

ESCAPE FROM SERIAL STIMULI LEADING TO FOOD

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If the functional relations governing the strength of a conditioned reinforcer correspond to those obtained with other Pavlovian procedures (e.g., Kaplan, 1984), the termination of stimuli appearing early in the interval between successive food deliveries should be reinforcing. During initial training we presented four key colors, followed by food, in a recurrent sequence to each of 6 pigeons. This established a baseline level of autoshaped pecking. In later sessions, we terminated each of these colors or only the first color for a brief period following each peck, replacing the original color with a standard substitute to avoid darkening the key. Pecking decreased in the presence of the last color in the sequence but increased in the presence of the first. In accord with contemporary models of Pavlovian conditioning, these and other data suggest that the behavioral effects of stimuli in a chain may be better understood in terms of what each stimulus predicts, as measured by relative time to the terminal reinforcer, than in the exclusively positive terms of the traditional formulation (Skinner, 1938). The same model may also account for the initial pause under fixed-interval and fixed-ratio schedules of reinforcement.

Key words: chaining model, sequence of stimuli, chain stimuli, relative time model, negative reinforcer, aversive stimulus, serial autoshaping, initial pause, key pecking, pigeons

At a fairly general and abstract level, the present study is an attempt to test one implication of the correspondence that has repeatedly been noted between the principles found to be operating in relatively simple Pavlovian experiments and those determining the efficacy of initially neutral stimuli as conditioned reinforcers. At a more immediate level, our work was instigated by the possibility that the relationships demonstrated most clearly in a sign-tracking experiment by Kaplan (1984) might provide an appropriate conceptual framework for understanding the reinforcing properties of the stimuli that link members of a behavioral chain.

Ever since Skinner (1938) and Hull (1943) promulgated systematic accounts of behavior, a widely accepted interpretation of conditioned reinforcement has been the very broad generalization that stimuli gain their power to

reinforce behavior in the same way they gain their power to elicit behavior, that is, in terms of the principles of Pavlovian conditioning (e.g., Dinsmoor, 1983, 1985; Gollub, 1977; Kelleher, 1966; Kelleher & Gollub, 1962; Rashotte, 1981). The functional relationships are assumed to be isomorphic. The difference between the two cases lies in the nature of the behavioral effect that is examined in each type of experiment.

Within this context, a particularly provocative test is suggested by studies showing that stimuli presented in a temporal relationship in which they function as negative predictors of food or shock acquire, correspondingly, a negative influence on the usual conditional response. In salivary conditioning or conditioned suppression, for example, when the conditional stimulus (CS) precedes the unconditional stimulus (US) by a period of time that is, on the average, relatively long—thereby signaling its absence—that CS reduces the normal response when presented in conjunction with a positive CS. The same CS is also slow to acquire the ability to function as a positive CS when subsequently presented in a more favorable temporal relationship to the US. (For reviews, see LoLordo & Fairless, 1985; Rescorla, 1969b.) Following Pavlov (1927), such a stimulus is described as “inhibitory.”

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A precedent for expecting a similar reversal of direction for conditioned reinforcers may be found in research on their negative counterparts, conditioned aversive stimuli. In experiments on avoidance and on preference for signaled shock, stimuli that regularly appear early in the interval before the receipt of shock, thus predicting a period of freedom or safety from that stimulus, do not become aversive; on the contrary, they become positive conditioned reinforcers, sometimes known as "safety signals." (See, for example, Abbott, 1985; Badia & Culbertson, 1972; Dinsmoor, Flint, Smith, & Viemeister, 1969; Dinsmoor & Sears, 1973; Rescorla, 1969a; Weisman & Litner, 1969.)

The experiment that directly instigated the present work was a study of sign tracking conducted by Kaplan (1984). In a typical sign-tracking experiment (e.g., Wasserman, Franklin, & Hearst, 1974), the position of the pigeon in the left or the right half of the conditioning chamber is monitored by means of a tilting floor. Lighting of either the left or the right key, in an unpredictable sequence, serves as the CS. Using that procedure, Kaplan found that when the illumination of a key (CS) preceded the delivery of grain (US) by only a short time, relative to the total time between deliveries, the bird tended to move to the same side of the chamber. Acquisition of this form of behavior was classified in Pavlovian language as "excitatory conditioning." But when the lighting of the key preceded the delivery of grain by a somewhat longer time, the bird tended to move to the other half of the chamber. For reasons discussed in detail in Kaplan's paper, the acquisition of this form of behavior has conventionally been treated as an example of "inhibitory conditioning." Most obviously, the direction of the bird's movement was away from rather than toward the lighted key.

If the principles governing the acquisition of reinforcing properties by a previously ineffective stimulus are the same as those describing the results when salivation, conditioned suppression, conditioned aversive properties, and sign tracking are monitored, then it should be possible to demonstrate an equivalent reversal in the direction of the effect: Stimuli that characteristically precede the reinforcer by a short period of time become positive conditioned reinforcers, but stimuli that com-

monly precede food, for example, by a long period of time should take on a function opposite in its mathematical sign to that normally acquired. That is, they should become negatively reinforcing. Unfortunately, the term "negative reinforcer" is ambiguous, as it has been used for stimuli that reduce the frequency of the response that produces them (e.g., Skinner, 1938) as well as for stimuli that increase the frequency of the response that terminates them. We will therefore use the term "aversive," as defined by the observation that their termination is a reinforcing event.

In his work, Kaplan (1984) used a trace conditioning procedure, holding the time between food deliveries constant from group to group and systematically varying the temporal placement within that interval of the period when the key was lighted. In our work, we substituted a serial procedure, which may not be wholly comparable to that used by Kaplan but which allowed us to test the effects of several different temporal placements on the behavior of the same subject during the same session. In our basic routine, we repeatedly presented a sequence of colors on the key, followed in each case by access to grain. In what might be described as an inverse observing procedure, each of the original colors could be turned off (rather than on) for a brief period of time and—to avoid any special effects of a darkened key—replaced by a different color. The same replacement color was used with each of the colors originally presented. If the parallel with sign tracking and other Pavlovian-type experiments is valid, stimuli appearing early in the sequence should be negatively reinforcing, as evidenced by an increase in the rate of pecking in their presence.

It will readily be seen that the procedure we have employed, in which a series of colors appears on the key, followed by food, is very similar to the procedure known as a chained schedule (Ferster & Skinner, 1957), which is commonly used to study the role of stimuli in standardized behavioral sequences. All that is missing in our procedure is the response that is normally required to advance the subject from one stimulus to the next through the progression and ultimately to procure the food. The similarity is not adventitious. A major consideration in designing the present experiment was our desire to explore a conceptual model of the relationships within a behavioral

chain that would be more in keeping with contemporary theories of Pavlovian conditioning (e.g., Balsam, 1984; Jenkins, 1984; Rescorla, 1968, 1975) than was the one formulated in the early days of conditioning research by Skinner (1938). It should perhaps also be noted here that our model is very much in harmony with Fantino's delay-reduction hypothesis of conditioned reinforcement (e.g., Case & Fantino, 1981; Fantino, 1977).

According to Skinner's (1938) analysis, which was the first to deal effectively with the special characteristics of chains maintained by their consequences, the successive stimuli play two different roles: (a) As discriminative stimuli, they control the responding that occurs in their presence; (b) as conditioned reinforcers, they establish and maintain the responding that precedes and produces them. There is a considerable body of evidence to support these two basic propositions. (For reviews, see Fantino, 1977; Gollub, 1977; Kelleher, 1966; Kelleher & Gollub, 1962.) But the principles by which the chain stimuli become reinforcing have been left somewhat vague, with only broad references being made to the reinforcing value being derived either from their functions as discriminative stimuli or via temporal contiguity or correlation with other stimuli, later in the sequence. In many accounts, a process similar to higher-order conditioning is explicitly suggested or implied, in which each stimulus gains its effectiveness from its temporal relationship to the stimulus immediately following it, until some innately reinforcing event finally arrives.

There have been some problems also at the empirical level. Skinner's description of the chain mentions only positive functions of the successive stimuli, and it leaves one with the impression that behavior that constitutes part of a chain will always and inevitably be better supported by the positive discriminative stimuli and by the positively reinforcing effects of the subsequent changes in stimulation than behavior that occurs under equivalent circumstances outside of the chain. Some data from two-component chained schedules have been consistent with such a prediction, but in cases where more than two components were involved ("extended" chains), empirical studies have typically shown the rate of responding in the initial component to be *lower* than that under a tandem schedule, in which no changes

in stimulation were provided (Gollub, 1977). This finding has been obtained both with chained fixed-interval (Gollub, 1958; Kelleher & Fry, 1962; Thomas, 1967) and with chained fixed-ratio schedules (Jwaideh, 1973; Thomas, 1964). Often the deficiency in responding has been interpreted as showing that the second, or even the third, stimulus in the sequence is ineffective as a reinforcer.

