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## THE AUTOSHAPING PROCEDURE AS A RESIDUAL BLOCK CLOCK

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In the first experiment, 4 pigeons were each presented with a recurring sequence of four key colors followed by the delivery of grain (block clock). Once the rate of pecking had stabilized, three of the colors were replaced, during different series of sessions, by a darkening of the key. The rate of pecking was reduced within those segments of the interval between deliveries of food during which the key was dark; when the key was dark during the final portion of the interval, rates were reduced throughout the entire interval. In the second experiment, 3 new pigeons were exposed to a different sequence of colors, and the final stimulus was replaced in successive conditions by a novel color, a darkened key, and a restoration of the original color. The data indicated that darkening the key had a more severe, more extensive, and more persistent effect than did a mere change in color. These results suggest that it may be fruitful to conceptualize the autoshaping procedure as a special version of the block clock in which pecking is suppressed throughout the greater part of the interval by darkening the key. In the final condition, the same stimulus appeared in each of the last three portions of the interval. The rate of pecking was lower during the last two portions than when distinctive colors were presented, with the peak rate now appearing in the fifth of seven equal temporal components.

*Key words:* autoshaping, block clock, serial stimuli, darkened key, early peak, pecking, pigeons

When the same sequence of colors is repeatedly displayed on a pigeon's key, followed in each instance by access to a hopper of grain, the bird usually begins to peck that key (Dinsmoor, Lee, & Brown, 1986; Palya, 1985; Palya & Bevins, 1990; Palya & Pevey, 1987). A temporal pattern develops in which pecking tends either to be extremely spasmodic or to be totally absent during the initial part of the interval but to increase as the time approaches for the receipt of the food. Palya (1985) has demonstrated that to be effective, the stimuli used in this type of procedure must be correlated with the passage of time. In his study, 10 colors were employed, and pecking depended on the order in which these stimuli were presented: When the order in which the colors appeared was consistent from one oc-

casion to the next, substantial rates were generated, but when the order was randomized, pecking all but disappeared. In his writings, Palya has referred to the consistent sequence as an "interfood clock" (e.g., Palya, 1985). However, a characteristic that is important in our version of the clock, at least, is that it is not continuous, like the clock originally used by Ferster and Skinner (1957, pp. 266ff), but is composed of a small number of relatively long-lasting, discrete stimuli. Consequently, following Ferster and Skinner's usage of the term "block counter" (pp. 109ff), we have adopted the analogous term, "block clock."

It is obvious that the block clock procedure has important elements in common with the procedure for "directed action" or "autoshaping," which has been so extensively studied in the conditioning laboratory (for early reviews see Hearst & Jenkins, 1974; Schwarz & Gamzu, 1977). The difference is that under the arrangements standard for autoshaping, the key is lighted during only one of the available segments of the interval between deliveries of food and remains dark during the remainder of the cycle. In their initial investigations, both Palya (1985) and Dinsmoor et al. (1986) were struck by the large number of key pecks generated by the clock

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procedure and suggested that it seemed substantially higher than would be expected under comparable parametric values with an autoshaping procedure.

At the theoretical level, autoshaping is customarily treated as a form of Pavlovian conditioning, with the lighted key serving as the conditional stimulus (CS) and the grain as the unconditional stimulus (US), and results are routinely interpreted in terms of the temporal and/or probability relationships between these two stimuli. But there is an alternative framework that may be used to organize such data. Note that not only the standard autoshaping procedure but also more specialized variants such as trace conditioning, filled gap procedures, long-delay conditioning, and serial conditioning may be regarded as procedures in which a darkened key has been substituted for one or more of the clock stimuli, leaving only a portion of the original sequence. Conceptualizing the various autoshaping procedures as fragmentary or abbreviated versions of the block clock may lead to new questions, new experimental manipulations, and new theoretical insights.

The present experiments represent an initial attempt to explore some implications of this perspective. If it is true that the clock procedure generates more pecking than is observed in conventional experiments on autoshaping, one of the factors responsible for the difference in performance may be the fact that under a clock procedure the key remains lighted throughout the entire interval between deliveries of food, whereas under the usual autoshaping procedures it is darkened during the greater part of that interval. Within the context of a Pavlovian model, periods during which the key is dark are typically characterized as "empty" intervals, devoid of stimulation, as illustrated by terms like "intertrial interval," "unfilled gap," and so on (e.g., Kaplan & Hearst, 1982; Rescorla, 1982). But within the context of a block clock, the darkened key is readily seen to be a special stimulus that differs in its physical properties from one that is lighted and may for that reason exert a different behavioral effect. Indeed, laboratory lore has it that pigeons peck keys less often when they are dark, and data reported in the very first study of autoshaping (Brown & Jenkins, 1968, pp. 5-6; forward pairing, dark key group vs. forward pairing, red key group) tend to bear

this out. (Another way of stating the matter may be to say that it is the lighted key, as a collective category, that has special behavioral properties and that these properties are absent when the key is dark.)

