Some tests of the additivity (autoshaping) theory of behavioral contrast

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Two experiments were performed to determine whether the location of the discriminative stimuli affects the amount of positive behavioral contrast exhibited during discrimination learning by pigeons. When signals for reinforcement and nonreinforcement of keypecking were situated directly on the response key (different line tilts), pecking rates during the positive stimulus were higher than when the source of the signals was located elsewhere (changes in chamber illumination or auditory click frequency). These results are in general agreement with the additivity theory of behavioral contrast, which attributes contrast to the combined effects of stimulus-reinforcer and response-reinforcer correlations on behavior directed at signals of reinforcement. Some shortcomings of the theory were discussed, and the notion that behavioral contrast is a basic, unitary phenomenon was criticized.

Although the phenomenon of positive behavioral contrast in operant conditioning has been the subject of extensive empirical investigation for almost 15 years (see reviews in Freeman, 1971; Mackintosh, 1974; Schwartz & Gamzu, in press), various attempts at theoretical integration of the data have proven inadequate. Recently, however, several workers (e.g., Boakes, Halliday, & Poli, 1975; Gamzu & Schwartz, 1973; Rachlin, 1973; Redford & Perkins, 1974) have proposed and tested a hypothesis that predicts fairly well which procedural arrangements will lead to large amounts of positive contrast and which arrangements will not. According to this general interpretation, positive contrast occurs because certain kinds of discrimination training (e.g., the initiation of reinforcement for keypecking to only one of two different colors on a pigeon's response key) establish a differential stimulus-reinforcer correlation which alone would produce behavior directed at the target of the previously conditioned operant response. These "Pavlovian" and "operant" sources of control combine to yield an increased response rate to the positive stimulus (S^+).

This "additivity" theory arose from consideration of the potential influence of (implicit) autoshaping in conventional operant conditioning arrangements. Autoshaping (Brown & Jenkins, 1968; see review by Hearst & Jenkins, 1974) refers to the acquisition of behavior (e.g., keypecking) directed at a localized signal of appetitive reinforcement, even though the behavior is not required for delivery of the reinforcer. The additivity theory suggests that positive contrast will be most prominent when the measured operant response has to be directed at the localized area on which the discriminative stimuli appear. Consequently, contrast should be absent or much less pronounced when the discriminative stimuli are located away from the manipulandum, or are diffuse ("nonlocalized") in nature. This theory might account for why positive contrast is so much

harder to obtain reliably in rats than in pigeons (Schwartz & Gamzu, in press); the stimuli used for rats in a Skinner box are usually diffuse and rarely appear directly on the response mechanism.

The experiments described in the above articles (see also Keller, 1974; Schwartz, 1974, 1975) generally support these predictions about effects of varying the location and diffuseness of differential signals for operant behavior. In this report, we summarize two studies that were based on essentially the same kind of reasoning as that underlying the additivity theory (see Hearst & Jenkins, 1974, pp. 34-37). We began the studies 4 years ago, unaware of the fact that very similar research was in progress in other labs; our experiments may now be best regarded as a series of systematic extensions or replications of already published studies. However, some comparison treatments not included in prior studies were examined here, and the kind of pretraining (S^+ -only or equalization) given before discrimination learning was manipulated.

GENERAL METHOD

Subjects

Experimentally naive female White Carneaux pigeons, 5-6 years old and maintained at 75% of their free-feeding weights, were used.

Apparatus

Two standard Lehigh Valley Electronics test chambers served as the experimental spaces. Only the center key was used. Situational details (e.g., houselight or keylight intensities and locations, the intensities and frequencies of auditory signals, etc.) were initially equated as closely as possible between the two chambers by means of a photometer, sound level meter, and oscilloscope and were rechecked periodically during the experiments. Different stimuli [a white field bisected by a thin black line, either vertical (0 deg) or tilted 30 deg clockwise] could be projected on the key by means of a miniprojector located directly behind it. A houselight (28 V dc; No. 1820X bulb), mounted in the center of the ceiling, projected white light through a translucent 13-cm square panel situated beneath the light; the intensity of the houselight could be changed by means of variable resistors. A loudspeaker, positioned 10 cm to the left

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Table 1
Mean Baseline S^+ Response Rate, Percentage Change in S^+ Response Rate During Discrimination Training, and Terminal Discrimination Level for the Three Groups in Experiment I

