The last segment of the graph shows the results when a 15-s timeout was included between successive component presentations.

Nose-Key Chamber

Figure 2 shows the results for the individual subjects for which the operant response was pressing a nose key. There were substantial differences in response rates to the two nose keys during the conditions in which EXT followed both nose-key presentations, so the response rates throughout training were again normalized. This was done by averaging the

Table 2

Response rates (responses per minute) for individual subjects during the last four sessions of each condition for subjects trained with nose-key apparatus in Experiment 1.

	Phase				
	1	2	3	4	5
S-106					
Left	41.5	16.9	37.6	53.6	21.2
Right	27.1	16.5	27.3	52.7	22.1
S-112					
Left	40.1	36.0	44.4	59.0	27.8
Right	26.1	37.8	31.5	51.7	25.0
S-118					
Left	27.0	14.6	17.2	22.9	11.2
Right	12.7	16.7	10.6	18.0	9.0
S-124					
Left	30.3	19.8	37.1	31.2	18.4
Right	25.9	21.2	17.4	22.1	14.0

response rates for each key across all sessions of both Phases 1 and 4, in which EXT followed both target components. These average rates were then assigned a value of 1.0 for their respective keys.

The overall degree of contrast can be assessed by comparing the response rates from Phases 1 and 4, in which both target components were followed by EXT, with those of Phases 2 and 3, in which one of the EXT components was replaced by the VT 30 s. Considerable variability is evident in the data, but when the response rates during the last four sessions of Phases 1 and 4 were averaged over both responses and compared to the corresponding averages for Phases 2 and 3 (see Table 2), all 4 subjects showed a higher average rate during the conditions in which both following schedules were EXT. Averaged over subjects and both responses, the mean response rate during Phases 1 and 4 was 33.9 responses per minute, and was 25.2 responses per minute during Phases 2 and 3. As assessed by a one-tailed t test, this difference was statistically significant, $t(3) = 2.46$, $p < .05$. Thus, a significant overall contrast effect did occur.

Of greater interest is how the pattern of response rates in the two target components were affected by the sequence of component presentation. During Phase 2, when the schedule following the right key was changed to VT 30 s, normalized response rates to the right key exceeded those to the left key for all subjects by the end of training. Then during Phase 3, when the VT schedule followed the left key, the pattern of response rates reversed for 3 of the 4 subjects, whereas the remaining subject (S-106) partially reversed its pattern by responding with virtually identical rates in the two target components during the last block of training.

These effects of the following schedule were analyzed statistically using the absolute response rates during the last four sessions of each condition (Table 2). Once again, a two-way ANOVA (Components × Following Schedule) was performed on the data from Phases 2 and 3. The effect of the component was significant, $F(1, 3) = 15.6$, $p < .05$, indicating a bias toward the left key. The effect of the following schedule was also significant, $F(1, 3) = 23.3$, $p < .05$, but the interaction was not significant, $F = 1.99$. Thus, as with the lever chamber, response rates were reliably higher in the target component that was followed by VT schedule than in the component followed by EXT. Relative to the baseline conditions (Phases 1 and 4) in which both following schedules were EXT, the response rate in the components followed by EXT was reliably reduced, $t(3) = 3.75$, $p < .05$, but the response rate in the components followed by VT was not, $t(3) = 1.34$, $p > .05$.

In the final phase of training, the VT schedule followed the left component and EXT followed the right component, as in Phase 3, but the procedure was modified to include 15-s blackout periods separating successive component presentations. Surprisingly, all subjects showed an overall decrease in responding as a result, an effect opposite from the contrast effect obtained with pigeons when timeout periods are interspersed (cf. Sadowsky, 1973; but see also Holder & Roberts, 1988, for results with rats comparable to those obtained here). Whether this decrease in rate was differentially greater as a function of the following-schedule condition is difficult to assess because a difference in rates between the two components was evident at the end of Phase 4 when both following schedules were EXT. This was due to the method of normalizing the data, in that all sessions from both Phases 1 and 4 were included in defining the base rate, and there was a smaller bias toward the left response key in Phase 4 than in Phase 1. To minimize the problem of this changing response bias, a two-way ANOVA (Component × Phase) was conducted to compare the last four sessions of Phases 4 and 5. The result was that the main effect of component was not significant, $F(1, 3) = 7.14$, $.10 > p > .05$, but the main effect of phase was significant, $F(1, 3) = 12.49$, $p < .05$, indicating that the apparent decrease in response rate was reliable. Most important, the interaction term was also significant, $F(1, 3) = 23.7$, $p < .05$, indicating that the decrease in rate was differential. Inspection of the data in Table 2 shows that this was due to the greater decrease for the left lever than for the right. Because the left lever was followed by the VT schedule, this implies that the effect of the following schedule in Phase 5 was the reverse of what it was in Phase 3, in which the VT following schedule decreased the size of the negative contrast effect that otherwise occurred.