Unfortunately for analytical purposes, the stimuli in a chained schedule act in a discriminative as well as in a reinforcing capacity, and it is difficult to disentangle the two functions (but see Tallen & Dinsmoor, 1969). An alternative explanation for the poor performance early in an extended chain is that the initial stimuli exercise a suppressive effect on the responding that occurs in their presence. We are not accustomed to thinking of discriminative stimuli as exercising suppressive effects on operant behavior. Early in his career, Skinner (1938, pp. 232ff.) rejected Pavlov's concept of inhibition, suggesting that the data could be explained more parsimoniously in terms of a reduction in excitation. But, in an experiment specifically designed to meet Skinner's objections, P. L. Brown and Jenkins (1967) showed that a tone that served in compound with an otherwise positive color as an S- for pecking one half of a split key (analogous to a Pavlovian conditioned inhibitor) also lowered the rate of pecking on the other half of the key when compounded with a different color that was positive for that half. In other words, there was a suppressive effect that traveled with the tone from one stimulus to another and from one locus of response to another. The reduction in pecking did not result from some alteration of the positive stimulus but from the presence of the negative stimulus. The concept of inhibition seems to be as valid for operant behavior as it is for respondents (see also Graham, 1943; Weiss & Schindler, 1985).

Although all of the stimuli in a chain except the final one are negative discriminative stimuli, according to the traditional definition that responding is not reinforced in their presence (Skinner, 1933, 1938), they differ in their temporal placement with respect to that primary reinforcer. In terms of their locus in time, some stimuli might be said to be more negative than others. (For similar relationships, in which the rate of responding seems to depend

on the temporal distance between the stimulus and the reinforcer rather than on the receipt or nonreceipt of the reinforcer, see Dews, 1962, 1966; Farmer & Schoenfeld, 1966; Segal, 1962.) However, this characterization is already stretching the definition of negative discriminative stimulus, both historically and as used in other contexts.

In Pavlovian conditioning, to be sure, it is well known that the effectiveness of the conditional stimulus (CS) is a function of the length of time by which it has characteristically preceded the unconditional stimulus (US), but this rule has not hitherto been applied to the discriminative control of operant behavior. If we accept such an extension, on a provisional basis, it becomes relatively easy to explain the poor performance at the beginning of a chain. Increasingly, in recent years, theorists studying Pavlovian conditioning have emphasized the prediction of the US by the CS, as expressed either by the correlation between the two stimuli or—using a different metric—by the temporal distance from CS to US, relative to the total time between two USs. (For proponents of a relative-time analysis, see Balsam, 1984; Brown, Hemmes, Coleman, Hassin, & Goldhammer, 1982; Gibbon & Balsam, 1981; Jenkins, 1984; Jenkins, Barnes, & Barrera, 1981; Jenkins & Shattuck, 1981.)

As mentioned earlier, under standard Pavlovian procedures stimuli that are negatively correlated or that precede the US by longer than average times are found to be inhibitory (LoLordo & Fairless, 1985; Rescorla, 1969b). In a chained schedule, the initial stimulus is in a peculiarly unfavorable locus in time. It, too, might be characterized as a negative predictor of the primary reinforcer. The time to food (or other primary reinforcer) when that stimulus is present is greater than in the presence of any other stimulus, including one that might accompany a tandem schedule, and it is therefore not surprising that the rate of responding is lower in its presence. In short, when the total array of data is considered, a predictive or relative-time model provides a better fit than does the purely incremental model formulated by Skinner (1938). In the present paper, we will offer additional support for a relative-time model by showing that the initial stimulus in a series like that used in a chained schedule is aversive to the sub-

ject—that the termination of such a stimulus is a reinforcing event.

METHOD

Subjects

Six retired White Carneaux breeding hens from the Palmetto Pigeon Plant, about 7 years of age, served as subjects. They were maintained at approximately 75% of their ad-lib weights by postsession feedings. Birds 3082 and 3168 had prior experience with feature-negative procedures (white square on green surround) in an autoshaping experiment; Birds 0002, 1224, 5668, and 5814 were experimentally naive. The parametric settings for individual subjects are presented in Table 1; the sequence of procedures is given in Table 2.

Apparatus

Experimental operations were conducted in a Lehigh Valley Electronics Model 1519 pigeon chamber that also included two crossbars ("perches") of local manufacture. The instrument panel was 35.0 cm wide and 35.4 cm high (from the mesh floor); the bird's working space extended back 27.5 cm to the rear wall. One of the original keys was covered with plastic tape. The other was mounted behind a circular opening 2.54 cm in diameter, centered 25.4 cm above the mesh floor and 11.1 cm to the left of the side wall (door). A peck of 0.20 N was required to operate the switch. Mounted behind this key was a Series 10 Industrial Electronics Engineers projection unit containing 12 IEE 1820X 28-V dc bulbs powered by Massey-Dickinson lamp driver modules. Two bulbs and their corresponding filters were made available for each of the five stimuli, in order to increase the intensity and the diffusion of the resulting displays. Two each of the following filters were used: Kodak Wratten 24 (red), Kodak Wratten 86 (green), Kodak Wratten .2 neutral density with white onionskin typing paper for diffusion (white), Roscolene 807 (yellow), and Roscolene 856 (blue). These filters were selected, on the basis of the hue boundaries described by Wright (1979), to be as distinctive as possible to the visual system of the pigeon.

The panel also included a shielded house-light with Type 757 (0.8A) bulb, centered 3.0

Table 1
Experimental parameters for individual subjects.

Bird	Key colors in successive periods					Duration in seconds		
	First	Second	Third	Fourth	Replace	Display	Delay	Hopper
3082	green	yellow	red	blue	white	1	3	3
3168	green	yellow	red	blue	white	5	3	3
0002	red	white	green	yellow	blue	5	4	4
1224	red	white	green	yellow	blue	5	4	4
5668	blue	green	yellow	white	red	1	2	5
5814	blue	green	yellow	white	red	1	2	5

cm from the top edge, and a rectangular opening 4.9 cm high by 6.0 cm wide, laterally centered with its lower edge 10.1 cm above the mesh floor, which gave the bird access to the hopper when grain was to be delivered. When raised to eating position, the hopper made an audible thump and was lighted by a concealed Type 757 bulb operated at 28 V dc. At such times, the houselight and keylight were extinguished.

Mounted side by side were two crossbars, parallel to and 4.5 cm out from the instrument panel and 2.8 cm above the mesh floor. Each crossbar was made of stainless steel tubing, 1.6 cm in outside diameter and 13.8 cm in length. They were separated by a gap of 0.4 cm and ended 3.9 cm from the side walls.

Downward forces of 0.5 N were required for closure of their respective pressure switches.

A 16-mm punched tape was used to control the basic temporal cycle; other details were determined by solid-state switching modules. Data were collected on running time meters and electromagnetic counters. The control and recording circuitry was housed in adjacent rooms. A blower attached to the experimental enclosure supplied both masking noise and ventilation.

Procedure

Experimental sessions were conducted at about the same time each day for a given bird and lasted 60 min. The same basic routine was used throughout the experiment, with

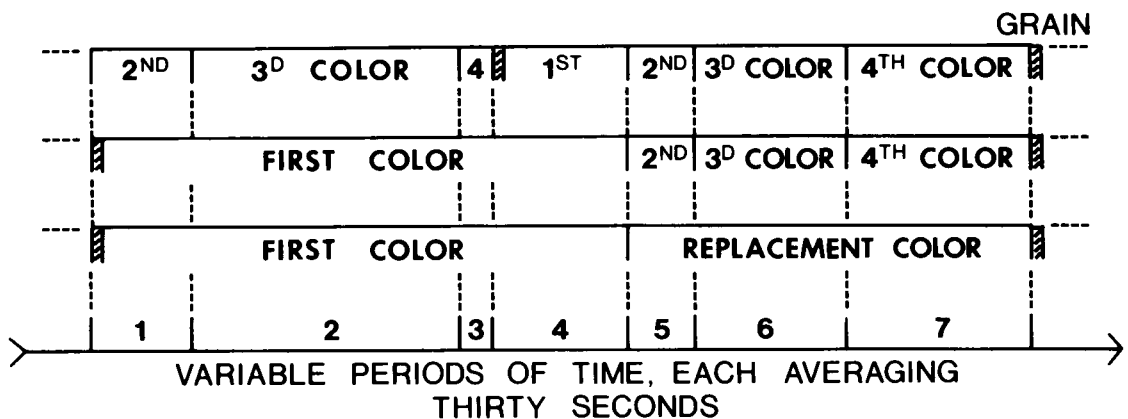


Fig. 1. Procedural diagram showing the three basic relations, used in different phases of the experiment, between the key colors and successive intervals of time. The set of intervals used for a given delivery of food was taken from a longer series punched into a programming tape. Over a number of repetitions, each interval averaged 30 s. For illustrative purposes, seven successive intervals are presented (see bottom line). Top line: During early sessions, grain (cross-hatching) was delivered after only four intervals, each accompanied by a different color. The last three intervals of one cycle and all four intervals of the next cycle are shown. Second line: Later, a seven-interval procedure was substituted, with the first color present throughout the first four intervals and different colors in each of the remaining intervals. Third line: As a special arrangement designed to clarify the role of the replacement stimulus (see text), the color used for that purpose was continuously present throughout Periods 5 through 7.