Experimental Group	Terminal VI Response Rate (Resp/Min)	Terminal Percentage Change During Discrimination	Terminal Discrimination Index
ON-KEY (Line Tilt)	36.6 (42.0)	+163.3 (+117.8)	.10 (.07)
OFF-KEY (Houselight)	37.5 (41.1)	+48.1 (+35.8)	.18 (.16)
OFF-KEY (Click)	37.4	+40.6	.72

Note—Values in parentheses are from the subjects in the pilot study.

of the grain aperture, was the source of auditory (click) discriminative stimuli in Experiment I and continuous low-level white noise in Experiment II. A 3-sec opportunity to eat from the lighted grain magazine served as the reinforcing stimulus.

Procedure

Experimental sessions were scheduled 7 days a week. On the first day of each experiment, subjects were trained to approach and eat from the grain magazine. Over the next 2 days, they were first manually shaped to peck the key and then given 30 continuous reinforcements (CRF) per day. The stimulus conditions that were to accompany variable interval (VI) reinforcement in the next phase of the experiment were present during shaping and CRF. Details of subsequent treatment of the subjects will be given in the procedure section for each individual experiment.

EXPERIMENT I: S^+ -ONLY PRETRAINING

The amount of positive behavioral contrast that develops during discrimination learning is generally evaluated with respect to a baseline of reinforced operant responding established before the start of discrimination training. Two such baselines have been employed in prior research: (a) single-stimulus pretraining, in which only the S^+ of the forthcoming discrimination is presented and responses are rewarded according to some intermittent schedule of reinforcement, or (b) equalization pretraining, in which both the S^+ and S^- of the forthcoming discrimination are presented and responses to each are rewarded according to the same intermittent schedule of reinforcement. We employed the first of these baselines in Experiment I, whereas equalization pretraining was given in Experiment II.

The specific line-tilt (on-key) and houselight (off-key) stimuli used as differential signals in Experiments I and II were selected on the basis of pilot studies performed to yield discriminations that would be of approximately equal difficulty. In addition to these two groups, we included a third group that was supposed to learn a discrimination ("off-key") between two frequencies of a clicking sound (not tested previously in pilot studies). Although discrimination learning in this latter group was poor, its data are valuable for comparison to

the two groups that actually learned their discriminations. For example, such factors as changes in the overall pattern of food deliveries from pretraining to "discrimination learning," or mere continued exposure to VI schedules of reinforcement—which could themselves affect responding to S^+ —were the same in the clicker group as in the line tilt and houselight groups.

Procedure

Eighteen pigeons served in this experiment. After shaping and CRF, all birds received S^+ -only training for 10 sessions. Each session consisted of 60 30-sec trials, during which the S^+ condition of the forthcoming discrimination phase was presented; these trials alternated with 10-sec blackouts. During trials, a 1-min VI schedule was in effect. Every trial involved three environmental changes: the presentation of a vertical line on the key, the presentation of the houselight at an intermediate intensity (0.80 fc, measured with the photometer placed on the floor of the chamber), and the presentation of a clicking sound (approximately 141 pps). After this phase of the experiment had been completed, the subjects were divided into three main groups ($n = 6$) for subsequent discrimination training. Groups were matched as closely as possible on the basis of VI response rates over the final three sessions of pretraining.

During discrimination training, the stimuli present on positive trials were the same as previously for all subjects and 1-min VI remained in force. However, a different set of conditions prevailed for each of the three groups during S^- , when keypecking was never reinforced. For the ON-KEY (line tilt) groups, S^- trials involved presentation of a 30-deg tilted line on the key, with the houselight intensity and the click rate remaining the same as on S^+ trials; for the OFF-KEY (houselight) group, S^- trials involved presentation of a low-intensity (0.25 fc) houselight, with the line tilt on the key and the click rate remaining the same as on S^+ trials; for the OFF-KEY (click) group, S^- trials involved presentation of clicks at a slow rate (approximately 0.7 pps), with the line tilt on the key and the houselight intensity remaining the same as on S^+ trials. There were 30 S^+ and 30 S^- trials daily, each 30 sec long with intervening 10-sec blackouts. Presentations of S^+ and S^- were scheduled in a mixed order, with the restriction that neither stimulus could occur on more than three consecutive trials. All subjects remained on their respective discrimination procedures for 15 sessions.