The effect of the 15-s timeout can be evaluated further by comparison of Phase 3 with Phase 5, which had the same sequence of component presentation and differed only in terms of timeout between components. To test the effect of timeout, a second ANOVA was conducted to compare the response rates during the last four sessions of Phases 3 and 5. The main effect of component was significant, $F(1, 3) = 16.6$, $p < .05$, as was the main effect of phase, $F(1, 3) = 25.5$, $p < .05$, which indicates that the addition of the timeout variable did significantly reduce response rate overall. The interaction term was also significant, $F(1, 3) = 20.8$, $p < .05$, indicating that the change in response rates was differential across the two components. Inspection of Table 2 reveals that the basis of the significant interaction was that the difference between the two components was considerably smaller in Phase 5 than in Phase 3. The average difference in response rates between the left and right levers was 12.4 for Phase 3, 5.6 for Phase 4, and 2.1 for Phase 5. Thus, the addition of the timeout not only reduced the size of the difference as a function of the following schedules, but also reversed its direction relative to that which occurred in Phase 4 when the schedule following the two target components was the same.

DISCUSSION

These investigations demonstrated significant negative contrast effects with rats when one of two EXT components was changed to a rich VT schedule. But the results also revealed that the basis of that contrast effect was different from those previously obtained with pigeons. Research with pigeons (Williams, 1976, 1979, 1981; Williams & Wixted, 1986) has shown that the major component of contrast is anticipatory in nature, which implies that the greatest decrease in response rate should occur in the target component preceding the component changed to the VT schedule. Instead, the opposite effect occurred, as significant negative contrast occurred in the target component with the unchanged following schedule (EXT), and smaller and inconsistent effects occurred in the target component followed by the VT. That is, despite the change in schedule (from EXT to VT) being temporally more proximal to the preceding target component (the two target components were equally likely to follow the VT schedule), the size of the negative contrast effect was significantly smaller in that preceding component. Thus, the contrast effects that occurred were not anticipatory in nature.

The issue raised by these results is why contrast was reduced in the component followed by the VT schedule. One possibility is that the richer following schedule reinforced the behavior in the preceding component "superstitiously," and this reinforcement effect counteracted the contrast effect that otherwise would have occurred because of the change in the relative rate of reinforcement. To assess this possibility, a 15-s timeout separating components was added in the last phase of training. The effect of the timeout was to clearly reduce the size of the following schedule effect and, relative to the pattern of performance in the preceding phase, to reverse it, although the later effect was very small. The results thus provide support for a superstitious reinforcement interpretation. But it should also be noted that the effect of the timeout could be due to Pavlovian contingencies, in that inserting a temporal gap between the target components and their following schedules should also weaken the "predictiveness" of the target component for its following schedule, and thus reduce any excitatory properties that the target stimulus leading to the VT might have as a positive conditioned stimulus (CS) for food.

One interpretation of the present results is that rats and pigeons differ in the basic mechanisms that determine behavior. Alternatively, it may be that procedural variables operated in these procedures, which were not present in the earlier studies with pigeons, and these variables counteracted the occurrence of anticipatory contrast. For example, Williams (1988) found very weak anticipatory contrast effects when the stimuli in the target and following components were similar, despite the fact that only intermediate degrees of similarity were used (horizontal vs. vertical lines compared to lines vs. colors). Had even more similar stimuli been used, it is possible that the anticipatory contrast effect would have been completely abolished. The degree of stimulus similarity operating in the present procedure is unknown, so it is possible that the present procedure was simply not optimal for demonstrating anticipatory contrast.

