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DETERMINANTS OF CONTRAST IN THE SIGNAL-KEY PROCEDURE: EVIDENCE AGAINST ADDITIVITY THEORY

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Two experiments are reported that challenge the interpretation of previous results with the signal-key procedure, in which the discriminative stimuli are located on a response key different from the key associated with the operant response requirement. Experiment 1 replicated the procedure of Keller (1974), and found that contrast effects on the operant key occurred reliably for only one of four subjects. High rates to the signal key initially occurred for only one subject, but modifications of the procedure produced substantial rates to the signal key for all subjects. In all cases, however, signal-key behavior was greatly reduced by the addition of a changeover delay which prevented reinforcement within 2 seconds of the last peck to the signal key, suggesting that signal-key pecking was maintained primarily by adventitious reinforcement. Experiment 2 modified the signal-key procedure by using three response keys, so that the discriminative stimuli on the signal key controlled different responses during all phases of training. With this modification, reliable contrast effects on the operant key occurred for all subjects, suggesting that the failure to find contrast in previous studies has been due to the confounding of changes in the discrimination requirements with changes in relative rate of reinforcement. The results challenge the additivity theory of contrast, and suggest that "elicited" behavior plays a minor role, if any, in the determination of contrast effects in multiple schedules.

Key words: signal-key procedure, additivity theory, multiple schedules, behavioral contrast, key peck, pigeons

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A major influence on theories of behavioral contrast was the development of the "signal-key" procedure by Keller (1974). With this procedure the response requirements for both components of a multiple schedule are associated with one response key that has a constant stimulus, whereas the discriminative stimuli for the two components are located on a second response key, which has no response requirement. Its rationale was derived from Catania's (1971) notion of "topographical tagging", on the assumption that behavior controlled by the response contingency will occur on the "operant" key, whereas that elicited by the discriminative properties of the stimulus will occur to the signal key.

Two aspects of the results with the signal-key procedure have been of major interest. First, contrast effects generally do not occur when "operant pecks" are considered in isolation. Second, the change from nondifferential reinforcement to differential reinforcement (e.g., mult VI 1-min VI 1-min to mult VI 1-min EXT) results in the development in responding to the signal key. These two effects together have led to the additivity theory of contrast (cf. Rachlin, 1973; Schwartz & Gamzu, 1977), which claims that the increase in responding in the usual contrast procedure, where the discriminative stimuli are located on the response manipulandum, is due to the addition of elicited pecks to the operant baseline.

Additivity theory is now recognized not to be capable of accounting for all instances of behavioral contrast, as there have been numerous demonstrations of contrast in situations in which the discriminative stimuli were located away from the response manipulandum (e.g., Bradshaw, Szabadi, & Bevan, 1978; Gutman, Sutterer, & Brush, 1975). However, it still is believed to account for the major segment of contrast effects in multiple schedules, with the implication that previous attempts to relate interactions in multiple schedules to interactions in concurrent schedules (Herrnstein, 1970) are incorrect. The further implication is that relative rate of reinforcement, which previously had been regarded as the major controlling

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variable (Lander & Irwin, 1968; Nevin, 1974), does not apply directly to operant behavior in multiple schedules, but has its effects via Pavlovian contingencies with respect to the discriminative stimuli.

The present paper provides data that challenge both empirical generalizations that have come from signal-key procedures. Not only do we show that contrast does occur with respect to operant behavior using the signal-key procedure, we also show that a significant portion of behavior to the signal key itself is controlled by operant contingencies, not by Pavlovian contingencies. Moreover, the data make a strong case that the signal-key procedure is fundamentally flawed as a method for determining the dynamics of operant behavior, because many of the results seen with the procedure may be due to confounding effects of changes in the unit of responding.

Table 1 presents a summary of the results of previous studies that have used the signal-key procedure. Their results are presented in tabular form to highlight the fact that previous results have been quite variable, so that the two empirical generalizations presented above are oversimplifications. With respect to the behavior to the operant key, it is apparent that contrast does occur in a significant number of cases. Moreover, the most frequent result of a contrast manipulation is not to leave responding to the operant key unaffected, but rather to *reduce* operant-key responding. Why some studies show contrast and some negative induction is uncertain, but the variable results provide little support for the notion that behavior controlled by the operant contingencies is independent of that controlled by the stimulus contingencies. The reasons why such independence should not be expected will be considered further in the introduction for Experiment 2.

Of primary relevance to Experiment 1 are the results shown on the right side of Table 1 for behavior to the signal key. Although a significant number of subjects have failed to show signal-key pecking, this number may be misleading because there are several reports of pecking directed toward the signal that do not break the key contacts for automatic recording. Moreover, the rates of signal-key pecking typically are much higher than can be gleaned from Table 1, with response rates typically 15 to 20 responses/min. In general, the occurrence of signal-key pecking is a robust phenomenon that occurs in most studies.

Of major interest from Table 1 is the different pattern of results for the last two studies that are listed. These used a change-over-delay (COD), where reinforcement was prevented within some minimum delay after the last signal-key peck. Schwartz, Hamilton, and Silberberg (1975) first suggested the importance of this control condition because of the possibility of adventitious reinforcement of signal-key pecking by operant-key reinforcement, (e.g. when the birds alternate rapidly between the keys). Schwartz et al. used a 2-sec COD; White

Table 1

Summary of findings of previous studies using the signal-key procedure. The entries represent the number of subjects showing each effect. Contrast and negative induction were defined as a minimum of a 10% change from the baseline level. When two baselines were run, the average of the two values was used. When several different schedules were used in the variable component, the two most extreme schedule values were used for the comparison.

