BEHAVIORAL CONTRAST WITHOUT RESPONSE-RATE REDUCTION¹

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Behavioral contrast was obtained in two experiments, which both employed a standard free-operant successive discrimination (a multiple variable-interval extinction schedule), without the occurrence of reductions of response rate in the extinction component. In Experiment I, one group of four pigeons was trained on a multiple schedule in which one stimulus was associated with a variable-interval schedule and the second stimulus with response-independent reinforcement on a free variable-interval schedule. Though by the end of this training three pigeons were responding very little to the second stimulus, when this stimulus was associated with extinction all subjects showed a contrast effect. In Experiment II, eight pigeons were trained extensively to respond to a single stimulus on a variable-interval schedule, before a second stimulus associated with extinction was introduced. This second stimulus was dissimilar to the initial stimulus and five pigeons never responded in its presence. Nevertheless, all pigeons showed a contrast effect and there was no evidence that the effect was smaller in errorless subjects or smaller than in a subsequent discrimination where all subjects made many errors. Both experiments indicated that response reduction in one component of a multiple schedule is not a necessary condition for the occurrence of contrast.

The role of response factors in the acquisition of a successive discrimination is poorly understood. At one extreme there are claims (e.g., Terrace, 1966) that a reduction in responding in one component of a multiple schedule is both a necessary and sufficient condition for the occurrence of the various "byproducts" of discrimination learning. Alternatively, there are analyses of the interactions between components of multiple schedules (e.g., Reynolds, 1961; Herrnstein, 1970) entirely in terms of reinforcement frequency, which assign no role whatsoever to changes in response rates.

Recent research on the properties of response-independent reinforcement schedules has provided new evidence on this topic (e.g., Halliday and Boakes, 1972; Weisman and Ramsden, 1973; Wilkie, 1972). This work has

shown conclusively that a reduction of responding cannot be a sufficient condition for the occurrence of at least one of the byproducts of discrimination learning, namely, behavioral contrast. When responding is reduced in one component (S2 component) of a multiple schedule by a change from a response-dependent to a response-independent schedule of the same reinforcement density, responding does not increase in the other (S1 component). In fact, some slight reduction in S1 response rate can be observed (Boakes, 1973; Weisman and Ramsden, 1973). The absence of an increase in S1 response rate is very different to what is observed when similar reduction in S2 response rate is produced by the introduction of extinction, or of schedules that differentially reinforce low rates (DRL) or other behavior (DRO) where these schedules are adjusted so as to maintain a constant reinforcement density (e.g., Terrace, 1968; Weisman, 1970). In such cases, a rise in S1 rates, behavioral contrast, accompanies the reduction in S2 response rates.

In the light of this evidence from the study of free variable-interval (Free VI) schedules, Terrace (1972) modified his previous position to one in which the various byproducts

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of discrimination learning are seen as the result of response reduction involving "active inhibition". A similar approach, using different terminology, was adopted by Halliday and Boakes (1972), who suggested that behavioral contrast was the result of "response inhibition". Both views imply that an increase in S1 responding cannot occur unless response rates fall in the S2 component; that is, response reduction is assumed to be a necessary, but not a sufficient, condition for the occurrence of contrast.

Much of the evidence for this claim arises from the study of errorless discrimination learning (e.g., Terrace, 1966, 1972), but another way of testing this hypothesis is suggested by the research on free reinforcement schedules described above. The basic idea is to establish a discrimination in two stages, which separate response reduction in the S2 component and reinforcement-density reduction in the same component. In the normal procedure of an immediate transition from baseline training to a multiple variable-interval extinction (*mult* VI EXT) schedule, these two changes occur at the same time. Their separation is achieved here by first training subjects on a multiple variable-interval free variable-interval (*mult* VI Free VI schedule until responding in the S2 component has been greatly reduced; only then is the multiple variable-interval extinction schedule introduced.

No behavioral contrast should be obtained in this final stage if a reduction in S2 responding is necessary for its occurrence, since there is now little responding to be reduced. On the other hand, if the major determinant of this phenomenon is a change in relative reinforcement frequency, behavioral contrast should not only occur, but the effect should be of similar magnitude to that obtained after a transition from *mult* VI VI to *mult* VI EXT.