In the pilot experiments on which the above choice of line-tilt and houselight-intensity values was based, the experimental procedures were the same as above for the ON-KEY (line tilt) and OFF-KEY (houselight) groups ($n = 3$ in each), except that an 80-dB noise (instead of clicks) accompanied all trials and the subjects received " S^+ -only" pretraining for 14 sessions (instead of 10 sessions). Because the procedural differences between the pilot work and Experiment I were so small, we will mention relevant results from the pilot work in the discussion of the findings.

Results and Discussion

Table 1 presents a summary of the results obtained in this experiment. Indicated in the table are the mean VI response rates for each group calculated over the last three sessions of pretraining, the mean percent change in S^+ response rate (compared to each subject's VI baseline) over the last 5 days of discrimination training, and the mean discrimination index (Total S^- responses/Total S^+ responses) achieved over the last 5 days of discrimination training. There were six subjects in the houselight and click groups of Table 1 for Experiment I and five subjects in the line tilt group (because of an apparatus failure, one subject in the latter

group received no reinforcement during either S^+ or S^- on the third day of discrimination training and its data were excluded from analysis of results). For the findings of the pilot study, given in parentheses in the table, there were three subjects in each group.

As predicted by the additivity theory, keypecking rates in S^+ during the discrimination phase of Experiment I were highest for the group that had the discriminative stimuli located directly on the response key. There was no overlap in percent-change scores between subjects in the line tilt group and subjects in both the other groups ($U_s = 0$, $p_s = .004$, two-tailed Mann-Whitney test). The houselight and click groups did not differ significantly on this measure ($U = 15$, $p = .70$). In the pilot study, percent-change scores for individual subjects in the line tilt group were all higher than for subjects in the houselight group.

Differences in terminal discrimination indices for the line tilt and houselight groups were not statistically significant ($U = 6$, $p = .13$). The click group, however, did considerably worse than the other two groups in learning its discrimination; only one subject in the click group achieved a terminal index (.20) that fell within the range of scores of the 11 subjects in the other two groups. For that individual subject, the mean percent increase in S^+ response rate over the last five sessions of discrimination training was only 34.5%, well below that of any subject in the ON-KEY group (in which the lowest individual value was +97.4% in Experiment I and +79.1% in the pilot study).

Therefore, even though the ON-KEY and OFF-KEY (houselight) groups reached approximately equal levels of discriminative performance, response rate to S^+ increased much more in the ON-KEY group during the discrimination phase. The increase in S^+ rate for the two off-key groups during the discrimination phase was approximately the same, despite the fact that their discriminative performance was quite different. Their increase of 40%-50% may, in part, reflect the general increase in VI responding that normally occurs when subjects are exposed to a VI schedule for many sessions (e.g., Gonzalez & Champlin, 1974; Sadowsky, 1973), or it may be partially due to effects of the change in the patterning of food deliveries that took place between pretraining and discrimination sessions.

EXPERIMENT II: EQUALIZATION PRETRAINING

Experiment II served as a systematic replication of Experiment I and added a new group for comparison to the two main discrimination groups. The same line tilt and houselight discriminations as in Experiment I had to be mastered during the discrimination phase of Experiment II, but pretraining involved presentation of both S^+ and S^- , with equivalent reinforcement for responses to each. In addition, we included a comparison group that received no S^- s at all during the "discrimination" phase; in this group, blackouts were substituted

for every S^- in the discrimination groups. Such a group would permit evaluation of the possibly separate effects of (a) discrimination training vs. (b) changes in the patterning of food delivery (e.g., lengthening of the average time between S^+ presentations), which occur when the subjects in most experiments on behavioral contrast are transferred from initial baseline determination to a discrimination procedure.

Procedure

Eighteen new pigeons served in this experiment. After manual shaping and CRF in the presence of alternations of the two stimulus conditions to be used during the next phase, all subjects received 60 daily 30-sec trials, 30 of one stimulus condition and 30 of the other. These different trials occurred in a mixed order and were separated by 10-sec blackouts. For half the subjects, trials consisted of the presentation of different line tilts on the key (0 deg or 30 deg), with the houselight at an intermediate intensity. For the other half of the subjects, different intensities of the houselight (intermediate and low, as in Experiment I) occurred on the two kinds of trials, with the 0-deg line present on the key. Keypecks were reinforced on a 1-min VI schedule during both kinds of trials for all subjects. This equalization phase lasted 10 sessions.