		Operant Key			*Signal Key (Responses/Minute)*		
Authors	*Number of Subjects*	*Contrast*	*No Effect*	*Negative Induction*	*5 or more*	*1 to 5*	*0 to 1*
Keller (1974) Exp. 1	3	0	0	3	2	1	0
Exp. 2	3	0	0	3	3	0	0
Schwartz (1975)	4	0	4	0	4	0	0
Spealman (1976) Exp. 3	6	0	2	4	5	1	0
Bouzas (1976)	6	3	1	2	1	0	5
Schwartz (1978)	4	4	0	0	4	0	0
Spealman, Katz, & Witkins (1978)	2	0	1	1	2	0	0
Woodruff (1979)	8	3	0	5	8	0	0
Schwartz, Hamilton & Silberberg (1975)	4	2	1	1	0	1	3
White & Braunstein (1979)	6	1	2	3	1	3	2
Totals	46	13	11	22	30	6	10

and Braunstein (1979) used a 1-sec COD. Although all of the subjects in both studies showed at least some amount of signal-key pecking (even those in the 0 to 1 column), it is nevertheless apparent that considerably less signal-key behavior occurred for these two studies, suggesting that adventitious "operant" reinforcement is a major reason that signal-key pecking is maintained. Unfortunately, this conclusion can be questioned because neither study determined whether more signal-key behavior would occur in the absence of the COD. It is possible, therefore, that the failure to find signal-key behavior was due to some procedural feature other than the COD.

The only study that explicitly assessed the effects of a COD was Spealman (1976). He presented a 1-sec COD for ten sessions after a lengthy period of training without a COD. Responses to the signal key were reduced for 5 of 6 subjects, but Spealman discounted the role of adventitious reinforcement because substantial signal-key behavior still remained. This conclusion is questionable, however, because the 1-sec COD may not be long enough to prevent adventitious reinforcement (especially if the animal is responding with bursts to the operant key) and because 10 sessions may not have been sufficient for the full effects of the COD to be evident.

The present study provides a direct assessment of the effects of a COD on signal-key pecking. Pigeons were presented a procedure similar to the original study of Keller (1974), first without a COD, and then a COD was added. As will be seen, the addition of the COD had substantial effects on behavior.

EXPERIMENT 1

Method

Subjects

Four experimentally naive White Carneaux pigeons were maintained at 80% of their free-feeding body weights by additional feeding, when necessary, after the end of the experimental sessions.

Apparatus

A standard operant chamber was constructed by attaching a clear Plexiglas cube to a three-key intelligence panel (Gerbrands model #G7113). The size of the cube was 30.5 cm in all dimensions. The interior chamber was then enclosed in a larger wood box with a ventilating fan for insulation. The three keys of the front panel were approximately 1.6 cm in diameter and were spaced 5.3 cm apart, edge to edge. Approximately 10 cm below the middle key was the opening to the food hopper, which was illuminated with white light by two 28-V dc bulbs when food was available. Each key required a minimum force of .10 N for the contact to be broken for the recording of a response. There was no auditory feedback. Mounted in the left rear corner of the interior chamber was a single 28-V dc unshielded light bulb which served as the houselight at all times during an experimental session.

Procedure

On the first day the subjects were trained to eat from the food magazine by leaving it up until eating occurred for the first time and then by presenting progressively shorter hopper durations until the 2.5-sec duration that was used for the remainder of the study. On the next two days, the subjects were hand-shaped to peck the left key of the chamber, which was illuminated with white light, and which was to serve as the operant key for the remainder of the experiment. During this training the center key was not illuminated.

All subjects were then placed on a two-component multiple schedule in which independent VI 30-sec schedules operated in the two components. Reinforcers that were scheduled but not obtained by the end of a component were held over to its next presentation. The left key was always white, whereas the other key alternated between red and green. The response requirement for both components was associated with the left key, whereas responding to the center key had no scheduled effect. Components alternated every 60 sec and sessions terminated after 30 min (15 complete cycles).

A total of 25 baseline sessions with equal VI schedules in the two components were conducted. The schedule during green was then changed to EXT for 30 sessions. Then, the mult VI EXT schedule was continued for either 10 or 15 sessions (depending on the subject) in which a 2-sec COD was imposed for signal-key pecking. With the COD, reinforcement on the operant key could not occur within 2 sec of the last peck on the signal key.

The subjects were then returned to the mult VI 30 VI 30-sec baseline condition with the COD removed. After 20 sessions with the procedure of the initial baseline, response feedback was added for all pecks, regardless of whether they were to the operant key or to the signal key. This feedback consisted of a 100-msec interruption of both keylights, which produced a blinking effect. This feedback was continued for the remainder of the experiment. It had no apparent effect, however, and will not be discussed further.

After a total of 30 sessions to the second baseline condition, the schedule during green was again changed to EXT and the multiple VI EXT schedule was continued for 20 sessions, without the COD being used.

Because several of the subjects developed only a small amount of signal-key pecking during the first four conditions of the study, a second series of conditions was undertaken with several procedural changes designed to produce more signal-key pecking. The VI component of the mult VI EXT was changed to a variable-time (VT) schedule, with all reinforcers delivered independently of responding. All other aspects of the procedure remained the same. This training continued for 20 sessions, at which time the operant key (left key) was turned off, so that only the signal key was illuminated (with red still correlated with VT and green with EXT). After 15 additional sessions without the operant key, it was again illuminated and 20 additional sessions were conducted.