Some evidence on this issue is provided by an experiment using rats by Wilkie (1972). His results suggest that a transition from *mult* VI EXT to *mult* VI Free VI produces behavioral contrast, but the data are consistent with an alternative interpretation discussed below. The following experiment was intended to extend this evidence and, by including appropriate control conditions, remove any ambiguity of interpretation.

EXPERIMENT I

METHOD

Subjects

Eight experimentally naive male homing pigeons, about 18 months old, were maintained at 80% of their free-feeding weight throughout the experiment.

Apparatus

The experimental chamber measured 30 by 30 by 30 cm. A single response key, mounted centrally above the grain hopper at a height of 21 cm, was transilluminated by an in-line projector (Counting Instruments Ltd.). A white, red, or green light could be projected onto the key. The reinforcement was 3.5-sec access to grain. While the key was illuminated, each peck on the key was accompanied by a feedback click from a relay mounted behind the response panel. A houselight was mounted at the top of the back wall of the box. The experimental chamber was housed in a sound-attenuating cubicle and continuous white noise was present during experimental sessions.

Procedure

After magazine training, key pecking at the white key was shaped. In the subsequent pre-training stages, the key remained white and responding was maintained by a variable-interval reinforcement schedule whose mean interval was gradually increased to 1 min over a period of three sessions and then kept at this value for three more sessions. For these three sessions and for the next two phases of the experiment, each session contained 40 stimulus periods of 1-min duration, separated by 4-sec intervals, during which the chamber was dark and responses had no effect.

The subjects were divided into pairs, roughly matched for their mean rate of responding during the last three sessions of pre-training. One member of each pair (Free VI group) was then transferred to a multiple schedule in which VI 1-min (S1 component) was associated with a red keylight and Free VI 1-min (S2 component) was associated with a green keylight; the VI and Free VI components occurred equally often during a session in a semirandom order. The other member of each pair (nondifferential group) received

the same sequence of red and green components in each session, but with VI 1-min associated with both components. Training continued for each pair until the Free VI bird's response rate in the Free VI component had stabilized; the number of sessions in this stage ranged between 25 and 38, as shown in Table I. In the next stage, all subjects received 10 sessions of *mult* VI EXT with the red light associated with the VI component. The final stage of the experiment consisted of 10 sessions in which the number of components was reduced to 20 and the schedule was changed to a simple VI 1-min with the red light associated with all components. One bird (P 105) began to lose weight during the last stage of the experiment and was therefore withdrawn after six sessions.

RESULTS

Table I shows the median rates of responding for each bird at each stage of training. The birds in the nondifferential group showed little disruption when they were transferred from the white key at the end of pretraining to the *mult* VI VI schedule, and in all cases their rates increased in the course of baseline training. In the Free VI group, rates in the S2 (Free VI) component were consistently lower than those in the S1 component from early in training; this may in part reflect a stimulus preference, in that the red key was associated with the S1 component in all birds. In the course of training, the rates in the S2 component declined further, and by the end of training were near zero for all birds except P 110. The rates of responding in the S1 component were, in general, lower than in the nondifferential group: by the end of baseline training three birds had increased their rate of responding to about the same level as at the end of pretraining, but P 105 continued to reduce its rate of responding in the VI component throughout baseline training. There was no significant difference between groups in their median rates of responding in the VI component during the last five sessions of baseline training, though all except one bird in the Free VI group were responding slower than any of the nondifferential group. The nondifferential group showed a significantly greater increase in response rate between pretraining and the last five days of baseline than the Free VI group ($p < 0.05$, Mann-Whitney).

In the next phase of the experiment, all birds showed marked increases in rate in the S1 component after extinction was introduced in the other component. There were considerable individual differences in the amount of contrast, but there was no significant difference between the groups in the response rates in the S1 component. From Table I it can be seen that the median response rates in S1 were almost identical in the two groups, though contrast, expressed as a percentage of the baseline, was greater in the Free VI group because of the lower baseline rates. All the birds in the Free VI group made a few responses in the S2 component on most days of the contrast phase, so the Free VI procedure had not completely eliminated responding; however, only one bird (P 110) has a substantial response rate in S2 (see Figure 1) and this bird actually showed less contrast (as a percentage of baseline responding) during the first five days of this phase than any of the other birds in the group.