Table 2

Pecks per minute during each 30-s segment of interval between deliveries of food. Medians are shown from last 5 sessions in each block of 15, with mean deviations from those medians in parentheses.

Session block	Seg-ments in first comp.	No. of colors in series	Stimuli terminable	30-s segments						
				1	2	3	4	5	6	7
Bird 3082										
1	1	4	None	—	—	—	0.25 (0.12)	0.31 (0.14)	4.84 (0.70)	19.61 (4.23)
2	1	4	All	—	—	—	1.71 (0.41)	1.89 (0.21)	7.13 (0.61)	13.61 (2.64)
3	4	4	All	0.71 (0.12)	0.71 (0.12)	0.71 (0.12)	0.71 (0.12)	3.17 (0.46)	8.84 (0.61)	31.94 (3.40)
4	4	2	First	1.78 (0.36)	1.78 (0.36)	1.78 (0.36)	1.78 (0.36)	6.11 (1.05)	4.01 (0.88)	2.90 (0.91)
5	4	4	First	0.58 (0.27)	0.58 (0.27)	0.58 (0.27)	0.58 (0.27)	1.91 (0.79)	7.52 (1.99)	22.13 (5.48)
Bird 3168										
1	1	4	None	—	—	—	0.00 (0.05)	0.07 (0.08)	0.00 (0.05)	0.07 (0.06)
2	1	4	All	—	—	—	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.06 (0.03)
3	4	4	All	0.00 (0.01)	0.00 (0.01)	0.00 (0.01)	0.00 (0.01)	0.00 (0.00)	0.00 (0.00)	0.00 (0.07)
4	4	2	First	2.26 (0.38)	2.26 (0.38)	2.26 (0.38)	2.26 (0.38)	0.11 (0.06)	0.00 (0.00)	0.00 (0.05)
5	4	4	First	0.00 (0.02)	0.00 (0.02)	0.00 (0.02)	0.00 (0.02)	0.00 (0.00)	0.00 (0.00)	0.11 (0.13)
Bird 0002										
1	4	4	None	1.41 (0.69)	1.41 (0.69)	1.41 (0.69)	1.41 (0.69)	7.55 (3.99)	32.57 (3.88)	52.94 (4.58)
2	4	4	First	1.57 (0.26)	1.57 (0.26)	1.57 (0.26)	1.57 (0.26)	9.04 (2.54)	31.76 (4.55)	48.61 (3.30)
3	4	4	All	2.21 (0.73)	2.21 (0.73)	2.21 (0.73)	2.21 (0.73)	3.49 (1.56)	8.99 (2.19)	14.60 (1.66)
4	4	2	First	5.60 (1.80)	5.60 (1.80)	5.60 (1.80)	5.60 (1.80)	1.13 (0.29)	0.27 (0.18)	0.19 (0.30)
5	4	2	None	1.69 (0.84)	1.69 (0.84)	1.69 (0.84)	1.69 (0.84)	2.66 (0.61)	0.89 (0.74)	0.12 (0.24)
Bird 1224										
1	4	4	None	0.19 (0.09)	0.19 (0.09)	0.19 (0.09)	0.19 (0.09)	0.11 (0.07)	5.23 (1.13)	11.35 (1.37)
2	4	4	First	0.47 (0.10)	0.47 (0.10)	0.47 (0.10)	0.47 (0.10)	0.12 (0.10)	3.35 (0.54)	8.13 (1.46)
3	4	4	All	0.44 (0.09)	0.44 (0.09)	0.44 (0.09)	0.44 (0.09)	0.22 (0.47)	2.37 (0.73)	4.69 (1.64)
4	4	2	First	0.52 (0.28)	0.52 (0.28)	0.52 (0.28)	0.52 (0.28)	0.00 (0.12)	0.00 (0.02)	0.00 (0.09)
5	4	2	None	0.05 (0.02)	0.05 (0.02)	0.05 (0.02)	0.05 (0.02)	0.13 (0.13)	0.00 (0.02)	0.00 (0.13)
Bird 5668										
1	4	4	None	0.00 (0.02)	0.00 (0.02)	0.00 (0.02)	0.00 (0.02)	0.51 (0.16)	0.27 (0.37)	1.82 (0.69)

Table 2 (Continued)

Session block	Seg-ments in first comp.	No. of colors in series	Stimuli terminable	30-s segments						
				1	2	3	4	5	6	7
2	4	4	All	0.29 (0.19)	0.29 (0.19)	0.29 (0.19)	0.29 (0.19)	2.80 (1.09)	1.43 (0.53)	0.64 (0.23)
3	1	4	All	—	—	—	0.00 (0.00)	0.56 (0.13)	0.38 (0.21)	0.81 (0.12)
4	4	4	All	0.49 (0.21)	0.49 (0.21)	1.83 (0.66)	1.38 (0.91)	7.30 (1.10)	1.90 (0.74)	1.23 (0.40)
5	4	4	None	0.20 (0.56)	0.17 (0.11)	0.44 (0.18)	0.33 (0.23)	3.14 (0.62)	1.72 (0.90)	1.66 (0.38)
6	1	4	None	—	—	—	0.16 (0.08)	0.50 (0.20)	1.51 (0.35)	0.89 (0.17)
7	1	2	None	—	—	—	0.00 (0.00)	0.00 (0.02)	0.00 (0.01)	0.00 (0.00)
8	1	2	None ^a	—	—	—	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
Bird 5814										
1	4	4	None	0.12 (0.05)	0.12 (0.05)	0.12 (0.05)	0.12 (0.05)	4.85 (1.00)	4.67 (0.88)	27.84 (5.84)
2	4	4	All	0.36 (0.19)	0.36 (0.19)	0.36 (0.19)	0.36 (0.19)	6.52 (2.09)	6.16 (1.16)	5.61 (1.31)
3	1	4	All	—	—	—	0.06 (0.04)	0.98 (0.70)	4.20 (0.73)	4.22 (0.35)
4	4	4	All	0.48 (0.65)	1.04 (0.77)	1.39 (1.02)	2.17 (1.47)	7.69 (1.59)	4.17 (1.05)	3.13 (0.42)
5	4	4	None	0.10 (0.15)	0.00 (0.15)	0.14 (0.15)	0.58 (0.26)	6.29 (1.06)	7.82 (1.55)	3.59 (1.30)
6	1	4	None	—	—	—	0.06 (0.06)	2.97 (1.10)	8.39 (1.31)	5.23 (1.57)
7	1	2	None	—	—	—	0.00 (0.00)	0.06 (0.05)	0.00 (0.00)	0.00 (0.00)
8	1	2	None ^a	—	—	—	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)

^a Although the control circuit was set for production of the replacement stimulus following a peck in the first component, no pecks occurred during the 15 sessions making up this block.

variations introduced during successive blocks of 15 sessions in order to compare the resulting performances. Early in our work, a temporal cycle composed of four (Figure 1, top line) variable periods of time, each averaging 30 s, recurred repeatedly throughout the session. Later, seven periods (Figure 1, second line) were used, to extend the time for which the first color was present. The length of each successive period within the cycle was determined by a single, continuously moving tape containing 27 holes, punched according to the formula published by Catania and Reynolds (1968, p. 381) for a "constant probability"

variable-interval schedule. (See top and bottom lines, especially, of Figure 1.) In the present instance, no pecking was required for the advance to the next interval and, in fact, after completion of the cycle scheduled by the moving tape, grain was not made available until a specified delay had elapsed since the last previous peck. (The length of this delay and the duration for which grain was made available were varied from one pair of subjects to the next, in an attempt to explore the appropriate experimental parameters. See Table 1.) When only four periods were used, each was normally accompanied by a different color on

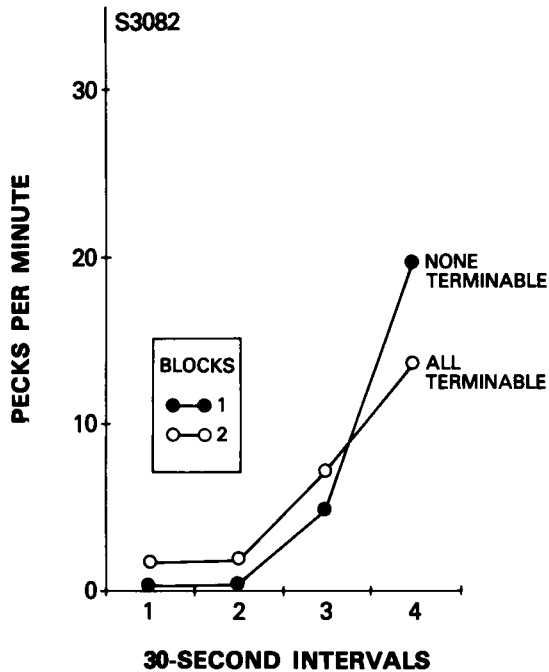


Fig. 2. Pigeon 3082: Rate of pecking in each of four variable-duration segments making up the total interval between successive deliveries of grain (Figure 1, top line). Each segment was accompanied by a different color on the key, and in Block 2 each peck produced a fifth color for 1 s. Data are medians for the last five sessions in each block.

the key, and the sequence in which these colors appeared was varied from one pair of subjects to the next in order to control for any inherent differences in salience or in preference (see Table 1). When seven periods of time were used, the first four were always accompanied by the same color and were treated as a single "first component," whereas the last three were normally accompanied by different colors. In effect, changing the number of time periods was simply a convenient device for increasing the length of the first component in the series. (See second line of Figure 1.)