The final experimental manipulation was the addition of the 2-sec COD for signal-key pecking. Reinforcers that were scheduled by the VT schedule were held until a 2-sec period had elapsed without a response to the signal key. Responses on the operant key had no scheduled effect. Training continued on the mult VT EXT schedule with the COD in effect for 25 sessions, followed by 20 sessions with the COD removed.

Results

Response-dependent schedules. Figure 1 shows the results for the first series of conditions in which either a mult VI VI or a mult VI EXT was presented. The circles show the rates of responding to the operant key during each of the two components. The triangles show response rates to the signal key during the red

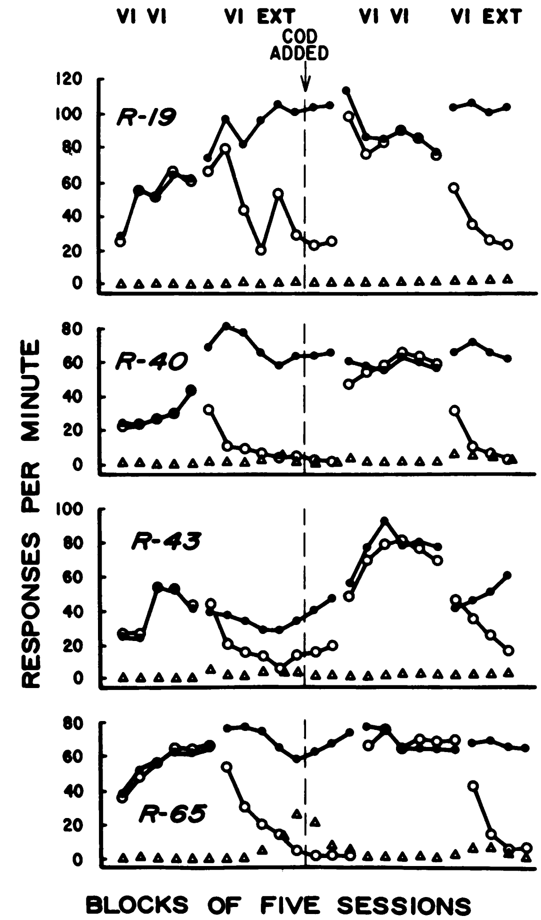

Fig. 1. Result for individual subjects for response-dependent schedules in Experiment 1. The circles show responding to the operant key (filled circles for unchanged component, unfilled circles for variable component), and the triangles show responding to the signal key. The dashed line in the center of the graph shows the point at which the COD was added.

component only, which was always associated with the VI schedule. Some signal-key pecking did occur during the green component as well, but it was minimal and easily could be interpreted as generalization from the red component.

First considering operant-key responding, considerable intersubject variability is evident from Figure 1, as one subject (R-19) showed a clear contrast effect during both exposures to the mult VI EXT, whereas a second subject (R-43) showed a clear negative induction effect during both exposures. The remaining two subjects both showed an increase in operant responding above that seen in the first baseline condition, but for both subjects the initial increase was followed by a decrease, which appeared to be associated with the development of pecking to the signal-key. This is seen most clearly for Subject R-65, where an inverse relation between signal-key pecking and operant-key pecking became more evident when the COD contingency was introduced (indicated by the dashed line). The COD greatly reduced signal-key pecking for that subject, and operant-key pecking for that subject increased once again. The result was that the terminal level of operant-key pecking with the COD in effect was above the final level of the first baseline condition, although the difference was not large. The second exposure to the mult VI EXT schedule (fourth panel) produced a still smaller effect, best seen in Table 2, which summarizes the response rates during the last five sessions of each condition shown in Figure 1.

Behavior to the signal key was also quite variable across subjects. Only one subject (R-65) developed any significant pecking to the signal key (shown by the triangles just to the left of the dashed line), although all subjects did respond at least somewhat to the signal key, as shown by Table 2. Moreover, it can be seen from Table 2 that the occurrence of signal-key pecking was due to the differential reinforcement in the two components of the schedule, as no subject exhibited such pecking during the first baseline condition, and all subjects once again decreased their rate of pecking to the signal key when the baseline condition was reinstated.

Of primary interest was the effect of the COD contingency. This is most evident from the comparison of columns 2 and 3 of Table 2, where it is seen that all subjects reduced their

Table 2

Response rates during the last five sessions of each of the conditions shown in Figure 1. Rates on the operant key are shown first. Rates on the signal key are presented in parentheses.

Subject	*VI VI*	*VI EXT*	*COD Added VI EXT*	*VI VI*	*VI EXT*
R-19	61.6	100.8	105.1	76.2	103.2
	(0.0)	(0.8)	(0.5)	(0.0)	(1.2)
R-40	43.6	62.1	64.2	56.7	60.5
	(0.0)	(1.6)	(0.6)	(0.5)	(1.5)
R-43	40.6	33.6	47.2	76.7	59.7
	(0.0)	(3.0)	(0.2)	(0.0)	(1.5)
R-65	62.3	58.5	73.3	64.6	64.1
	(0.0)	(25.8)	(3.9)	(1.9)	(0.9)

rate of pecking to the signal key after the COD was imposed. The significance of this effect is equivocal, however, as only one subject had any substantial amount of signal-key pecking even without the COD (R-65), and it never resumed such pecking upon the second exposure to the mult VI EXT when the COD was not in effect. It should be emphasized, nevertheless, that the signal-key behavior that did occur was greatly reduced during the fifteen sessions in which the COD was in effect.