EXPERIMENT 2

The procedure of Experiment 1 was somewhat unusual in that a VT schedule was one of the components. Contrast effects have been obtained readily using VT schedules with pigeons as subjects (e.g., Halliday & Boakes, 1974), but their effects on rats are unknown. Consequently, Experiment 2 shifted to a procedure more similar to that conventionally employed in order to explore further the conditions that might produce anticipatory contrast. A three-component schedule was used in which different stimuli and different response types occurred in each component; we assumed that this would increase the dissimilarity between the components of the schedule and consequently, on the basis of previous data (Williams, 1988), increase the likelihood of anticipatory contrast. Two of the components were targets that had identical schedules that remained unchanged throughout training. The schedule for the third component was then varied to determine the pattern of contrast in the target components as a function of their location in the sequence of presentation relative to the variable schedule. In addition, to provide a further test of the superstitious reinforcement interpretation of the sequential effects, a 5-s delay was interposed between transitions between components; this was reset whenever responses occurred during the delay. The supposition was that this procedural feature should minimize any possibility of superstitious reinforcement and thus eliminate the pattern of sequential effects seen in Experiment 1 if superstitious contingencies were indeed the controlling variable.

METHOD

Subjects

Four experimentally naive albino rats were maintained in individual cages with continuous access to water. Food deprivation was maintained by allowing 2-hr access to Purina Rat Chow®, beginning approximately 5 min after removal from the experimental chamber.

Apparatus

A second Coulbourn modular chamber, like that used for the nose-key apparatus in Experiment 1, was used, with several modifications. The liquid dipper was replaced with a 45-mg Noyes pellet dispenser that was connected to a recessed food well located in the center of the front panel, 3 cm above the floor. Directly above the food well and 20 cm above the floor was a nonretractable stainless steel metal rod, 1.9 cm wide and 0.6 cm thick, that protruded 2.5 cm from the panel wall. In order for the rod to be reached, the rat was required to stand on its rear legs and extend its body to an almost completely upright position. A minimum force of 0.10 N was required to depress the rod. Seven centimeters above the rod was a shielded 28-V houselight that was projected toward the ceiling of the chamber. On the left side of the front panel, 2.5 cm above the floor, was a standard pigeon key (Coulbourn Model E21-15), 2.5 cm in diameter, that required a force of approximately 0.12 N for operation. The key was illuminated from behind by a 28-V IEE in-line stimulus projector with a diffuse white light with a small dark circle in the middle of the key. On the right side of the front panel, 10 cm above the floor, was mounted a stainless steel retractable lever (Coulbourn Model E21-03), 3.7 cm wide and 0.3 cm thick, extending 3.0 cm into the chamber when not in the retracted position. A minimum force of 0.25 N was required for operation.

Procedure

All subjects were first hand shaped to press the retractable lever and then received 50 continuous reinforcements. The retractable lever was then removed, the houselight above the rod was illuminated, and the subjects were shaped to depress the rod. After 50 reinforcements had occurred for that response, the houselight was turned off, the keylight was illuminated, and nose pressing was shaped; again 50 reinforcements were presented. After this preliminary training, the three-component multiple schedule was presented in which each component was 2 min in duration and successive components were separated by a 5-s timeout, which reset if responses occurred to any of the three manipulanda. Initially a continuous-reinforcement schedule occurred in all three components. Only the response appropriate to a particular component had any scheduled consequences. The key component was signaled by the keylight illumination, the rod component was signaled by the houselight illumination, and the lever component was signaled by the introduction of the lever into the chamber (it was retracted during the other two components) and extinguishing all lights. The schedules during the three components were then extended to VI 15 s in each component for two sessions, followed by two sessions with all schedules extended to VI 30 s. Finally, the schedules used for the remainder of training were introduced: These were VI 90 s for the key and lever components and VI 30 s during the rod component (which later was changed to VI 270 s).

The major variable of interest was the sequence of schedule components. For Subjects S-9 and S-10, the sequence during Phase 1 was key–rod–lever, which then continuously recycled. For S-11 and S-12, the sequence was lever–rod–key. Because the schedule during the rod component provided more reinforcement than either the key or lever, the issue was whether there would be differential suppression for the key versus lever components. Training during Phase 1 continued for 30 sessions, with each session consisting of 30 2-min components. During Phase 2, which also continued for 30 sessions, the orders of presentation for the two pairs of subjects were reversed, such that the rod component now followed the lever for S-9 and S-10 and followed the key for S-11 and S-12.

During Phases 3 and 4, each of which continued for 25 sessions, the schedule during the rod component was changed from VI 30 s to VI 270 s, and the schedules during the lever and key components remained unchanged at VI 90 s. During Phase 3 the sequence used in Phase 2 was continued for all subjects, whereas during Phase 4 the sequence was again reversed, reinstating the sequence used in Phase 1 for all subjects. Thus, across the four phases of training each subject was exposed to both component sequences with high versus low reinforcement values in the rod component.