In the final phase, all birds except P 102 reduced their rate of responding to below the levels obtaining at the end of the contrast phase; however they were, in general, responding at higher rates than during the last stage of baseline training. The Free VI group did have somewhat lower S1 rates than the nondifferential group in this stage of training, but the difference was not significant.

DISCUSSION

The main finding of this experiment is that a transition from Free VI to Extinction in the S2 component of a multiple schedule leads to a considerable increase in the rate of responding in the unchanged S1 component. This increase is consistent with previous evidence (Wilkie, 1972) and occurred even though the amount of S2 responding before the transition was low in three of the Free VI birds.

There are at least two possible interpretations of this change in S1 response rates. One is that it is an instance of behavioral contrast. An alternative is that it represents a recovery from the prior depression of S1 rates (*negative induction*, as defined by Reynolds, 1961) induced by the response-independent reinforcement schedule of the S2 component. There is good evidence for negative induction under such conditions (e.g., Boakes, 1973;

Table 1
Median Responses per Minute for Individual Birds in the Various Stages of the Experiment

Bird No.	Group	Pretrain	Baseline				VI/EXT				Simple VI		No. of Baseline Sessions
			Sessions 1 to 5		Last Five Sessions		Sessions 1 to 5		Last Five Sessions		Sessions 1 to 5	Last Five Sessions	
			S1	S2	S1	S2	S1	S2	S1	S2			
P 104	Free VI	30.3	9.0	2.6	33.2	5.5	63.5	1.4	92.4	0.3	33.6	51.4	38
P 105	Free VI	16.1	15.3	4.2	8.0	0	13.1	0	14.1	0	12.7	—	28
P 110	Free VI	42.6	50.5	42.7	48.9	24.5	57.4	20.8	81.2	16.7	69.5	76.3	38
P 111	Free VI	36.9	15.0	4.0	31.4	0.2	50.0	0.5	55.8	0.4	47.5	48.5	25
Medians		33.6	15.2	4.1	31.8	2.5	53.7	0.9	68.5	0.3	40.5	51.4	
P 101	Nondif.	25.1	27.5	24.4	53.8	57.6	61.7	52.0	73.8	35.4	68.6	65.5	38
P 102	Nondif.	35.2	25.5	22.5	38.9	37.5	47.1	17.1	66.0	9.8	77.1	69.2	38
P 106	Nondif.	24.8	20.4	27.1	41.6	48.9	44.5	13.4	42.3	4.5	41.8	39.0	25
P 107	Nondif.	29.5	47.7	26.4	72.4	58.0	112.5	63.5	119.0	47.9	105.0	91.0	28
Medians		27.3	26.5	25.4	47.7	53.2	54.4	34.6	69.9	22.6	72.8	67.3	

Fig. 1. Experiment I: rates of responding during the last five sessions of baseline training and all subsequent stages of the experiment. The horizontal dotted lines show the median rate of responding during the last five days of the previous stage of training.

Weisman and Ramsden, 1973), and the effect is seen in the present results. Consequently, the possibility that the increases in S1 rates observed here and in the two previous studies were due to a decline in induction is a plausible one.

Nevertheless, two aspects of the present results show that this is not an appropriate explanation here and that the increase in response rates was a genuine contrast effect. First, when the birds in the Free VI group were given simple VI conditions following the *mult* VI EXT phase, S1 response rates decreased. This would be expected if the rate increase had been a contrast effect, but not if it were a decline in induction. Second, the S1 rates in the Free VI group during the *mult* VI EXT phase were very much the same as those of the nondifferential group in the same phase; a decline in induction should have led to recovery only to a level comparable to that during the *mult* VI VI phase of the nondifferential group.

These two sources of evidence, which rule out the possibility of a decline in induction as the sole basis for the increase in S1 responding, were not available in Wilkie (1972). In that study, the only way of deciding this question was by comparison with response rates during a much earlier baseline (*mult* VI VI) phase. This evidence is compatible with the present interpretation, since S1 response rates were higher after the transition than during the earlier baseline phase. However, it should be noted that this comparison on its own is unsatisfactory, since the baseline rates were obtained 15 to 21 sessions earlier and response rates on a VI schedule are known to increase with extended training.