Response-independent schedules. The response rates during the VT component of the mult VT EXT schedule are shown in Figure 2. The first condition shown there came immediately after the last condition shown in Figure 1, where a mult VI EXT schedule was used. The change to response-independent reinforcement had variable effects across subjects. Two subjects (R-19 and R-40) continued to respond to the operant key, with little responding to the signal key, in much the same way as they had with the response-dependent schedules. A third subject (R-43) responded progressively less on the operant key as training continued, but this was not accompanied by an increase in responding to the signal key. The remaining subject (R-65) not only decreased its responding to the operant key, but also increased its responding to the signal key. It should be noted that this was the one subject that exhibited considerable signal-key pecking when the VI schedule was in effect.

Because it seemed possible that the failure of signal-key pecking to develop was due to competition from responding to the operant key, the procedure was changed to eliminate such competition by turning off the operant key altogether. The second segment of Figure 2 shows the results. Subject R-19 immediately began responding to the signal key with a high rate, despite little responding to the signal key previously. For Subject R-40, substantial pecking to the signal key developed over sessions. In contrast, Subject R-43 continued to respond with low rates to the signal. The remaining subject, R-65, which had already developed high rates to the signal key, exhibited an initial decrease in signal-key pecking which then recovered.

The third segment shows the results when the "operant" key was once again illuminated (the same conditions as in the first segment). The results were generally more consistent, as

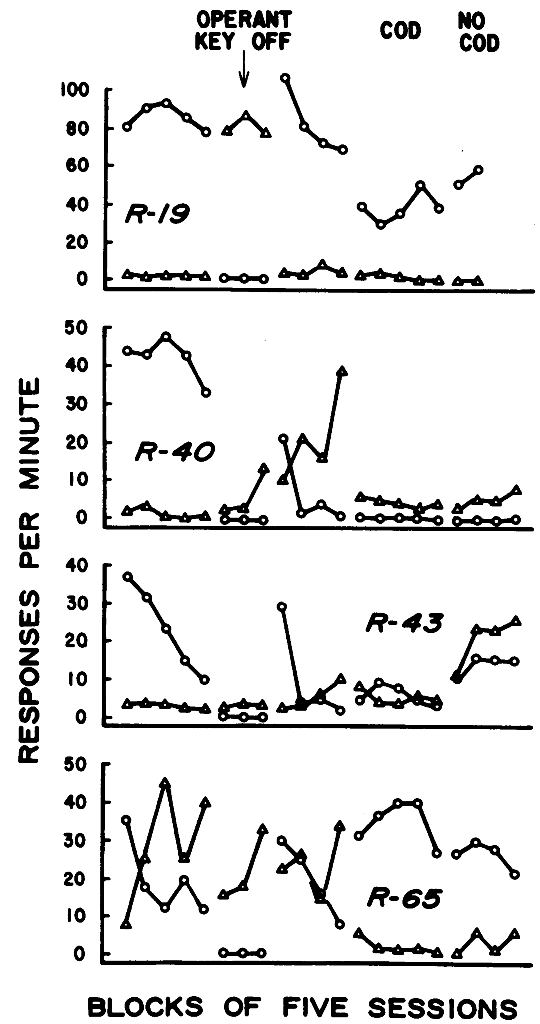

Fig. 2. Results for individual subjects for response-independent schedules in Experiment 1. Only the results for the VT component of the mult VT EXT are shown. The circles show responding to the operant key. The triangles show the responding to the signal key.

three of the subjects had developed substantial signal-key behavior by the end of training on this condition, whereas their behavior to the operant key had been reduced to generally low levels. The remaining bird (R-19) returned to a behavior pattern similar to that in panel 1, with high rates to the operant key and low rates to the signal key, despite the immediately preceding training in which high rates occurred to the signal key.

The fourth segment of Figure 2 shows the results of adding the 2-sec COD to the multiple VT EXT schedule. It is evident that responses to the signal key were substantially reduced for all subjects. The fifth segment shows the effect of removing the COD; response rates to the signal once again increased for three of the four subjects. The effects of the COD occurred despite little change in the obtained rate of reinforcement, which was never reduced more than 5% per session. The magnitude of the effect of the COD is most clearly seen in Table 3, which shows the signal-key rates during the last 5 sessions of each of the three conditions (segments 3, 4, and 5 of Figure 2).

The subjects were observed during the period of training shown in the fourth segment of Figure 2, to determine what behavior, if any, replaced signal-key pecking when the COD was introduced. All subjects were seen to direct pecking toward the signal key, sometimes to the panel of the side of the signal key, but more often with "air pecks" that made no contact. Apparently, therefore, the primary effect of the COD was to change the location of the pecking behavior, not necessarily its frequency.

A final observation from Figure 2 is the inverse relation between signal-key pecking and operant-key pecking that occurred for Subject R-65. Prior to the use of the COD its operant-key behavior had been reduced to a low level as signal-key pecking increased, but then once again returned when signal-key pecking was reduced by the COD (fourth segment). Finally, the operant-key behavior was again reduced when the signal-key behavior partially resumed after the COD was removed (fifth segment).

Discussion

The results show that signal-key pecking was substantially reduced by imposing a delay between such pecking and the reinforcer. The results are consistent with two previous studies

Table 3

Response rates on the signal key as a function of the presence or absence of the COD requirement. The data are taken from the last five sessions prior to the addition of the COD, the last five sessions of the training period with the COD, and the last five sessions of the training period following the removal of the COD (corresponding to Panels 3, 4, and 5 of Figure 2). Throughout all training the schedule was multiple VT 30-sec EXT.