During the first 29 sessions, which we used to establish and stabilize a baseline level of performance, pecking had no effect on the color displayed on the key. (For the first four of those sessions, the variable periods governing the length of time each color was presented averaged only 15 rather than 30 s.) In other words, this was an autoshaping procedure (for a very similar procedure, see Palya, 1985). Later, however, the following consequence was added: Each peck terminated the color cur-

rently displayed on the key for either 1 s or 5 s, as specified in Table 1. To avoid leaving the key dark—a stimulus that may have special properties—we substituted a fifth color, which we will refer to as the replacement color. The replacement color remained the same for a given pair of birds throughout the experiment. (For color and duration of replacement displays, see Table 1.) In some blocks of sessions, only pecks occurring in the first component produced the replacement color. In other blocks, a still more specialized procedure was sometimes employed, in which the replacement color reappeared when the programmed period for the first color ended and this color remained present until the end of the standard interval between deliveries of grain. (See third line of Figure 1.) This procedure is indicated in Table 2 and in Figures 6 and 7 by a notation stating that only two colors were presented, instead of the usual four.

Variations in experimental procedure were introduced in a different sequence for each pair of birds to control for possible order effects. In each case, we tried to arrange the sequence so that the blocks to be compared followed in immediate succession, as larger differences in calendar time might be accompanied by larger drifts in the level of activity or the pattern of behavior. Each variation was maintained for a fixed number of sessions (15) to prevent inadvertent selection of data, and median rates of pecking for the last 5 of those sessions were used to represent the final performance in each component. The order and the procedures used for successive blocks of sessions for each bird are presented in Table 2, along with the median rates under each condition and the mean deviations about those medians.

RESULTS

Under the initial baseline procedure, in which pecking had no programmed consequence (autoshaping), the overall rate typically reached its peak early in training and thereafter tended gradually and irregularly to decline. Half of our birds produced their high-totals by the sixth session.

In the presence of the first color, the pigeons showed substantial levels of wing flapping and frequently struck the wall of the

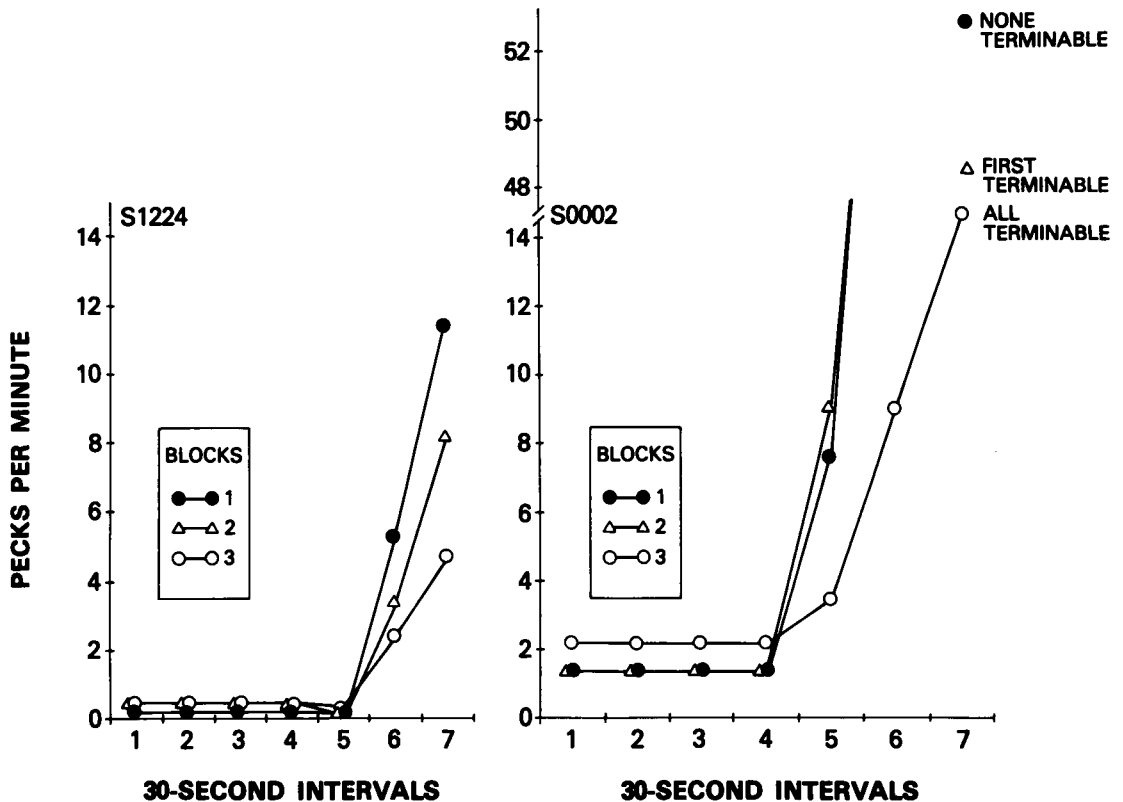


Fig. 3. Pigeons 1224 and 0002: Rate of pecking in each of seven variable-duration segments making up the total interval between successive deliveries of grain. The first four segments were accompanied by the same color on the key and are represented by a single rate; the last three segments were accompanied by different colors (Figure 1, line 2). Median values are plotted for the last five sessions of blocks in which only the first color, all colors, or no color were replaced for 5 s following each peck on the key. (For S0002, note the break in the abscissa necessary to accommodate the values recorded during the last segment of the cycle.)

chamber. Also, in accord with Palya's (1985) findings, the rate at which the birds pecked was a positively sloped and positively accelerated function of the ordinal position of each color within the overall interval between deliveries of food. The median rates for the baseline procedure appear in numerical form in Table 2 and as solid circles (Block 1—"none terminable") in Figures 2, 3, and 4.

All Stimuli Terminable

The first comparison to be considered is between the performance when all of the colors in the series were presented and each could be turned off temporarily by pecking the key (open circles, Block 2 or 3) and the performance when all of the colors were presented but could not be terminated by the subject (Block 1). The difference in performance indicates the effect of the replacement color, in

relation to the color that was already present, as a consequence of pecking. There is at least one set of data on this issue from each pair of birds. The data from one member of the first pair of birds (3082) are presented in Figure 2. Its experimental partner, Pigeon 3168, did not peck the key to any appreciable extent when no consequence was programmed (Block 1) and, as a result, did not receive substantial exposure to the altered contingency when the replacement color was made available (Block 2). This bird did not peck sufficiently often in either block to produce data points that would lie discernibly above the abscissa. All of the other birds, however, showed the same general pattern of results. When each peck produced the replacement color for 1 s, pecking by Pigeon 3082 was reduced during the final component of the series from a median of 19.61 per minute to 13.61. During the first com-