An additional feature of the present experiment was that the Free VI schedule was more effective in eliminating responding than in the earlier study. Thus, it provides an example of the occurrence of behavioral contrast in the absence of a reduction of instrumental responding in the other component. It is possible that some other, unrecorded response was maintained at a high frequency by the Free VI schedule and that this frequency declined after extinction was introduced. That is, it could be claimed that a reduction in the rate of some response, similar or dissimilar to the instrumental response in the S1 component is a necessary condition for behavioral contrast.

To the extent that such a claim is testable, it appears unlikely on present evidence. Scull and Westbrook (1973) observed no increase in the rate of key pecking on a VI schedule (S1 component) when treadle pressing in the S2 component, previously maintained by an identical VI schedule, was extinguished.

EXPERIMENT II

The above results are difficult to reconcile with the findings on errorless discrimination learning. Where subjects have learned a successive discrimination without making more than a few errors (S2 responses), Terrace has reported that none of the usual byproducts of discrimination learning have been observed (Terrace, 1972). Such errorless learning has been achieved by means of two different procedures. In one case, the S2 stimulus is introduced by special fading procedures, in such a way that the animal never responds in its presence; following training of this sort, the rate of responding in S1 was not reduced when the S2 component was removed, nor did it rise when the S2 component was reintroduced (Terrace, 1963). Although this is not the conventional way of measuring contrast, the results are good evidence for the absence of contrast following this type of errorless training. There are, however, difficulties in interpreting these results; when errorless learning is achieved by a fading procedure it is possible that any difference in behavior does not arise from the absence of errors, but is a direct result of the procedure used to prevent the occurrence of errors. For example, Rilling, Kramer, and Richards (1973) found that the reduction of an animal's tendency to escape from a negative stimulus following a fading procedure was a function of the gradual introduction of the nonreinforced component, rather than of the absence of errors in that component. Comparable evidence is not available in the case of behavioral contrast, but it is at least possible that similar results would be obtained.

The second means of obtaining an errorless discrimination is to introduce abruptly a negative stimulus that is very dissimilar to the positive stimulus. Using a procedure of this kind, Terrace (1966) trained eight pigeons to respond to a vertical white line on the response key and then introduced a plain green key as

S2. Half the birds never responded to the green key after extensive training on the white line, and these birds showed no increase in responding in S1; the remaining birds did respond initially to S2 and showed contrast to S1. Terrace interpreted this result as showing that responding to S2 was a necessary condition for the occurrence of contrast. This result is slightly surprising in view of the fact that the introduction of periods of blackout, during which the bird never responds, produces reliable contrast (Sadowski, 1973; Taus and Hearst, 1970). An experiment was therefore carried out that followed Terrace's (1966) procedure closely, except that component length was kept constant: Terrace allowed S2 periods to end only after 30 sec had passed without a response.

METHOD

Subjects

Eight experimentally naive male homing pigeons were maintained at 80% of their free-feeding weights throughout the experiment.

Apparatus

The experimental chambers and scheduling equipment were similar to those in Experiment I. Three stimuli could be presented on the response key by means of an in-line projector (Counting Instruments Ltd.); these were a plain green key, a white X on the black background and a white $\blacktriangleleft$ on a black background.

Procedure

Following magazine training, key pecking was shaped to the white X; in the subsequent pretraining stage, the white X remained on the key and responding was reinforced on a VI schedule whose mean interval was gradually increased to 1 min over a period of three sessions. During this and all subsequent stages of the experiment, each session contained 24 stimulus periods of 1-min duration, separated by 3-sec intervals, during which the chamber was dark and responses were ineffective.

Following pretraining, all subjects received 15 sessions of training (Baseline I) during which the white X was present during all components and a VI 1-min schedule was in effect. They then received six sessions of *mult* VI 1-min EXT (Discrimination I) with the

white X associated with the VI schedule and the green key associated with extinction; the two components occurred equally often during a session in a semirandom order. In the next stage, all subjects were returned to the same training conditions as during Baseline I for a further six sessions (Baseline II). Finally, they received six sessions of discrimination training under similar conditions to Discrimination I, except that the white $\blacktriangleleft$ was associated with extinction (Discrimination II).