Subject	*No COD*	*COD*	*No COD*
R-19	3.8	0.5	0.5
R-40	39.1	4.3	8.8
R-43	10.1	4.7	26.1
R-65	33.6	0.6	6.6

that used a COD in a signal-key procedure (Schwartz et al., 1975; White & Braunstein, 1979), where very low rates of signal-key responding were also found. The results also challenge the conclusions drawn from a third study using a COD (Spealman, 1976), in which substantial signal-key pecking still occurred after the COD was introduced. The most likely reason for the high rates in that study is that the COD was only 1 sec in duration and was used for a short period of training.

The results argue against the stimulus-reinforcer contingency as the sole determinant of signal-key pecking. Since the procedural effect of the COD is to increase the temporal distance between pecks to the signal key and the reinforcer, the response-reinforcer relation must also play a role. Moreover, the importance of the response-reinforcer relation is emphasized by a feature of previous signal-key procedures (and of studies with response-independent reinforcement: e.g., Gamzu & Schwartz, 1973) that is seldom noted. Almost all such studies have used reinforcement schedules with frequencies of reinforcement (e.g. VI 30-sec) far greater than generally used to study behavioral contrast. In fact such high frequencies are less likely to produce contrast in the typical procedure than are lower frequencies (Reynolds, 1963; Spealman & Gollub, 1974). High rates of reinforcement obviously increase the likelihood that a signal-key peck will be followed adventitiously by a reinforcer. Whether such high rates are actually necessary to maintain behavior to the signal key is uncertain.

Although we believe the best interpretation of the COD effects is in terms of eliminating adventitious reinforcement of signal-key pecking, this interpretation can be challenged by the observations taken after the COD was introduced, where all subjects were found to continue a high level of pecking directed toward the signal, but these pecks no longer made contact with the key surface. A possible interpretation is that the signal-reinforcer contingency continued to exert a powerful elicited effect on pecking, whereas the effect of the COD response contingency was solely to direct the location of those pecks (cf. Staddon & Simmelhag, 1971). We have no way of excluding this explanation, although it should be noted that air pecks, etc., could have been controlled by adventitious reinforcement in the same way as was the location of pecking. The latter interpretation has the advantage of parsimony, as it requires that only one mechanism be invoked for the control of both the frequency and location of the pecking behavior.

But an explanation in terms of adventitious reinforcement is itself challenged by the finding that signal-key pecking is eliminated when differential reinforcement in the two components is returned to nondifferential reinforcement (cf. Gamzu & Schwartz, 1973). Since such changes in the stimulus contingency should not alter the temporal relation between the response and reinforcer, an interpretation in terms of adventitious reinforcement would seem to require that signal-key pecking, once initiated, would be maintained even without a differential stimulus-reinforcer contingency.

But such an objection may be less serious than it first appears, if it is recognized that sequences of activity involving orientation to the signal key have differential probabilities of reinforcement depending upon the operant schedule in the two components. This can be seen by considering the implicit contingency for attention to the signal key when differential reinforcement is in effect, but not otherwise. With nondifferential reinforcement there is no reason why the animal should orient toward the signal key, and such orientation should suffer the effects of response cost because it interferes with the operant-key pecking that produces the reinforcer. But with differential reinforcement, orientation to the signal key is necessary if nonreinforced pecking to the operant key is to be eliminated. Thus, sequences of behavior involving orientation to the signal key will be differentially reinforced relative to response sequences consisting only of pecks to the operant key itself. When this implicit contingency is removed upon the return to nondifferential reinforcement (mult VI VI), it should then not be surprising that orientation (and pecking) to the signal key should also disappear.

Even if it were true that the stimulus-reinforcer contingency, per se, played a critical role in maintaining signal-key pecking, it is important to recognize that the present results show that the stimulus contingency is not the sole determinant of such pecking. This recognition challenges the interpretation of previous signal-key studies (e.g. Schwartz, 1975), where the similarity between the amount of signal-key pecking to the magnitude of contrast effects in one-key multiple schedules has been taken as strong evidence that contrast is due entirely to the stimulus-reinforcer contingency. The present results provide evidence against this interpretation, both in terms of the effects of the COD, and in terms of the inverse relation between signal-key pecking and operant-key pecking that was noted in several instances (e.g., Subject R-65). The implication is that signal-key pecking is not independent either of the operant contingencies or of the degree of operant-key pecking itself. Consequently, the motivation behind the signal-key procedure—the functional separation of the two types of behavior—has been severely compromised.

EXPERIMENT 2

Experiment 2 addresses the second main finding from the signal-key procedure—that contrast does not occur when the operant key is considered in isolation. Such a generalization is already suspect, as shown by the frequent occurrence of contrast in the studies listed in Table 1, and the occurrence of contrast for some of the subjects in Experiment 1. But the argument that will be supported here is stronger than the fact that contrast occasionally does occur. It is instead that the signal-key procedure is inherently flawed as a method of assessing "operant" contrast, because it is confounded by changes in the type of behavior that is measured.

What is meant by changes in the type of behavior can be understood by considering how responses during the baseline condition of the signal-key procedure differ from those during the contrast manipulation with differential reinforcement. During the baseline the animal may completely ignore the stimulus on the signal key because it contains no information, i.e., the schedule is the same regardless of the stimulus that is present. The most likely behavior is to orient only to the operant key. But with differential reinforcement, stimulus control by the signal key occurs, so the animal's orientation should switch back and forth between the operant and signal keys. In other words, during the baseline the animal may look straight ahead and peck the operant key, whereas during the contrast manipulation it will alternate such pecking with looking at the signal key. Given that looking at the signal key should interfere with operant-key pecking, it should not be surprising that the increase in responding on the operant key that is expected from the contrast manipulation is less likely to occur.[1]