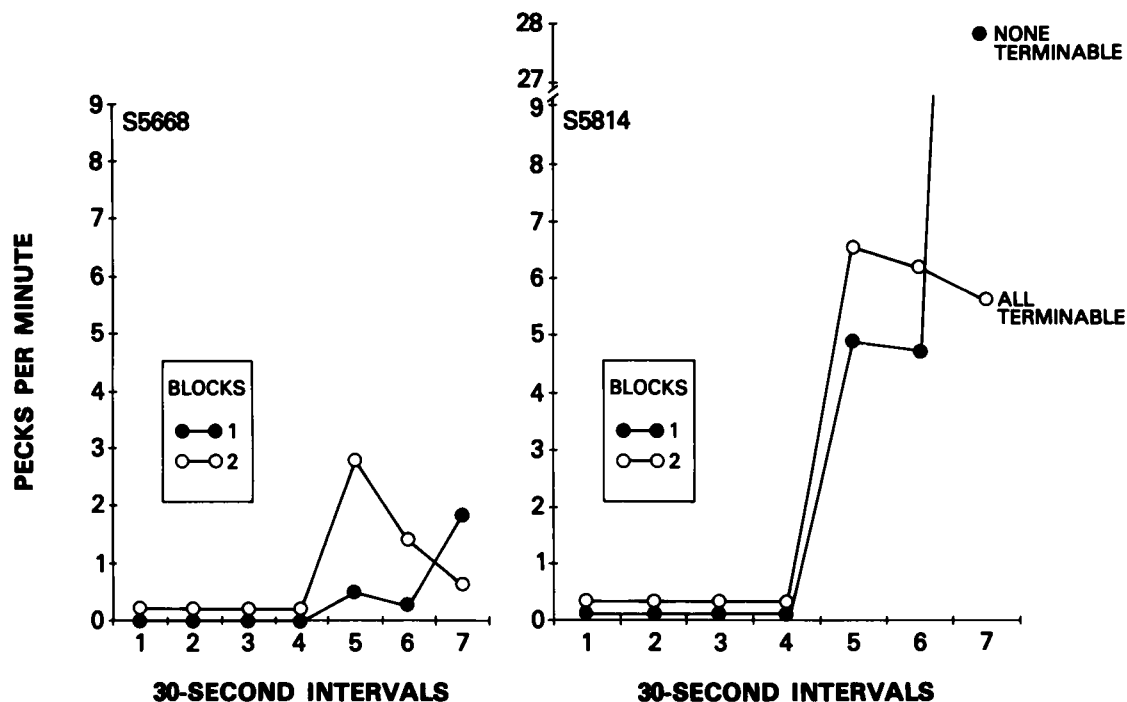


Fig. 4. Pigeons 5668 and 5814: Rate of pecking in each of seven variable-duration segments making up the total interval between successive deliveries of grain. The first four segments were accompanied by the same color on the key and are represented by a single rate; the last three segments were accompanied by different colors (Figure 1, line 2). In Block 2, the original colors were replaced for 1 s following each peck on the key. Median values are plotted for the last five sessions in each block. (For S5814, note the break in the abscissa necessary to accommodate the values recorded during the last segment of the cycle.)

ponent, on the other hand, its median rate increased from 0.25 to 1.70. Although the increase was not large in absolute terms, as a ratio it was quite substantial.

Figure 3 shows the change produced by essentially the same operation in the second pair of birds, 2 and 1224. When pecking produced the replacement color for 5 s, both birds' rates were reduced to less than half of the original level in the last component and more than doubled in the first component. (Changes in the intermediate components were not as consistent from bird to bird, and the performance in Block 2 will be taken up in a later paragraph.) Figure 4 presents corresponding data for the third pair of birds, 5668 and 5814. These birds show a somewhat different baseline pattern than the others, with slightly less pecking in the sixth than in the fifth component. Nevertheless, the effect of producing the replacement color for 1 s remains consistent with the effects shown by the other birds: The rate of pecking in the last component is less

than half of what it was, and the rate in the first component is more than double.

Up to this point, all of these comparisons have utilized a baseline (pecking produces no change in color) from the first block of sessions for a given bird and comparison data (pecking in any component produces the replacement color) taken from the second or third block. To provide a control for the possibility that the results might be a product of the order in which they were obtained or might be restricted to sessions early in training, we replicated the comparison for Birds 5668 and 5814 in a reversed order, later in training. The effect of producing the replacement color for 1 s tested in Block 4 and the baseline performance in Block 5. These results are presented in Figure 5. Again, the rate for these 2 birds was relatively high in the fifth component, as compared to those later in the sequence. When the replacement color was eliminated from the procedure (Block 5), responding dropped, as expected, during the ini-

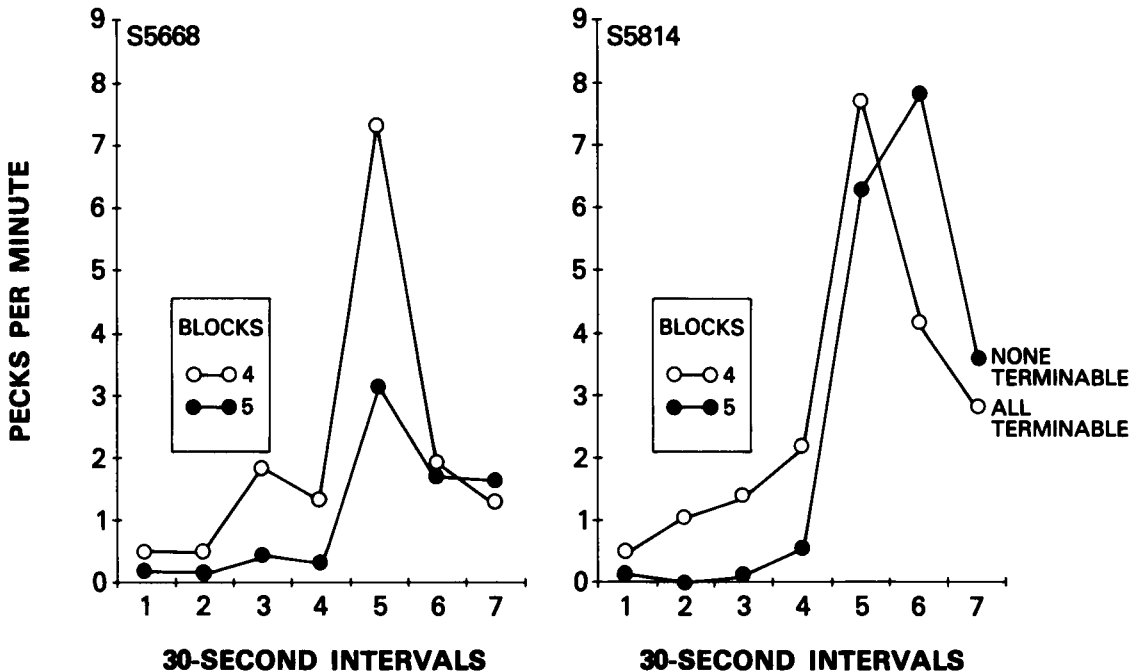


Fig. 5. Pigeons 5668 and 5814: Rate of pecking in each of seven variable-duration segments making up the total interval between successive deliveries of grain. The first four segments were accompanied by the same color on the key, the last three by different colors (Figure 1, line 2). Median values are plotted for the last five sessions of Block 4, in which each color was replaced for 1 s following a peck on the key, and Block 5, in which the original colors could not be terminated.

tial portion of the interval between deliveries of food but did not increase to any substantial extent during the last component. In this respect, previous findings were not replicated. Perhaps more sessions are required for the rate to recover under the baseline procedure following 45 sessions of suppression.

Increasing the Duration of the First Color

One parameter of the experimental procedure that we altered primarily for methodological reasons was the length of time for which the first color appeared. When one member of our first pair of birds failed to peck at an experimentally useful rate in Blocks 1 and 2 (Table 1, S3168), we increased the time for which the first color was displayed in Block 3 from a single period averaging 30 s to four such periods. In discussing the relatively small effect exerted by his CS in the group for which it came immediately after the delivery of food, Kaplan (1984) suggested that it might have been rendered redundant by the food itself. If Kaplan's suggestion applied to our situation, perhaps the influence of the food delivery could

be reduced by extending the duration of the initial stimulus well beyond that point in time. It also seemed possible that lengthening the "intertrial interval"—to which the first color was temporally equivalent—would increase the overall rate of pecking (see Balsam, 1984; Jenkins, 1984). This maneuver did not improve the performance of the bird in question (3168, Block 3), but its experimental partner (3082) pecked at a higher rate than before in the presence of all colors except the first one. Later, we tested the same parameter with Birds 5668 and 5814. As may be seen in Table 2, during Blocks 2 and 4 four periods were used for the first color, but during Block 3 only one. In almost all cases, the rate of pecking was lower during Block 3, when the shorter duration was used. The four-period first color was again compared with a single-period first color in Blocks 5 and 6, this time under a straight autoshaping (baseline) procedure, in which no change in color was produced following a peck on the key. Again, in most cases the rate was reduced when the duration of the first color was reduced, including