The design of our first experiment is similar to that of the multiple baseline sometimes used in applied behavior analysis. Our primary objective was to determine the effects of darkening the key during different portions of the interval between deliveries of food; the behavior in each portion of the interval was recorded as a separate measure. A secondary objective was to take advantage of birds trained on a baseline procedure identical to that used by Dinsmoor *et al.* (1986) to replicate some of their observations. However, because the replication work neither challenged nor provided substantial additional support for the original conclusions, we have not reported those data.

## EXPERIMENT 1

### *Method*

*Subjects.* In this experiment, we obtained our data from 4 retired White Carneau breeding hens, 7 years of age, purchased from the Palmetto Pigeon Plant. All 4 pigeons were experimentally naive. Between experimental sessions, they were housed with the departmental colony. Whenever a subject's weight following the session fell more than 25% below the level it had attained when food was continuously available, the bird was provided with extra grain.

*Apparatus.* Except for the addition of a black floor made of particle board that tilted along an axis bisecting the front panel, the apparatus was the same as that used in the previous work by Dinsmoor *et al.* (1986). A downward excursion measuring about 4 mm in the right edge of the floor actuated a pressure switch mounted on its bottom surface. The chamber was manufactured by Lehigh Valley Electronics (Model 1519). An attached blower provided both masking noise and ventilation during the experimental session. The stimulus and response panel was 35.0 cm wide and extended 34.2 cm above the floor; it was mounted 27.5 cm from the rear wall. Throughout the present work, the left key was covered with plastic tape. The right key was mounted behind a circular opening 2.54 cm in diameter, centered 24.2 cm above the floor and 11.1 cm from the

entry door. A force of 0.20 N was required to transfer the contacts within the switch. The key was illuminated from behind with a Series 10 Industrial Electronics Engineering projection unit powered by a Massey-Dickinson lamp driver module. Each stimulus in the sequence was produced by the concurrent lighting of two IEE 1820X 28-V dc bulbs behind a corresponding pair of filters. Six pairs of filters were available: Roscolene 807 (yellow), 839 (purple), and 856 (blue), Kodak Wratten 24 (red) and 86 (green), and Kodak Wratten 0.2 neutral density with white onion skin typing paper for diffusion (white). The panel also included a shielded houselight centered 3.0 cm from its top edge and containing a Type 757 (0.8A) bulb.

Mounted side by side on supporting shafts extending through the panel were two crossbars of stainless steel tubing, 1.6 cm in outside diameter and 13.8 cm in length. The crossbars were separated by a gap of 0.4 cm and ended 3.9 cm from the side walls. They were 1.6 cm above the tilting floor and 4.5 cm from the surface of the panel. During this experiment, however, they had no function.

Access to the grain hopper was through a rectangular opening 4.9 cm high by 6.0 cm wide, laterally centered with its lower edge 8.9 cm above the floor. When raised to provide reinforcement, the hopper made an audible thump and was lighted from above by a concealed Type 757 bulb operated at 28 V dc. During such occasions, the keylight and houselight were extinguished.

Control and recording equipment housed in adjacent rooms included a 16-mm punched tape on a constant-speed sprocket for timing the stimulus sequence, solid state timing and switching modules, electromagnetic counters, and running-time meters.

*Procedure.* To deal with the large differences among individual birds characteristic of work in this area, we continued using a within-subject design, with the data for successive subjects treated as independent replications of a common procedure. To minimize the effect of any changes in performance that might occur as a function of the passage of time without regard to the experimental manipulations, we scheduled all comparisons to be made between immediately adjacent blocks of sessions. To minimize the possibility of inadvertent selection of data, we fixed the length of each block at 15

sessions. Occasional extensions were permitted if they could serve only to decrease, not to increase, the likelihood of confirming the initial conclusion.

For a given subject, experimental sessions were conducted at approximately the same time each day and lasted for 60 min. The daily routine followed that established in the previous work by Dinsmoor et al. (1986): Grain was made available for 3 s following each completion of a temporal cycle composed of seven variable-duration components, each lasting a mean of 30 s. Sixteen cycles constituted a session. The length of the successive components was controlled 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. Delivery of the grain was delayed, when necessary, until the criterion was met that no peck on the key had occurred within the previous 1 s. Under the standard baseline procedure, the key was illuminated from the rear with yellow light during the first four components of the procedure, with blue during the fifth, with white during the sixth, and with red during the seventh. The changes introduced in successive blocks of sessions are detailed in Table 1. During some session blocks, not analyzed in the present data, the current color was terminated for 1 s following each peck and replaced by green illumination of the key (see Dinsmoor et al., 1986). For this reason, all rates have been calculated from counts and times that exclude those 1-s periods.