The preceding example is a specific instance of a common misunderstanding involved in most recent studies of contrast in which the discriminative stimuli are located off the response manipulandum. Such studies have the implicit assumption that the unit of behavior is simply the contact of the pigeon's beak with the key, per se. An alternative view is that the definition of the response unit must include the entire three-term contingency. Accordingly, comparisons between different rates of responding produced by different experimental conditions are meaningful only to the extent that stimulus control remains the same over the various conditions. Otherwise the different rates of responding may only reflect incommensurate response units. This is likely to be a severe problem for off-key discrimination procedures, because the source of stimulus control is changed from being entirely on the response key (when nondifferential reinforcement is in effect) to elsewhere in the chamber, with the possible results that the pattern of pecking will also be changed. And because the nature of such changes will depend upon the characteristics of the particular experimental chambers, it should not be surprising that the outcome of off-key discrimination procedures have been quite variable, some showing contrast, some no effect, and some negative induction.

It is possible to overcome the problem of changing response units by insuring that control by the signal-key stimulus occurs during all of the conditions of the experiment. To accomplish this, Experiment 2 used a three-key procedure in which the discriminative stimuli for the two components of a multiple schedule were located on the center key, which was not associated with the operant response requirement. During the first stimulus, responding to the left key was reinforced and responding to the right key was nonreinforced; during the

[1]A similar argument has been made by Madden and Menlove (Note 1), who pointed out that the signal-key procedure involves different stimulus processing requirements in the baseline and experimental conditions. Those authors also reported the results of a three-key procedure similar to that used here.

second stimulus, responding to the right key was reinforced and responding to the left key was nonreinforced. By use of such a procedure stimulus control by the signal key is insured during the baseline phase of the experiment, so that changes in relative rate of reinforcement during the contrast phase of the study do not result in changes in the stimulus control relation. At issue is whether reliable contrast occurs with this version of the signal-key procedure.

METHOD

Subjects and Apparatus

Four White Carneaux pigeons were maintained at 80% of their free-feeding body weights by additional feeding, when necessary, after the end of the experimental sessions. All had extensive experimental histories, including previous training with one-key multiple schedules. The apparatus was identical to Experiment 1, with the modification that all three response keys were now illuminated.

Procedure

Because of the previous experience of the subjects, they were immediately exposed to the multiple schedule that was used for the first part of the study. A two-component schedule was presented, in which all three response keys were illuminated. During Component One, both side keys were white and the center key was red, and pecks to the left key were reinforced on a VI 3-min schedule. Pecks to the center or right side key had no scheduled consequences. During Component Two, the side keys remained white, the center key was green, and pecks to the right key were reinforced on a VI 3-min schedule. Again pecks to the remaining two keys had no scheduled consequences. The two components alternated regularly with a component duration of 1 min. Sessions terminated after 90 min.

After 30 sessions with the mult VI 3 VI 3, the schedule associated with the green center key was changed to EXT for 25 sessions. Then the mult VI 3 VI 3 was returned for 25 additional sessions, followed by 25 more sessions in which the schedule associated with green was again returned to EXT. Finally, the schedule associated with green was changed for 15 sessions to VI 1 min. Throughout all of the conditions the schedule associated with the red center key was always VI 3 min for left-key pecks.

RESULTS

Table 4 shows the results for the last five sessions of each condition for the behavior during the constant VI 3 min components (with red as the signal) for both the operant and signal keys. With respect to the operant key, contrast did occur for all four subjects, as response rates were lower when VI 3 or VI 1 was associated with the variable component than when EXT was the variable schedule. The effects were reversible across the two replications of the mult VI 3 VI 3 and mult VI 3 EXT conditions, although there was some variability in the size of the effects. For one subject (R-4) the effects were quite small, but were also reversible. The remaining three subjects had rate increases of 30 to 90%, depending upon the particular subject and the baseline condition used for comparison.

Only one subject (B-4) developed any significant amount of pecking to the signal key, as it responded to the signal key with a rate similar to its rate on the operant key. Despite this high rate to the signal key, however, B-4 also exhibited a reliable contrast effect on the operant key. It should be noted that no COD was used, so that the role of the response-reinforcer relation in maintaining the signal-key responding is unknown. Observation of the subject suggested that adventitious reinforcement was involved because the subject's behavior consisted primarily of alternation between the two response keys. It also should be noted, however, that signal-key pecking occurred only during

Table 4

Response rates during the last five sessions of each condition of Experiment 2. Only the behavior during the constant VI 3-min component is shown, presented separately for behavior to the operant key and signal key.

		Schedule in Variable Component				
Subject		*VI 3*	*EXT*	*VI 3*	*EXT*	*VI 1*
R-3	Operant	30.4	50.8	37.9	45.7	34.8
	Signal	0	0	0	0	0
R-4	Operant	27.1	29.0	23.1	26.9	23.7
	Signal	0.1	0.6	0.1	0.1	0.0
R-7	Operant	25.7	39.1	33.8	50.9	31.8
	Signal	0.0	0.0	0.0	0.2	0.1
B-4	Operant	13.9	24.7	22.3	27.7	13.4
	Signal	0.1	22.5	1.1	29.7	1.4
Mean	Operant	24.3	35.9	29.3	37.8	25.9
	Signal	0.0	5.8	0.3	7.5	0.4

the mult VI 3 EXT conditions, and quickly disappeared during the mult VI 3 VI 3 condition, showing that differential reinforcement was a critical variable. Also, signal-key pecking did not develop during the mult VI 3 VI 1 condition, for either component, indicating that differential reinforcement was not always a sufficient condition.