RESULTS

Figure 3 shows the response rates for individual subjects during the two target components that were continued on the same reinforcement schedules throughout training. Responding during the rod component is not shown, but in general response rates in that component tracked its reinforcement rate reliably, being high when the VI 30-s schedule was in effect and low when the VI 270-s schedule was in effect. Because the response rates to the lever and key were very different, their response rates were again normalized. This was done by averaging the response rates to each manipulandum across all sessions of Phases 1 and 2 in which the rod schedule was VI 30 s and assigning the mean rate a value of 1.0 for their respective responses.

Contrast effects as a function of varying the schedule during the rod component are assessed by a comparison of the rates in Phases 1 and 2, in which the rich schedule (VI 30 s) was associated with the rod component, with those during Phases 3 and 4, in which the rod component was associated with a lean schedule (VI 270 s). An assessment of overall contrast independent of the sequential effects can be made by averaging the last five sessions of Phases 1 and 2 and comparing them with the corresponding average of Phases 3 and 4 (Table 3). From this comparison, both S-9 and S-12 showed a contrast effect in both components, and S-10 exhibited negative induction in both components. No clear pattern occurred for S-11. Overall, therefore, there was no significant contrast effect.

The effects of the order of component presentation are seen by comparing Phase 1 versus Phase 2 and Phase 3 versus Phase 4. During Phase 1, when the schedule for the rod was VI 30 s, higher response rates occurred in the target component preceding the rod for 3 of the 4 subjects, and the remaining subject (S-9) had similar rates in the two target components. During Phase 2, when the target com-