### *Results and Discussion*

As in conventional autoshaping, the rate of pecking generated by a block clock varies a great deal from bird to bird and from session to session. (For a graphic representation, see Palya, 1985, Figure 1.) To reduce the influence of extreme readings that might cover up or be mistaken for systematic effects, we have reported our data in the form of medians for each set of five sessions.

The purpose of the first 28 sessions was to establish an asymptotic baseline performance. As may be seen in the first three rows of Table 2, substantial rates of pecking were generated; these reached maximum levels in the sixth (Birds 1635, 1914, and 1963) or seventh (Bird 1633) component of the interval between de-

Table 1

Experiment 1: Number of sessions under each condition, sequence of key colors, and use of termination procedure. Each of the periods varied in duration, with a mean of 30 s. Grain was presented at the end of the seventh period. Under the termination procedure, each key peck was followed by a 1-s substitution of green for the color currently on the key.

| Condition | Number of sessions | First four components | Fifth component | Sixth component | Seventh component | Colors terminable |
|-----------|--------------------|-----------------------|-----------------|-----------------|-------------------|-------------------|
| 1         | 28                 | yellow                | blue            | white           | red               | none              |
| 2         | 15                 | yellow                | blue            | white           | red               | all               |
| 3         | 15                 | yellow                | blue            | white           | red               | none              |
| 4         | 15                 | yellow                | blue            | dark            | red               | none              |
| 5         | 15                 | yellow                | blue            | white           | red               | none              |
| 6         | 15                 | dark                  | blue            | white           | red               | none              |
| 7         | 20                 | dark                  | blue            | white           | red               | all               |
| 8         | 15                 | yellow                | blue            | white           | red               | all               |
| 9         | 15                 | yellow                | blue            | white           | red               | none              |
| 10        | 15                 | yellow                | blue            | white           | dark              | none              |
| 11        | 20                 | yellow                | blue            | white           | purple            | none              |

liveries of food. Birds 1963 and 1635 did not peck very much during the first four components (yellow stimulus), but Birds 1633 and 1914 frequently pecked more than 100 times per session.

We also maintained records of the number of shifts in lateral position and the percentage of time spent on the left or right side of the chamber, classified in the same way as the key pecking, but could detect no trends warranting more extensive analysis.

*Darkening the key during the sixth component.* We began our examination of the effect of darkening the key by removing the white illumination during the next-to-last (sixth) component in Condition 4 and restoring it in Condition 5 (see Table 2). When the key was darkened, Bird 1914 virtually ceased to peck during that component. The other 3 birds all showed initial declines in rate, with some indication of a recovery within the 15-session block. Only for Bird 1633, however, did this recovery appear to be complete. The rates for Birds 1633, 1914, and 1963 appeared to have been reduced in the component immediately preceding the darkening of the key (fifth component) as well, and they remained low during the subsequent block of baseline sessions. Bird 1914 responded somewhat less often than before during the final component (immediately following the darkened key), but there was no evidence of a change in the rate of pecking by any bird at any other point in the interval between deliveries of grain. When the white illumination was restored during the sixth

component (Condition 5), the rates in that component returned to a level similar to those observed prior to the use of the darkened key but did not typically remain that high.

*Darkening the key during the first four components.* When the yellow illumination was removed from the key during the early part of the interval (Components 1 through 4), the results were less conclusive (Table 2, Condition 6) but remained consistent with the general finding that darkening the key tended to reduce the rate of pecking. All 4 birds showed possible increases in rate in Component 5 (immediately following the darkened key), but these were of substantial magnitude only for Birds 1635 and 1914, the 2 birds that had shown clear declines in rate in the presence of the darkened key. Both of the latter birds continued to peck at higher than usual rates with continued darkening of the key during another 15 sessions (not shown).

*Darkening the key during the last component.* Under Condition 10, the key was darkened during the last of the seven components making up the interval between deliveries of grain. For all 4 birds, the rate of pecking declined in the presence of the darkened key (Figure 1; for details, see Table 2). Without obvious exception, it also declined throughout the rest of the interval. Often these declines were substantial. The pervasive effect of darkening the key during the final component of the block clock is, in all probability, related to that component's temporal proximity to the receipt of the food. Because the performance during earlier por-