Figure 3 shows the responses to both the left and right operant keys throughout the period of training. Of major interest is the relation between the acquisition of stimulus control and the occurrence of contrast for left-key responding during the unchanged component. Although stimulus control was generally stable by the end of the first baseline, the first change to the mult VI EXT (Panel 2) disrupted stimulus control to some degree, as all subjects increased their rate of left-key responding during the green stimulus (incorrect pecks) when reinforcement for right-key pecks was removed during green. This incorrect responding to the left key then substantially decreased, but remained at a moderate level for some subjects. A similar pattern occurred during the second exposure to mult VI EXT (Panel 4), but there the increase in left-key responding was substantially less and the amount of such responding reached near zero level by the end of that phase of training.

An important observation from Figure 3 is the degree of right-key responding during red (incorrect right-key pecks). To the extent such responding occurred during the baseline conditions and then disappeared during mult VI EXT, the contrast effect with respect to left-key responding becomes difficult to interpret. Namely, the increase in correct left-key responding could be a reflection of an increase in the time available for such responding, after right-key incorrect responding was eliminated. For example, for Subject B-4, the rate of incorrect right-key responding was 8.6 responses/min during the last five sessions of the first baseline, and this behavior was completely eliminated during subsequent exposure to mult VI EXT. Since the increase in left-key responding (from 13.9 to 24.7) was of a similar magnitude, the contrast effect could be due simply to the decrease in competition from right-key responding. Such competition did occur to some degree, as shown by all subjects at the beginning of mult VI 3 VI 1 (fifth panel), where there occurred a transitory decrease in left-key responding that was correlated with the resurgence of incorrect right-key responding.

Although the role of response competition complicates the present analysis, it clearly is not sufficient to explain the full range of contrast effects. Only Subject B-4 had any substantial amount of incorrect right-key responding, so that the size of the contrast effects with respect to left-key responding was always considerably larger than the corresponding changes in right-key responding. Excluding Subject B-4 (which was also unusual because of its considerable signal-key pecking), the average rate of incorrect right-key responding was 2.5 responses/min in the first baseline condition (last five sessions) and 1.2 responses/min in the second baseline, whereas as shown in Table 4, the average size of the corresponding contrast effects was 11.9 and 9.6 responses/min. Similarly, the average increase in incorrect right-key responding with the change to mult VI 3 VI 1 was 2.1 responses/min, whereas the average size of the decrease in left-key responding (negative contrast) was 11.1 responses/min.

DISCUSSION

The results shown in Table 4 leave little doubt that contrast does occur reliably in a procedure in which the discriminative stimuli are presented off the response manipulanda. The results thus support the contention that the failure to find operant-key contrast in other signal-key studies has been due to the confounding of changes in stimulus control with the dynamic effects of varying relative rate of reinforcement. As discussed in the introduction to Experiment 2, such confounding should work against the demonstration of contrast, because the development of stimulus control for the first time during the contrast phase should generally lower the rate of responding.

The present emphasis on changes in stimulus control has important implications for understanding several results that have been obtained previously with signal-key procedures, several of which have been considered of theoretical importance. For example, Schwartz (1975) presented data showing that positive contrast was not a reliable effect with the signal-key procedure, whereas negative contrast was a reliable effect. He then concluded that the two types of contrast must be functionally