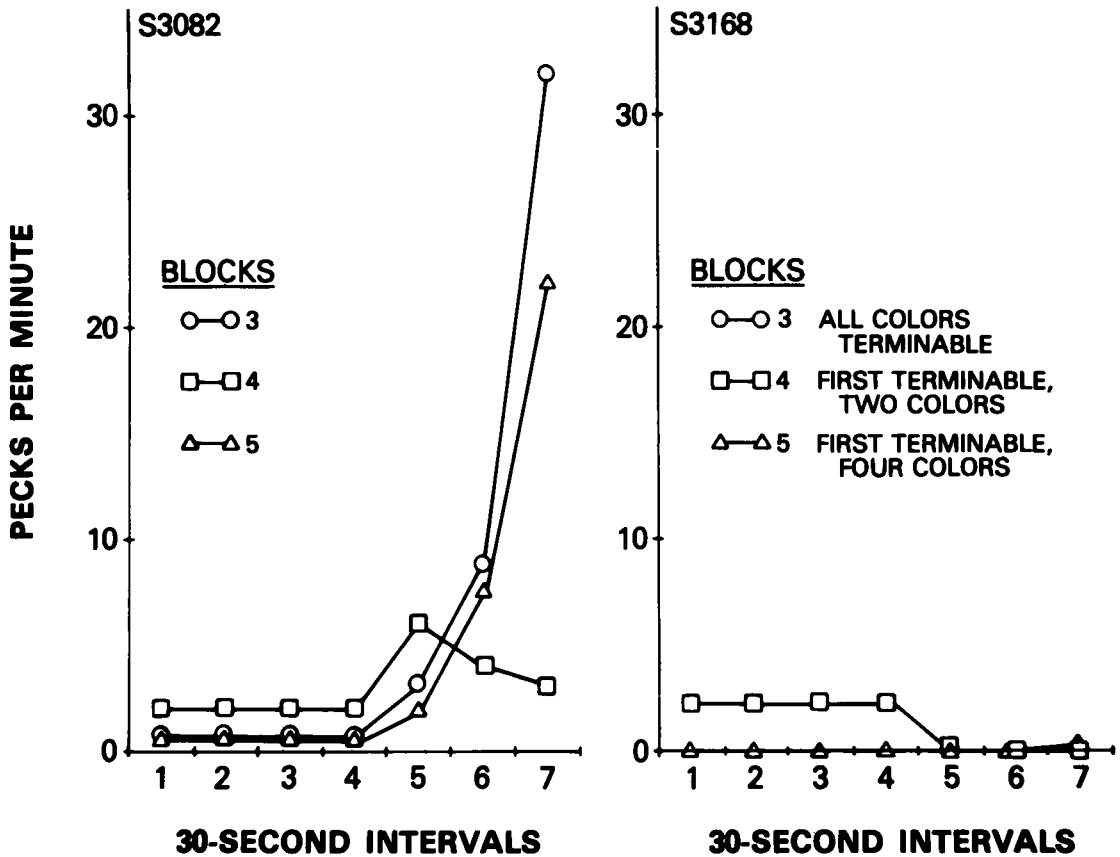


Fig. 6. Pigeons 3082 and 3168: Rate of pecking in each of seven variable-duration segments making up the total interval between successive deliveries of grain. In Blocks 3 and 5, the first four segments were accompanied by the same color, the last three by different colors (Figure 1, line 2), but in Block 5 only the first color was terminable. In Block 4, the first color was terminable and the replacement color was continuously present throughout the last three segments (Figure 1, line 3). Data points have not been plotted for the performance of S3168 during Block 3, as no pecking occurred.

the rate in the presence of the first color itself. In general, the four-period procedure appears to generate slightly higher rates than the one-period procedure.

Temporal Locus of the Replacement Stimulus

We suspected that the positioning of the replacement stimulus within the temporal cycle, as well as that of the stimulus that it replaced, must have some bearing on the effect that it would produce when used as a behavioral consequence. One way in which the temporal location of the replacement stimulus could be manipulated was to restrict the opportunity for its production to the first component of the interval between food deliveries. Under this procedure, the replacement stimulus would bear much the same temporal re-

lationship to the food as did the stimulus that it replaced, the first stimulus in the series. When still novel to the subject, its effect might be difficult to predict, but with repeated exposure it should lose most of its reinforcing value, relative to the first stimulus. The results of such a procedure may be compared either with those of the baseline condition, in which pecking the key produces no stimulus change, or with those of the procedure in which all pecks, in any part of the interval between food deliveries, produce the replacement stimulus.

The results for the first pair of birds, 3082 and 3168, are shown in Figure 6 (Block 5, plotted as triangular data points). No baseline data are available in which the same component duration and the same interval between

food deliveries were employed. However, as expected, Bird 3082 showed a lower rate of pecking during the first component in Block 5, when only pecks during that component produced the replacement stimulus, than during the same component in Block 3, when pecks in any component were effective (circular points). Bird 3168 may not have provided as strong a test, as this subject was not active during the first three blocks. However, it did peck the key regularly in the presence of the first color during Block 4 (see below), and this performance dropped out in Block 5, when the temporal relationship of the replacement stimulus to the food became less favorable.

The relevant data for Birds 2 and 1224 appear in Figure 3. Bird 2 pecked at about the same rates in all components during Block 2 (first stimulus terminable) as it did during Block 1 (baseline), and pecked less in the presence of the first color, specifically, than it did when the replacement stimulus could be produced at any point in the interval between the deliveries of food (Block 3). Bird 1224 pecked somewhat more often in the first component during Block 2 than it did during Block 1, but no more often, at least, than during Block 3. The rate was quite low under all three procedures. Note that in later components within the overall cycle, pecking produced no change in key color; therefore, there was little reason to expect any systematic deviation from baseline performance.

As this procedure was not used with the third pair of birds, 5668 and 5814, our data are limited, but in no case did production of the replacement color in only the first component lead to a substantial rate of pecking in that component.

Pairing the Replacement Stimulus with the Food

On the other hand, when the first component was the only one that was accompanied by a distinctive color and the stimulus present throughout the remainder of the interval between food deliveries was the same as the replacement stimulus, the rates in the first component were typically higher than under other procedures. This arrangement was initially tested with Birds 3082 and 3168. The results for Block 4 are shown in Figure 6 (open squares). Bird 3082 pecked at a substantially higher rate in the first component under this

procedure than during the preceding (all colors presented, all replaceable) or subsequent (all colors presented, only first color replaceable) blocks. The same bird pecked at a substantially lower rate than usual in the last component, presumably because the color used during this component was no longer distinctive but was the same as that used throughout much of the rest of the interval and was no longer as predictive of food. Or to put it another way, the CS-US interval was longer than in any other block of sessions. Like 3082, Bird 3168 rarely pecked the key during the later components, but during the first component it maintained a median rate of 2.26 pecks per minute. This was the only sustained pecking shown by this bird at any point in its experimental history.

The same procedure was also tested with the second pair of birds, 2 and 1224. In Figure 7, the results obtained in Block 4 (open squares) are compared with the results obtained in Block 3 (open circles) when different colors were used for each component and a peck at any time produced the replacement color, and with the results obtained in Block 5 (filled squares), when only the first component differed in color and that color could not be terminated. Compared with the performance under the straight autoshaping (no consequence) procedure, both birds pecked at substantially higher rates in the first component. Bird 2 pecked at a higher rate than under the procedure in which all four colors were presented and terminable, while Bird 1224 pecked at about the same rate. It is clear that the replacement stimulus was an effective reinforcer. It did not, however, elicit a substantial amount of pecking in its presence, as can be seen by inspecting the data for the last three components within the interval.

To summarize our findings, when we presented a standard replacement color for a brief period following each peck on the key, its effect varied as a function of the temporal locus within the interval between food deliveries of the color that was replaced. In the presence of the last color in the sequence, the rate of pecking decreased. In the presence of the first color, the rate increased. The effect also varied as a function of the characteristic locus of the replacement color. In the presence of the first color, the smallest increment in rate was obtained when the replacement color was re-

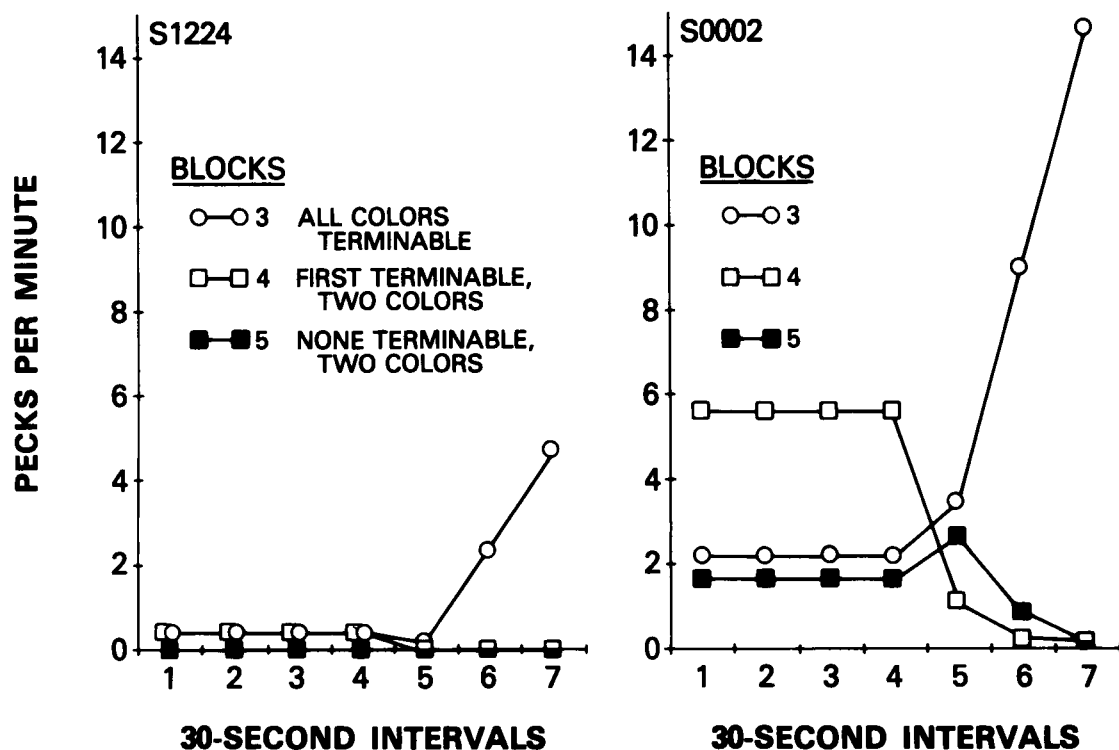


Fig. 7. Pigeons 1224 and 0002: Rate of pecking in each of seven variable-duration segments making up the total interval between successive deliveries of grain. In all blocks, the same color was present during the first four components (Figure 1, lines 2 and 3). In Block 4, only that color was terminable, and the replacement color was present throughout the remainder of the interval (Figure 1, line 3). In Block 5, neither the first color nor the color prevailing throughout the rest of the interval was terminable.