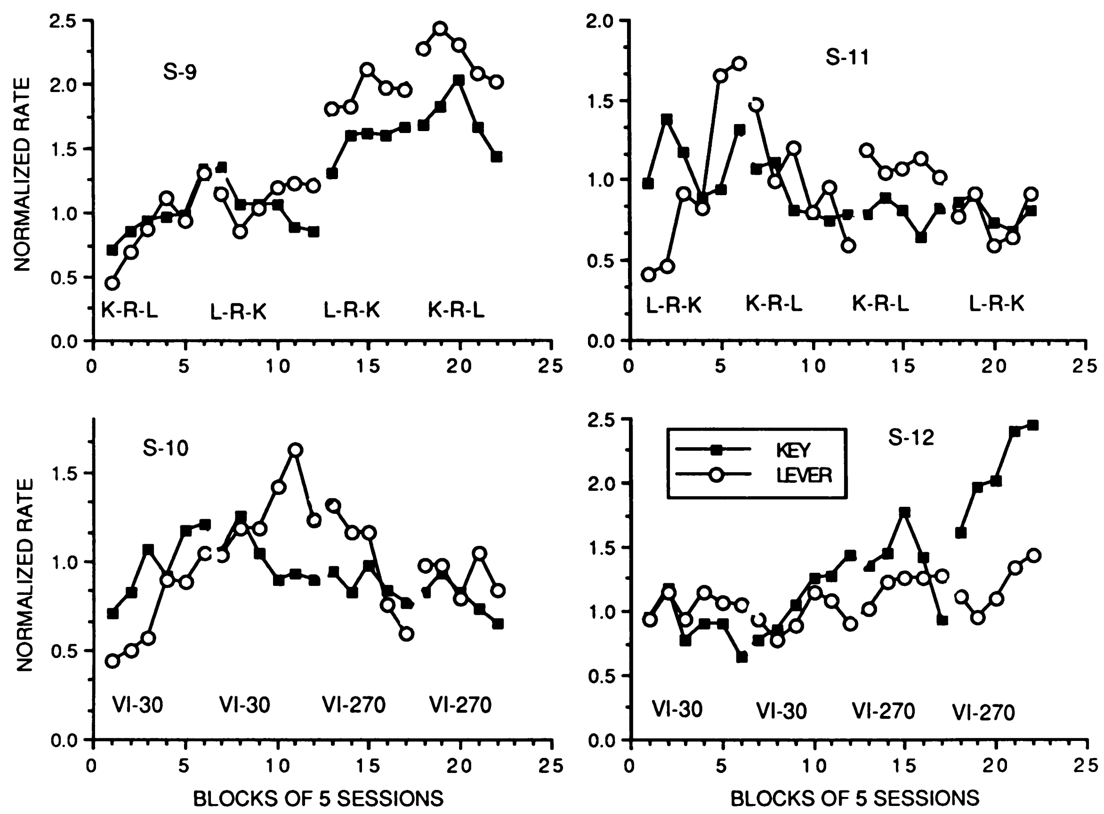

Fig. 3. Normalized response rates during the two target components of Experiment 2. The designations (K = key, R = rod, L = lever) at the top of the panel for S-9 show the order of component presentations for S-9 and S-10; the designations at the top of the panel for S-11 show the order for S-11 and S-12. The schedule designations at the bottom of the panels of S-10 and S-12 show the value of the schedule in the rod component, which varied across training.

ponent followed by the VI 30-s schedule was reversed, the pattern of response rates reversed as well, so that by the end of Phase 2 a higher response rate occurred in the target component preceding the VT 30-s schedule for all subjects.

During Phases 3 and 4, in which the schedule during the rod component was decreased to VI 270 s, the results were somewhat less consistent. During Phase 3, in which there was no change in the order of component presentation from that in Phase 2, 3 of the 4 subjects reversed their patterns of responding seen at the end of Phase 2, such that a lower response rate occurred in the target component preceding the rod in comparison to the target following the rod. The exception was S-9, which maintained the pattern of responding at the end of Phase 2 for the duration of training but with higher response rates during both components. During Phase 4, the pattern of responding again reversed for 2 of the 4 subjects (S-10 and S-12) and partially reversed for the 3rd (S-11), such that lower response rates again generally occurred in the target preceding the rod than in the component following the rod.

The effects of component sequence on the degree of contrast were analyzed statistically using the absolute response rates during the last block of five sessions (Table 3) assessed by a three-way ANOVA (Response × Schedule × Location in Sequence). The effect of the schedule ($F < 1$) was not significant, indicating that there was no consistent overall contrast effect. The effect of response was also not significant, $F(1, 3) = 6.21$, $.10 > p > .05$, indicating that the response biases seen in Table 3 were not consistent across subjects. Neither the location in the sequence ($F = 2.95$) nor the three-way interaction ($F < 1$) approached significance. The interaction between the schedule and sequence location was significant, $F(1, 3) = 34.7$, $p < .05$. Because of this significant interaction, separate t tests were performed on the difference between the target components that occurred before versus after the rod component. Averaged over both responses, the mean response rate (responses per minute) during the target component preceding the VI 30-s schedule during the rod component was 37.7, and the average rate during the target component following the VI 30-s rod schedule was 28.9; this difference was statistically significant, $t(3) = 5.54, p < .05$. When the schedule during the rod component was VI 270 s, the average rate in the target component preceding it was 36.6 and was 41.8 in the target component following it; this difference was also statistically significant, $t(3) = -3.30$, $p < .05$. In both cases, the order of component presentation reliably affected response rates in the target components, but in opposite directions depending on whether the schedule in the variable component was higher or lower in value than the target components themselves.

Table 3

Response rates (responses per minute) for individual subjects during the last five sessions of each condition during Experiment 2.

	Phase			
	1	2	3	4
S-9				
Key	37.3	23.6	46.1	40.1
Lever	58.0	53.2	85.8	89.1
S-10				
Key	41.6	30.9	26.4	22.5
Lever	34.2	40.6	19.4	27.8
S-11				
Key	7.0	4.2	4.4	4.3
Lever	37.5	12.9	22.2	20.0
S-12				
Key	11.1	25.0	16.4	42.6
Lever	62.3	53.2	75.8	84.5

DISCUSSION

In general, the results of Experiment 2 were consistent with those of Experiment 1, although an overall contrast effect did not occur for all subjects. When the schedule during the variable component was high in value, the target component preceding that schedule had a higher response rate than did the target component that followed the schedule. When the variable schedule was low in value, higher rates occurred in the target component that followed the variable schedule. Thus, the effect of the variable schedule was exactly opposite that obtained in similar experiments using pigeons as subjects (Williams, 1981, Experiment 2; Williams & Wixted, 1986). Given that the procedures used in Experiments 1 and 2 differed in several dimensions, this different pattern with rats seems to have considerable generality. Similar results have also been obtained in several other unpublished experiments in our laboratory using a variety of different stimulus conditions; in no case have we been able to produce reliable anticipatory contrast with rats trained on conventional multiple schedules.