Then 12 subjects received discrimination training on either the ON-KEY (line tilt; $n = 6$) or OFF-KEY (houselight; $n = 6$) procedure of Experiment I. The other 6 subjects (half previously given equalization training with different line tilts and half with different houselight intensities) received a treatment analogous to the other two groups, except that blackouts of 30 sec were substituted for every S^- in the other groups. Thus, these "extended blackout" subjects received blackouts of 10 sec or 40 sec between S^+ trials.

Results and Discussion

Table 2 presents group results for three different performance measures: (a) mean VI response rates to the forthcoming S^+ calculated over the last three sessions of the equalization phase; (b) the mean percent change in response rate to S^+ (compared to each subject's terminal VI rate to that stimulus during equalization) over Sessions 6-10 and 16-20 of discrimination training; and (c) the mean discrimination index achieved over Sessions 6-10 and 16-20 of discrimination training. All the groups began the experiment with six subjects, but experimenter errors on Day 11 of discrimination training decreased the subsequent number in the house-

Table 2
Mean Baseline S^+ Response Rate, Percentage Change in S^+ Response Rate During Discrimination Training, and Discrimination Levels for the Three Groups in Experiment II

Experimental Group	Terminal VI Response Rate (Resp/Min)	Percentage Change		Discrimination Index	
		Days 6-10	Days 16-20	Days 6-10	Days 16-20
ON-KEY (Line Tilt)	28.2	+130.2	+155.7	.16	.04
OFF-KEY (Houselight)	37.1	+40.7	+55.7	.37	.28
Extended Blackout	31.7	+88.7	+103.4		

light and extended blackout groups to five each. Thus the data presented for Sessions 6-10 include all 18 subjects, whereas only 16 subjects are considered in the results for Sessions 16-20.

As in Experiment I, response rates to S^+ during discrimination training were highest for the group that had discriminative stimuli located directly on the key. This result held for Sessions 6-10 as well as Sessions 16-20. However, due mainly to one anomalous subject (whose overall percent change in S^+ response rate during discrimination learning was much lower than that of any of the other 23 on-key subjects in our experiments, including the work mentioned in Footnote 1), the difference in mean percent change between line tilt and houselight groups during discrimination learning was not significant in this experiment (Sessions 6-10: $U = 8$, $p = .13$; Sessions 16-20: $U = 9$, $p = .33$). Observation of this anomalous subject during Session 14 of discrimination training revealed that it had developed what was apparently a superstitious chain of behavior (placing its head near the loudspeaker, then pecking the key, then returning to the loudspeaker, etc.), which may account for its reduced keypecking rate. If this subject is excluded from the statistical computations, then the difference in percent change in S^+ response rate between the houselight and line tilt groups is significant ($U = 2$, $p = .018$) for Sessions 6-10, although insignificant ($U = 5$, $p = .15$) for Sessions 16-20.

The mean percent change in S^+ response rate in the line tilt group was considerably higher but did not differ significantly from the mean change in the extended blackout group, even when the anomalous subject was excluded (Sessions 6-10: $U = 5$, $p = .08$; Sessions 16-20: $U = 9$, $p = .55$). However, the extended blackout group showed a significantly greater percent increase than did the houselight group (Sessions 6-10: $U = 5$, $p = .04$; Sessions 16-20: $U = 0$, $p = .008$). Thus, mere substitution of nonresponse (blackout) periods for S^- periods led to more of an increase in S^+ response rate than did learning the off-key discrimination. This finding seems to suggest, as did Experiment I and Taus and Hearst's (1970) results, that part of the increase in S^+ responding which is generally included in assessment of the magnitude of behavioral contrast may be due to changes in the patterning of reinforcement deliveries, e.g., the lengthening of the average time between S^+ periods that occurs on most discrimination procedures when S^- periods are inserted. Hearst and Jenkins (1974, pp. 36-37; see also p. 43) pointed out that such facilitation of responding on positive trials would be predicted by results in autoshaping experiments, since lengthening of the intertrial interval produces a facilitation of autoshaped behavior. Therefore, the extended-blackout results provide more support for the additivity (autoshaping) theory of contrast.