stricted to the same segment of time; higher rates were obtained when the replacement color could be produced anywhere within the interval between deliveries of food; and the highest rates were obtained when the replacement color reappeared at the end of the period marked by the first color and continued to be present until the food arrived. Despite the efficacy of this last arrangement in maintaining pecking in the presence of the first color, it should be noted that very little autoshaped pecking occurred in the presence of the replacement color.

DISCUSSION

With the present technique, the variability in performance (including baseline sessions) was substantial, relative to the differences between successive blocks of sessions. Accordingly, we rely primarily on consistency in replication to provide evidence for the systematic nature of a given effect. We hope that future

work directed toward other relationships will confirm those indicated by the present data. It seems likely that the influence of the autoshaping process on these data could be reduced by removing the controlling stimuli from the key, but in that case the baseline rate of pecking might be too low to provide effective contact with the contingencies we wish to examine—as appears already to have happened with a large portion of the data produced by Bird 3168.

In accord with Palya's (1985) analysis, the pecking that arose under the original baseline procedure, in which it produced no change in programmed stimulation, presumably can be attributed to the process known as autoshaping. If autoshaping is a form of Pavlovian conditioning, however, as conventionally assumed, it seems strange to find that with most birds there is a sustained if modest level of pecking in the presence of the very first color in the sequence. The first color is a negative predictor of food and should, by conventional

wisdom, exercise an inhibitory effect. Indeed, in Kaplan's work, for example, "very few key pecks were made" (Kaplan, 1984, p. 120) when the gap between the end of the key illumination and the delivery of the food was greater than 12 s; also, under such circumstances, the birds tended to move away from the side of the box on which the key was illuminated and toward the side on which it remained dark.

A notable difference between our procedure and that used in most autoshaping studies is that in our study the key was never darkened except when grain was delivered: The interval between deliveries was entirely occupied by a succession of key colors that followed each other in a consistent sequence. In our work, manipulations that increased or decreased the autoshaped pecking in the presence of the last color typically had a corresponding effect on the rate of pecking in the presence of the first color. For example, when only two stimuli were used (Birds 5668 and 5814, Blocks 7 and 8), both birds completely ceased pecking the key. It is possible that the behavior that might be observed with isolated conditional stimuli—preceded and, in the case of trace autoshaping, followed by a darkened key—has here been modified by a process of second-order conditioning (see Rashotte, 1981). It should also be noted that under our procedure, each component of the sequence varied in duration from one cycle to the next; if second-order conditioning is indeed involved, then the use of a variable interval may alleviate any reduction in responding that might be produced by temporal discrimination (Pavlov's, 1927, "inhibition of delay").

The decrease in rate of pecking during the last component when the response-dependent stimulus was added to the procedure is difficult to evaluate. The original stimulus, which with most birds produced a substantial rate of responding, was repeatedly interrupted by the replacement stimulus, and it is not clear how much effect those brief absences might have had on the original autoshaped pecking, entirely aside from any behavioral effect exerted by the replacement stimulus acting as a punishing consequence. But the failure of the rate to recover for Birds 5668 and 5814, following their return to baseline in Block 5 (Figure 5), suggests that the change in behavior does not have the inevitability that one would expect if

it were attributable solely to a difference in the proportion of time for which the stimulus was present.

In any case, the direction of the change for the last color provides a striking contrast for the direction of the change obtained with the first color. Some part of the increase in rate repeatedly obtained in the presence of the first color when pecks were allowed to turn it off may possibly be the result of stimulus change per se (Kish, 1966); there is some suggestion of an effect (Bird 1224, Block 2) even when the replacement stimulus is also restricted to the first component and does not enjoy an appreciably better temporal relationship to the food than the stimulus it replaces. But the magnitude of the effect does appear to be influenced by the average temporal position of the replacement stimulus. Rates of responding typically were higher when that stimulus was free to appear in any part of the overall interval between deliveries of grain—analogous to the tandem stimulus sometimes used in studies of chained schedules—and were still higher when the same stimulus was programmed to reappear at the end of the first component, filling the remainder of the interval until the delivery of the grain. The effect of the response-dependent change appears to be a joint function of the temporal characteristics of the replacement stimulus and of the stimulus that it replaces.

It seems strange that the pigeon does not make more of a distinction than is implied by these findings between the replacement stimulus when it is produced by pecks in the presence of the first color and the same stimulus when it is closer temporally to the food. Apparently the stimulus retains some portion of its reinforcing power, regardless of the context or the temporal locus within which it appears. There is precedent for this independence from context, to be sure, in the finding by Squires, Norborg, and Fantino (1975) that pigeons had difficulty discriminating among the very brief stimuli used to mark successive components of a second-order schedule. But in the present case the stimuli in question were longer in duration and the successive parts of the interval between grain deliveries were accompanied by distinctive stimuli.

If we may extrapolate from Kaplan's (1984) findings, another factor that might be expected to reduce the size of the increase in

pecking in the presence of the first color is the bird's tendency to shift its position at the onset of such a stimulus to the side of the box laterally opposite to that in which the lighted key is located. Presumably when the bird is in this position it neither observes the stimulus nor pecks the key as much as it would when standing directly in front of the key. It might be instructive to replicate portions of the present work with stimuli that are not located on the key.

The words that will be considered appropriate to describe the results of the present experiment depend on the way we characterize the stimulus that appears following a peck on the key. If that stimulus is categorized as neutral, for example, then we have demonstrated that the initial stimulus in the series is aversive. But there may be no such thing as a neutral stimulus, in a strict sense, in any experimental procedure. When first introduced, a stimulus with no intrinsic effects is often considered to be neutral because it bears no prior relationship to any experimental event; but it is also novel, and by virtue of that novelty may constitute a special case. We cannot ascribe to stimuli in general behavioral effects that may be specific to one that is newly introduced. If the stimulus is presented on a strictly random schedule throughout its experimental history, it may remain neutral. But if it enters in any nonrandom fashion into the experimental arrangements, it will of necessity bear some temporal relationship, on the average, to the primary reinforcer, whether consistent or inconsistent, near or far. No experimentally meaningful stimulus can remain completely neutral.

In none of our procedures, however, does the replacement stimulus appear to occupy a highly favorable temporal position. As a response-dependent stimulus, it is most effective under the procedure in which it reappears at the end of the first component and remains present throughout the last three components. But even under that procedure the stimulus does not enjoy a sufficiently favorable relationship to the food to serve as a reliable source of autoshaped pecking. Furthermore, the reinforcing effect of the replacement stimulus is not manifested throughout the series of colors but, in most instances, only in the first one. Clearly the temporal position of that first color plays a decisive role, and it seems ap-

propriate to refer to such a stimulus as a source of negative reinforcement; in other words, the first of a series of stimuli intervening between successive deliveries of food can be described as an aversive stimulus.

The finding that the initial stimulus can serve as a negative reinforcer is consistent with and was predicted on the basis of earlier findings that stimuli similarly located in trace conditioning procedures exercise an inhibitory effect. To this extent, the functional relations determining the effectiveness of conditioned reinforcers appear to parallel those governing the effectiveness of conditional stimuli in Pavlovian experiments.

The issue is not a simple one, however. Let us switch our consideration from the first stimulus in the series as a conditional stimulus to the replacement stimulus. When the latter stimulus reappeared at the end of the first color and remained continuously present until the arrival of the grain, it was strikingly ineffective in producing autoshaped pecking. This particular finding is not surprising, as the basic procedure could be categorized as one of relatively long delay (CS onset to US onset) conditioning, and previous data have shown such an arrangement to be ineffective specifically for autoshaping (Gibbon, Baldock, Locurto, Gold, & Terrace, 1977). Yet as a reinforcer of pecking in the presence of the first color in the series, the same stimulus was more effective under this arrangement than under any other we explored. The juxtaposition of these opposing effects for the same birds in the same experimental sessions may raise a question concerning the correspondence we have hypothesized between the principles by which a stimulus gains the power to elicit and the principles by which it gains the power to reinforce behavior.