It was expected that relatively few errors would be made during Discrimination I, due to the extensive training on S1 (the white X) and the large difference between S1 and S2 (the green key), while many more errors would be made in Discrimination II, where S1 and S2 were much more similar.

RESULTS

Figure 2 shows the rates of responding for each bird during the last five sessions of Baseline I and all subsequent sessions. In the six sessions of Discrimination I (X *versus* green) five birds (P 71, P 74, P 77, P 87, and P 178) never responded to the green key, one (P 76) made a total of 10 responses in Sessions 3 and 4, one (P 179) began to respond to the green key in Session 3 and thereafter made a total of 107 responses, and one bird (P 78) responded to the green key on all sessions, making a total of 862 errors in all. Overall, therefore, five birds made an errorless discrimination and seven birds made no errors (S2 responses) until the third session. Inspection of the figure shows that all birds showed evidence of contrast. The five totally errorless birds showed a mean increase in S1 rate of 60.9% during Discrimination I as compared with the last five baseline sessions. The remaining birds also showed contrast; P 76—71.6%; P 78—19.6%; P 179—66.5%; of these birds, the ones that made no errors on the first two days showed as much contrast on those days as they did on the remaining sessions when they were making errors (68.5% as compared to 69%). P 78, the only bird that made errors in the first two sessions, and the one that made by far the greatest number of errors overall, showed the least contrast during Discrimination I.

There was, in general, a reduction in S1 responding when baseline conditions were

Fig. 2. Experiment II: rates of responding during the last five sessions of Baseline I and all subsequent stages of the experiment.

re-introduced. All birds, except P 87, showed lower mean rates of S1 responding during the six Baseline II sessions than during Discrimination I. However, the rates of responding were, except in the case of P 78, considerably higher than during Baseline I.

During Discrimination II (X versus $\triangleleft$), all birds responded to the S2 stimulus in every session, and all birds increased their rate of responding in S1. In each case, the mean rate of S1 responding during Discrimination II was greater than during Discrimination I. However, it should be remembered that the S1 rates during Baseline II were higher than during Baseline I; if the rate increases in each discrimination are calculated as a percentage of the rate in the preceding baseline stage, it appears that, for all birds except P 78, the percentage increase in S1 rate was greater during Discrimination I than during Discrimination II.

DISCUSSION

In the present experiment, behavioral contrast was obtained in both discrimination phases, regardless of whether responses occurred in S2. In the course of Discrimination I, the five totally errorless birds showed as much contrast as the birds that made errors and the two birds that were initially errorless showed no increase in contrast when they began to make errors. Thus, these results show, as did Experiment I, that contrast can occur in the absence of S1 responding. Original baseline rates of responding were not recovered during Baseline II and for this reason it is difficult to reach firm conclusions about the relative amount of contrast produced by discriminations learned with and without errors; however, the data do not suggest that much less contrast occurs in the errorless case.

The only major respect in which this experiment differed from that of Terrace (1966) was the absence of a correction procedure in S2 periods; however, the major discrepancy between his results and the present ones was the presence of contrast in the errorless discriminations. Since the correction procedure has no effect on errorless discriminations there is no obvious explanation of our failure to obtain the same results as Terrace. It is possible that minor procedural differences led to a greater sensitivity to contrast effects in the present experiment, but it

is unclear what these differences are, since care was taken to repeat the details of Terrace's study. Alternatively, since even such a robust phenomenon as behavioral contrast is not observed in all subjects, the discrepancy may be the result of the small sample used (four errorless birds in Terrace's experiment), enhanced by the self-selecting nature of this method for obtaining errorless discrimination learning.

GENERAL DISCUSSION

In both these experiments, behavioral contrast was obtained under conditions where there was no reduction of responding in the S2 component. These results give no support to accounts of contrast that lay emphasis on the role of reduction of responding in S2, as a necessary condition for the occurrence of behavioral contrast.

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