Relevant to this point is the possibility that the significantly lower S^+ rates in the OFF-KEY group than

in the extended blackout group during the discrimination phase resulted from a tendency of the off-key subjects to look toward or to move toward the source of the discriminative stimuli, the houselight panel. Such orientation and approach behavior could have interfere with pecking at the response key. Unfortunately, we did not obtain enough observations of subjects in that situation to evaluate this possibility.

In Experiment II, the line tilt discrimination proved easier to learn than the houselight discrimination—an outcome that somewhat reduces the impact of any differences in S^+ response rate between the groups in Experiment II. Differences between the groups in mean discrimination indices were significant during Sessions 6-10 ($U = 3$, $p = .016$) and marginally significant during Sessions 16-20 ($U = 4$, $p = .052$). This difference in discriminative difficulty, not significantly present in Experiment I and the pilot work, may be due to differential effects of equalization pretraining on the subjects' attention to on-key vs. off-key stimuli. In any event, if the additivity theory of contrast is essentially correct, it should be very hard to meaningfully equate the "discriminability" of pairs of on-key and off-key discriminative stimuli when a response directed at the key provides the measure of performance.

GENERAL DISCUSSION

These experiments¹ indicate that signal location affects the amount of increase in S^+ response rate which is produced when subjects are shifted from nondifferential (VI) training to a discrimination procedure. When signals for reinforcement and nonreinforcement of keypecking are located directly on the response key, increases in S^+ response rate are greater than when the signals are "diffuse" or located elsewhere in the experimental chamber. For example, terminal performance of 16 of the 24 on-key subjects during the discrimination phase of our experiments (including the work mentioned in Footnote 1) displayed more than a 100% increase in S^+ response rate compared to baseline levels, whereas none of the 41 off-key subjects showed an increase of as much as 100%. These results support the findings of other workers, discussed above and summarized in Schwartz and Gamzu (in press), who have concluded that positive behavioral contrast in operant conditioning is strongly dependent on a close correspondence between signal location and operant-response target. Therefore, the additivity (autoshaping) theory of behavioral contrast handles our general findings well.

However, in accordance with Schwartz and Gamzu's (in press) conclusions, our opinion is that the additivity theory cannot explain all cases of response-rate increase that have been labeled "behavioral contrast" by previous researchers. We did observe consistent increases in S^+ response rate during discrimination training in most of our off-key groups. Furthermore, published experi-

ments (see Schwartz & Gamzu's summary), as well as unpublished research from our own laboratory, have occasionally provided convincing evidence of positive contrast in situations involving auditory discriminations in pigeons (even when the operant response is not directed at a specific target; see Hearst & Jenkins, 1974, p. 43) and in arrangements with rats in which diffuse auditory or visual stimuli provide the discriminative cues. The generally smaller but reliable response-rate increases in these other situations are difficult for additivity theory to explain without additional assumptions—unless one can demonstrate that the physical proximity of the sound source to the manipulandum, or the specific effect of changes in houselight intensity, e.g., on the brightness of the manipulandum, are crucial factors.

It seems time to discard the prevalent view that "behavioral contrast" is a basic or unitary phenomenon of operant discrimination learning. Some researchers would (a) apply the term to response rate increases occurring when blackouts are inserted between periods of reinforcement (i.e., an arrangement in which no discrimination learning is presumably involved; cf. effects in Experiment II above), or (b) subdivide contrast effects into two perhaps independent types (local or transient vs. sustained), or (c) consider operant schedule-contrast effects in the same general category as incentive-shift effects of the Crespi variety, or (d) wonder whether positive and negative contrast in operant conditioning are fundamentally different phenomena, or (e) ask how different the amount of "contrast" is on mixed vs. multiple schedules, or (f) argue that contrast effects on multiple schedules are intrinsically different from those on concurrent schedules. Apparently the term "behavioral contrast" has been used to refer to a conglomeration of related but possibly separate effects (cf. Mackintosh, 1974). If "contrast" were not viewed as a unitary phenomenon, more analytical experiments might be performed to determine how these different effects arise and interact, and experimenters might be reluctant to lump them all together under the same label.