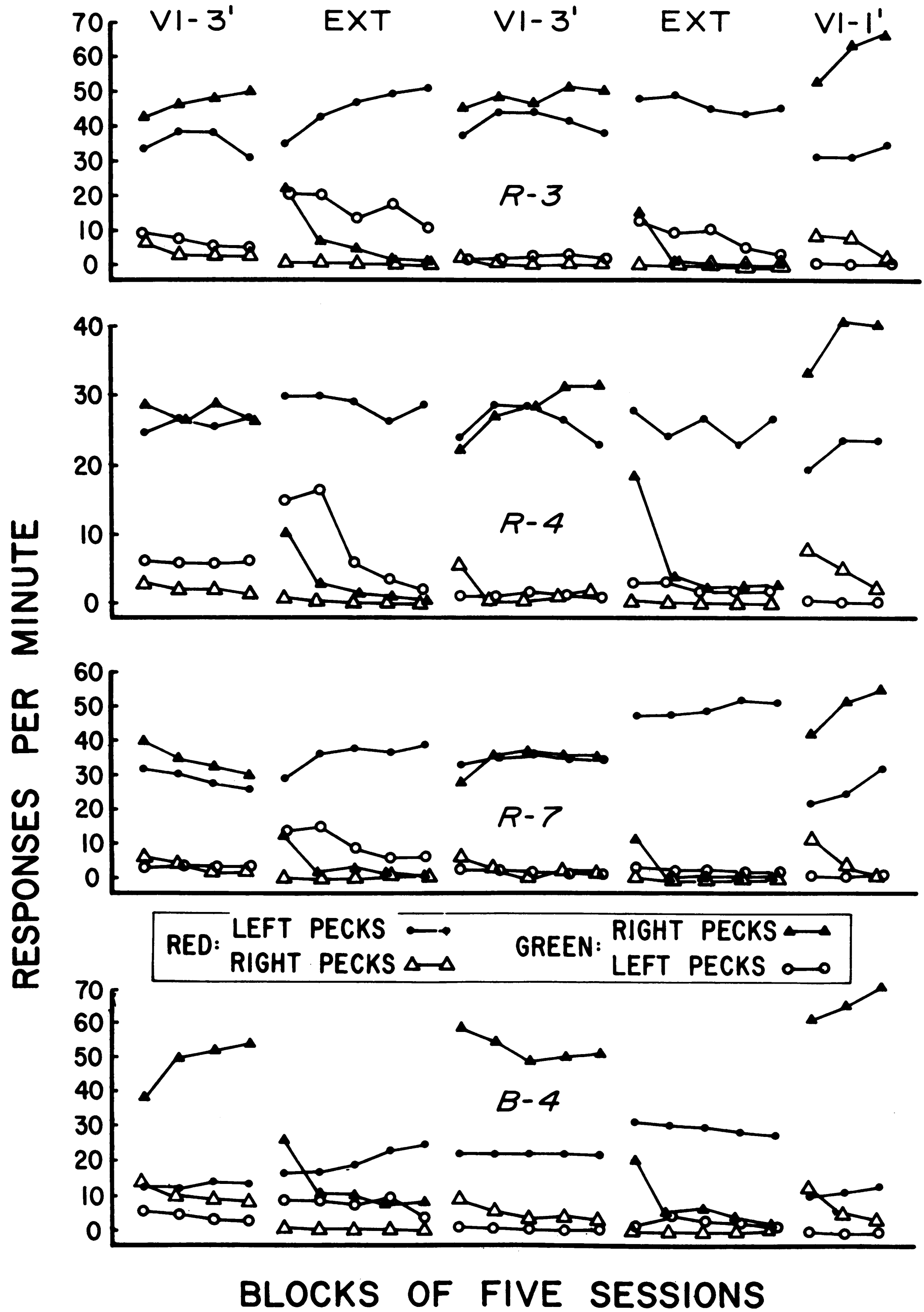

Fig. 3. Results for individual subjects for all conditions in Experiment 2. The schedule designation at the top of each segment shows the schedule in effect for pecks to the right key during the green stimulus. The schedule for pecks to the left key, during red, was always VI 3-min. Unfilled symbols represent pecks that were always incorrect.

separate. The differences found by Schwartz are in fact to be expected on the basis of the present formulation. We have argued that the use of nondifferential reinforcement in a signal-key multiple schedule produces higher response rates than the use of differential reinforcement because the unit of behavior is more efficient (i.e., pecks on the operant key are not interrupted by looking at the signal key). Thus, when a baseline schedule with nondifferential reinforcement is changed to a contrast manipulation with differential reinforcement, the results should be a general decrease in the measured rate of responding, independent of other variables that might also change the rate. With a positive contrast procedure, this decrease in rate will work against the demonstration of contrast, whereas with a negative contrast procedure it will work in favor of the demonstration.

The present formulation also makes a more exact prediction that is supported by Schwartz's (1975) data. Namely, negative contrast should occur when the experimental manipulation is a change from nondifferential to differential reinforcement, but should be less likely when the manipulation is a change from differential to nondifferential reinforcement. His study reported the effects of two separate manipulations designed to show negative contrast: mult VI 3-min VI 3-min changed to mult VI 3-min VI 72-sec, and mult VI 3-min VI 72-sec changed to mult VI 72-sec VI 72-sec. His results were that the first of these did produce reliable negative contrast, whereas the second manipulation did not.

The present conception is also pertinent to the effects of varying component duration with a signal-key procedure. The magnitude of contrast in the standard procedure is inversely related to component duration (Shimp & Wheatley, 1971; Williams, in press), and with short components (e.g., 10 sec) the relative rate of responding matches the relative rate of reinforcement (cf. Killeen, 1972). Using the signal-key procedure, Spealman (1976) and Schwartz (1978) interpreted these general effects to result from changes in the degree of elicited responding. That is, shorter components had no consistent effect on the response rates to the operant key, but increased rates to the signal key in the component with the higher density of reinforcement. Given the central importance of component-duration effects in understanding contrast, these results have been taken as strong evidence for additivity-theory interpretation.

But the increase in responding to the signal key with short components need not be interpreted as increases in the number of elicited pecks. This is true because implicit contingencies created by the signal-key procedure are altered by changes in component duration. The subject can determine the schedule in operation only by attending to the signal-key, and the uncertainty regarding the schedule is greater the more frequently the schedules alternate. Thus, the operant contingency itself should increase the frequency of signal-key orientation with shorter components, so that the baseline pattern of behavior is also changed. Consequently, the rate of pecking the operant key should be reduced by using shorter components, because there is greater competition from orientation responses to the signal. Similarly, the likelihood of signal-key pecking should increase, because the increase in frequency of orientation to the signal key should increase the opportunities for adventitious reinforcement for signal-key pecking.

The preceding account is post hoc, but is supported empirically by the results of Bouzas (1976; also described by de Villiers, 1977). He first used 60-sec components with a signal-key procedure, and found that several (but not all) subjects exhibited contrast on the operant key, but with little responding to the signal key. Notably, the one subject that exhibited negative induction to the operant key also had a high rate of signal-key pecking. He then shortened the component duration to 10 sec and found that all subjects then exhibited negative induction on the operant key, but this effect was now accompanied by the development of considerable behavior to the signal key. Such a pattern would be predicted by the account just given.

In summary, the present study is consistent with a growing number of studies (e.g. Guttman et al., 1975; Williams, 1979) showing that additivity theory cannot provide a complete account of contrast interactions in multiple schedules. The present results go beyond previous findings, however, by suggesting that the mechanism implied by additivity theory need not be involved, in any way, in steady-state interactions, because the major evidence in favor of additivity theory cannot be taken at face value. The implication is that an account of schedule interactions may yet be possible that is sufficiently general to encompass a variety of schedule situations. Whether such an account will be based on the concept of relative rate of reinforcement (e.g. Herrnstein, 1970; Lander & Irwin, 1968; Nevin, 1974), or whether it will involve some other variable, remains to be determined.

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