Note, however, that what we are here comparing are the absolute magnitudes of two qualitatively different behavioral effects under a single experimental condition; we are not examining the similarity or dissimilarity of the functional relations to which these two isolated values belong. At no point in this experiment, for example, have we examined the magnitude of the reinforcing effect of a replacement stimulus that demonstrably *was* effective in eliciting autoshaped pecking. It may be that the threshold conditions for the appearance of the autoshaped pecking are much

higher than those for demonstrating the negatively reinforcing function of the first stimulus in the series. It should also be remembered that the reinforcing effect we are studying is a function not only of the replacement stimulus but also of the stimulus that it replaces. It is possible that the change in hues is especially effective in this instance because the first color is unusually aversive when separated from the food by a single stimulus rather than by a sequence of stimuli.

We know of two studies that have reported theoretically congruent effects of stimuli in a sequence similar to ours on responses that produced or removed them. In an unpublished portion of her dissertation, Jwaideh (1968) also used a reversed version of the standard observing procedure. In a series of tests, she allowed one of her birds to terminate the stimuli in a chained schedule of three links, each requiring 40 pecks on the food key. Each peck on the observing key produced a familiar tandem stimulus for a period of time ranging in different test sessions from 15 to 60 s. Even when the actual order of the stimuli was scrambled for test purposes, the bird pecked the key that removed them mostly in the presence of the stimulus that normally came first in the series, occasionally in the presence of the stimulus that came second, but almost never in the presence of the third.

Similarly, in another variation on the standard observing procedure, Auge (1977) began with a sequence of three stimuli that accompanied successive thirds of the interval between food deliveries on a 32-s fixed-interval schedule of reinforcement. When he allowed his birds to produce one-second or half-second displays of the third stimulus in the presence of the first stimulus, pecking increased on the observing key, indicating that the third stimulus was a conditioned reinforcer; but when he allowed the same birds to produce the first stimulus in the presence of the third stimulus, the rate of pecking decreased, indicating that the first stimulus in the series functioned as a conditioned punisher.

Taken in conjunction with our own data, these findings suggest that a theoretical structure based on relative-time treatments of conditioning might be more effective in analyzing the processes at work in a chain that is the paradigm originally proposed by Skinner (1938). The average times from the onset and

from the offset of a given stimulus to the arrival of the reinforcer would be the critical variables determining the value of that stimulus to the organism, and these times would be considered in relation to total cycle time. In particular, as the time from stimulus to reinforcer becomes sufficiently long, relative to total time, the stimulus becomes negatively reinforcing with respect to other stimuli that might be available. By extension, stimuli in such a position that they become inhibitors in their eliciting function and negative in their reinforcing function might also become suppressive in their discriminative function for operant behavior. More emphasis needs to be placed on the fact that the situation in which the organism finds itself at the beginning of a chain is one that is less favorable than normal and is one that might properly be described as aversive in its behavioral effects.

The same theoretical framework may also be relevant to the pausing observed at the beginning of the interval between food deliveries under fixed-interval and fixed-ratio schedules of reinforcement. The main differences between our basic experimental routine and the fixed-interval (FI) schedule, for example, are that in our study exteroceptive stimuli were provided to the bird as a rough sort of clock and that no response was required at the end of the interval to produce the food. Also, because our total interval was produced by the summation of a series of smaller intervals, each of which was variable, its duration was not completely constant but fluctuated to some degree from one occasion to the next.

Under an FI schedule, time since reinforcement apparently serves a discriminative function similar to that of the colors displayed on our key; when exteroceptive stimuli are added to such a schedule, as in Ferster and Skinner's (1957) "added clock," the pause at the beginning of the interval is lengthened (see also Segal, 1962). Similarly, when brief exteroceptive stimuli are regularly substituted for some deliveries of the reinforcer, pauses develop following each presentation of the brief stimulus (Gollub, 1977).

Under an FI schedule, the early part of the interval is thought to have aversive properties. For example, Richards and Rilling (1972) found that attacks by the subject on a restrained target pigeon were higher under an FI schedule than prior to such training and

that the attacks occurred most frequently during the early part of the interval. The authors suggested that the frequency of aggression be used as an index of aversiveness, although they obviously used the latter term in some sense more general than we have. T. G. Brown and Flory (1972; see also Flory, 1969) found that pigeons pecked an auxiliary key when that response turned off the color accompanying a fixed-interval schedule, doing this most frequently during the first quarter of the interval and fairly often during the second. The birds also restored the FI color by pecking the same key. No data were furnished as to precisely when the restoration occurred, but obviously it had to be later in the interval. The compound of FI color and time appears to have been aversive by our definition (i.e., negatively reinforcing) early in the interval, but positively reinforcing at a point closer to the arrival of the food.

There is also evidence indicating that the stimuli characteristic of the first part of the interval between reinforcers have a suppressive effect on responding in their presence. Skinner and Morse (1958) found that reinforcing running in a wheel on an FI schedule sometimes produced pauses that lasted longer than any observed during other parts of the session, when no reinforcers were delivered. Skinner and Morse (1957) also found early-interval pauses in running when rats operating a lever under fixed-interval reinforcement were permitted concurrent access to a wheel. Following each delivery of food, there was a period during which the rats neither ran nor pressed the lever. Apparently the stimuli at the beginning of the interval did not simply indicate that a particular response would be ineffective: They produced an active suppression that applied not only to the behavior that produced the reinforcer but to other behavior as well.

The suppressive effect of stimuli marking the beginning of a relatively long interval prior to the receipt of food may also play a role in the effects produced by the addition of what have traditionally been called "brief stimuli" to schedules employing the food as a primary reinforcer, but the relationships are complex and the data do not always appear to be consistent (Gollub, 1977).

The same process that accounts for the suppression of responding in the early part of

the interval between reinforcements under chained and fixed-interval schedules may also be responsible for the characteristic pause prior to the beginning of responding under large fixed-ratio (FR) schedules. Again, behavior that has been categorized as "aggressive" occurs most frequently during the pause (Gentry, 1968; Hutchinson, Azrin, & Hunt, 1968). Again, during the pause pigeons peck a key that terminates the stimulus normally accompanying the schedule, even when that action reduces the frequency of reinforcement (Appel, 1963; Azrin, 1961; Thompson, 1964, 1965). They also restore the stimulus by pecking the same key later in the interval between reinforcements. Jwaideh (1973) found that when she provided her pigeons with a different key color for each third of a substantial fixed ratio (i.e., added a block counter), the pauses became longer than before.

Sometimes the aversive character of the stimuli at the beginning of the ratio is attributed to frustration produced by termination of the opportunity to eat, but in the studies just cited the frequency of the escape response was a function of the size of the ratio employed (see also Felton & Lyon, 1966). Sometimes the pause is attributed to the fatigue resulting from completion of the previous ratio requirement, but by using a multiple schedule involving two different ratios, Crossman (1968) and Griffiths and Thompson (1973) have shown that the magnitude of the pause is a function of the size of the ratio to come rather than of the ratio just completed. According to our interpretation, it is at least in part a function of the characteristic time, indicated by a given stimulus, until the receipt of the next reinforcer.

It is usually assumed that the fixed-ratio pause is in some way a product of the onerous nature or the energy cost of required responding, but even that is open to question. Killeen (1969) found no difference in the length of pauses between pigeons pecking on various FR schedules and yoked control birds receiving the same distributions of reinforcements in time but without the ratio requirement (see also Shull, 1971). Moreover, by inserting blackouts after each nonreinforced response and manipulating their duration, Neuringer and Schneider (1968) were able to vary the number of responses under an FI schedule without varying the time until the food was

delivered. This procedure had little or no effect on the length of the pause. Similarly, the same authors were able to manipulate the time between reinforcements under an FR schedule without varying the response requirement. When the time increased, so did the duration of the initial pause following each reinforcement. The Killeen, the Shull, and the Neuringer and Schneider studies suggest that it is the time to food rather than the number of responses that is the important dimension so far as the pause is concerned. On the other hand, by inserting a blackout between the two pecks required for reinforcement, Crossman, Heaps, Nunes, and Alferink (1974) were able to match the time between food deliveries in one component of a multiple schedule to the time required for the completion of a fixed ratio in the other. They found that the ratio component produced longer pauses and that the difference between the two components in pause length increased with increases in the size of the ratio. These data are difficult to reconcile with the data indicating that number of responses is not an important determinant of the length of the pause.

In our work, no response other than approach to the hopper was necessary for procurement of the grain, but the first stimulus in the series proved to be aversive. Whatever the role of responses, time to the next delivery of food appears to be a relevant dimension. Stimuli arising early in the interval between food deliveries appear not only to be inhibitory but also to be aversive to the subject in a wide variety of experimental contexts.

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