The difference between the present results with rats and previous results with pigeons is paralleled by similar differences obtained from presentations of timeout. Using pigeons as subjects, Leitenberg (1966) reported that a stimulus superimposed on a VI baseline produced a rate increase if the stimulus terminated in timeout. Similar results were obtained by Pliskoff (1963) and Buck (1975). But attempts to demonstrate the same effect with rats as subjects failed to produce a rate increase during the pretimeout signal (Kaufman, 1969) and in some cases produced a rate decrease (Leitenberg, Bertsch, & Coughlin, 1968). Given that such procedures are similar to following the VI component of a multiple schedule with an EXT component, the failure of the latter studies to show contrast provides further support for the generality of the present findings.

The failure to find any evidence of anticipatory contrast is surprising given that such effects are evident with rats in other preparations. Bacotti (1976) trained rats on a VI food schedule and then varied the time between the termination of the session and postsession feeding. When food was given immediately (in their home cages), response rates during the session were consistently lower than when feeding was delayed for 1 hr; this effect was particularly evident during the last 15 min of the session. Other evidence of anticipatory contrast has been found with licking procedures in which the rate of licking some target solution is found to vary with the palatability of a second solution that is available only after the target solution has been removed (Flaherty &

Checke, 1982; Flaherty & Rowan, 1985, 1986; Lucas, Gawley, & Timberlake, 1988). The typical finding is that the rate of licking for the target solution varies inversely with the value of the following solution, and that this effect is diminished by increasing times between the different opportunities to lick.

The differences between the contrast effects with such procedures and the opposite findings with the present procedures are puzzling. It is worth noting, however, that Flaherty and Grigson (1988) have reported that either anticipatory contrast or reinforcement effects can occur, depending upon the response contingency between licking the tube of the target solution and access to the following solution. When no response requirement was in effect, contrast was obtained, but when access to the following schedule was dependent on some specified number of licks to the target solution, reinforcement effects were obtained. The present results differ from this pattern in that reinforcement effects were obtained in the absence of a response requirement for component transition; moreover, they occurred in Experiment 2 when the possibility of superstitious reinforcement was minimized. It remains to be seen how the results from the different procedures are related.

The present results show that response rates in a target component are affected by the schedule in the following component by being driven in the direction of the value of the following schedule. As noted in the discussion of Experiment 1, one interpretation of this effect is that access to the following schedule superstitiously reinforces target-component responding. This interpretation is weakened by the failure of the 5-s resetting delay to abolish the effect in Experiment 2, because that procedural feature prevented contiguous pairings of responding during the target components with the onset of the following components. An alternative explanation is that the stimuli in the target components serve as Pavlovian CSs for the reinforcement conditions in the following components, and this CS function may excite or inhibit target-component behavior in a manner opposed to contrast effects. Whatever the explanation, the finding has substantial implications for why overall behavioral contrast effects are difficult to produce with rats. Consider, for example, a two-component schedule that is changed from multiple VI 60 s VI 30 s to multiple VI 60 s EXT. Whereas contrast would be expected in the VI 60-s component because its relative rate of reinforcement has increased, it is possible that this effect would be obscured by differences in the following schedule. During baseline, responding during the VI 60-s component would be increased by having the richer following schedule, and this source of response rate would then be eliminated by the change to EXT. Depending upon the size of this following-schedule effect relative to the effect of the overall relative rate of reinforcement, contrast might or might not be evident.

The present results also are relevant to understanding the relation between anticipatory contrast and overall contrast. Previous results with pigeons (Williams, 1981; Williams & Wixted, 1986) have shown that the great majority of overall contrast is due to anticipatory contrast (at least with highly discriminable stimuli), although some residual effect of the preceding schedule also does occur for some subjects. Given that anticipatory contrast did not occur in the present studies, the implication is that overall contrast should not occur as well. In fact, substantial overall contrast effects did occur for some individual subjects in Experiment 2 (e.g., S-9 and S-12) and for the majority of subjects in Experiment 1. It is clear, therefore, that overall contrast and anticipatory contrast can be functionally independent. However, it should be noted that the contrast effects obtained here need not be interpreted as due to changes in the overall relative rate of reinforcement. In both of the present experiments it was possible for all of the change in overall response rate to be caused by variation in the reinforcement schedule preceding the target components, so that the dynamics of local contrast could have been a significant component of the results. Unfortunately, response rates as a function of the preceding components were not recorded separately, so the mechanisms underlying the present contrast effects remain uncertain.

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