Several researchers (Gonzalez & Champlin, 1974; Hearst, 1971; Sadowsky, 1973) have already pointed out that, in many studies of behavioral contrast within the free-operant paradigm (including the present experiments), specific control groups or procedures are not included to assess the amount of increase in VI responding that would have occurred if the subjects had merely been left on the baseline procedure indefinitely; these writers argued that baseline stability has not been convincingly achieved before the start of discrimination training in many experiments. Evidence in the present research from subjects not learning their respective discriminations supports this possibility, since these subjects exhibited reliable rate increases during S^+ . Furthermore, even when some method for evaluating progressive baseline shifts is included in the design of a given study, another interpretive problem remains

that is less often considered: increases in response rate after the initiation of reinforcement during S^+ and extinction during S^- might occur not as a direct result of the mixture of S^+ and S^- trials ("discrimination training"), but because of ensuing changes in the patterning of food deliveries compared to the baseline phase. Future comparisons of mixed- and multiple-schedule procedures following baseline determinations might be valuable in assessing the influence of actual learning of a discrimination between S^+ and S^- (cf. Jenkins, 1965; Pear & Wilkie, 1970), as was the comparison of houselight vs. click OFF-KEY groups for Experiment I—in which the former group learned its discrimination well and the latter did not.

The additivity theory of behavioral contrast, which received good support in the present experiments, is based on the idea that effects of stimulus-reinforcer ("Pavlovian") contingencies instituted during discrimination training combine with effects of already established response-reinforcer ("operant") contingencies to account for changes in S^+ response rate. However, stimulus-reinforcer contingencies exist even before explicit discrimination training is initiated (cf. Hearst & Jenkins, 1974). During manual shaping and baseline determinations, the subject receives food only when it stands in close proximity to the manipulandum and receives visual and tactile stimulation from the manipulandum. Because localizable cues that are positively correlated with appetitive reinforcement usually evoke approach and contact behavior (e.g., a pigeon's consummatory-like keypecking), it seems very likely that stimulus-reinforcer correlations are controlling directed behavior even before the discrimination phase of a standard contrast experiment begins. In other words, both stimulus-reinforcer and response-reinforcer correlations are probably affecting the subject's behavior throughout the entire experiment; the introduction of explicit discrimination training after the baseline phase apparently makes certain manipulandum cues even more informative with regard to presentation of the reinforcer than they were previously.

Thus we prefer to conceptualize the basic notion behind additivity theory in a somewhat different way from that expressed by Rachlin (1973), Schwartz & Gamzu (in press), and others. They imply that response-reinforcer correlations alone control baseline performance and that stimulus-reinforcer correlations become important only after explicit discrimination training is begun. We would stress the constant interaction between and changes in these two types of correlation that occur *throughout* experiments on behavioral contrast. The increase in the positive correlation between a manipulandum cue (S^+) and food seems likely to provide the main cause of the *increased* responding during operant discrimination training that is often labeled behavioral contrast, since the explicit response-reinforcer correlation is *lowered* during discrimination phases (the overall frequency of reinforcement for responding is decreased).

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NOTE

1. In another experiment, not reported in detail here mainly because many subjects in the off-key groups did not master their discrimination, we attempted to employ the same dimension (color) as a basis for discrimination learning in both the on-key and the off-key groups. Ten subjects that had red and green discriminative stimuli located on the response key learned the discrimination well and showed a mean increase of 118.8% in S^+ response rate during Sessions 6-10 of discrimination training, as compared to a prior (equalization) phase. Of 20 subjects that had the colors projected off-key, either on the houselight panel ($n = 10$) or on a jeweled lamp located near the upper left-hand corner of the front wall ($n = 10$), only four subjects showed good discriminative performance (discrimination indices for these subjects ranged from .29 to .49 over Sessions 6-10). Their changes in S^+ response rate during discrimination training ranged from -50.8% to +5.0%. These subjects often looked at and moved toward the off-key signals; such behavior presumably competed with keypecking so as to affect response outputs. Using on-key and off-key color discriminations, Redford and Perkins (1974) reached the same general conclusions that we reached in Experiments I and II with line tilt and houselight intensity discriminations. Redford and Perkins' work with color discriminations was more successful and convincing than our research with colors because the final levels of discriminative performance in their experiment were similar for subjects in the on-key and off-key groups.

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