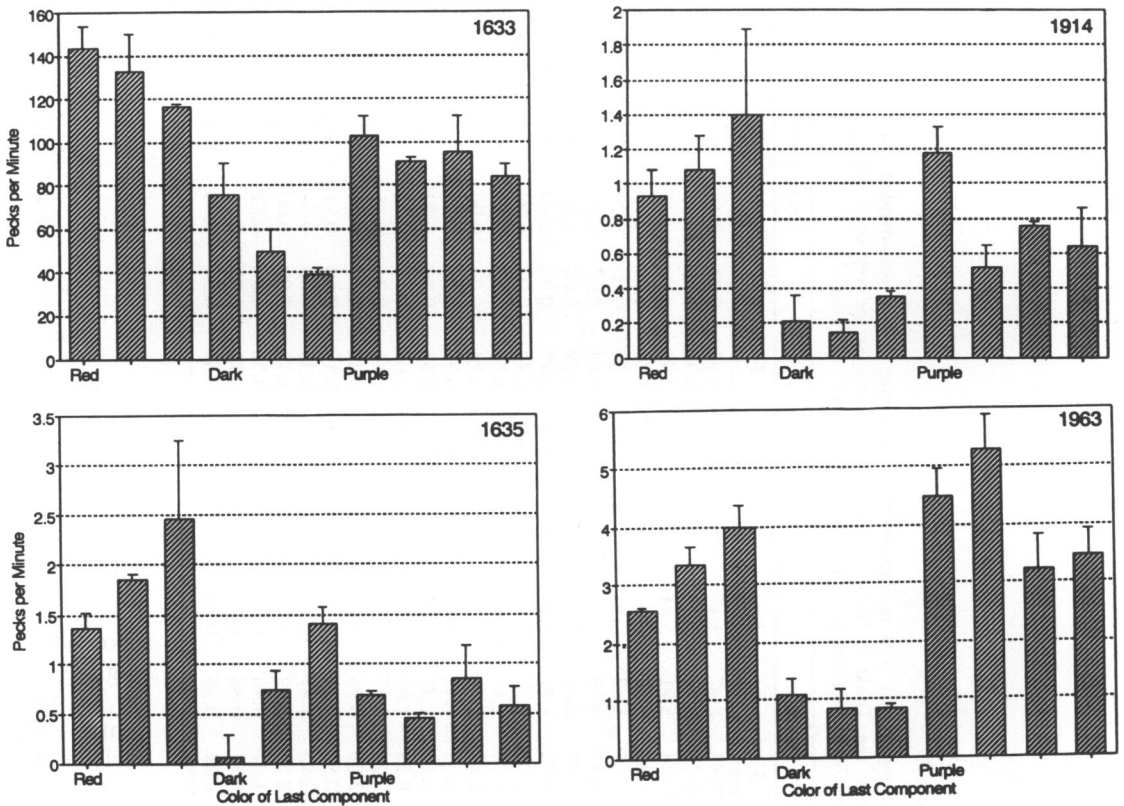


Fig. 1. Successive 5-day medians for rate of pecking during the final segment of the interval between food deliveries when the key was red (baseline), dark, or purple (novel color). The vertical lines indicate the semiinterquartile range. For all 4 birds, the rate with the darkened key was lower than during baseline, and for 3 of the 4 it was lower than with the novel color. However, in only one case did recovery in the presence of the novel color appear to reach the level attained during baseline.

tions of the interval may depend either on higher order conditioning or on some more direct form of induction from the pecking generated in the presence of this stimulus (but see Palya, 1985, p. 329), it is not surprising that in this case the decline in rate extended throughout the entire interval (see also Condition 3 of Experiment 2).

*Substituting a new color during the final component.* To determine whether the decremental effect was specific to a particular physical configuration (the darkened key) or might be a more general consequence of altering the original stimulus, in Condition 11 we presented a new color (purple) as a replacement both for the original red illumination and for the subsequent darkening of the key. This change resulted in recovery in the rate of pecking during the final component for Birds 1633, 1914, and

1963—providing additional evidence for the suppressive effect of the darkened key—but not for Bird 1635 (see Figure 1 and Table 2). Only for Bird 1963, however, did the recovery appear to be complete, even though we extended our test to 20 sessions before ending the experiment. Pecking in earlier portions of the interval also increased in some instances but for the most part did not return to the levels observed in other phases of the experiment. The incomplete nature of the recovery was not anticipated. It was not clear whether it should be attributed to the novelty of the color used as a replacement in the final part of the interval or whether it represented a lingering, possibly irreversible effect of the intervening operation of darkening the key. The issue was taken up again in Experiment 2 (see Conditions 2, 3, and 4).

Table 2

Experiment 1: Median number of pecks per minute for each five sessions (rows). The interval between deliveries of food was divided into seven components, each averaging 30 s (columns). For color sequence, see Table 1. Interventions included leaving the key dark during Component 6, during Components 1 through 4, and during Component 7, and replacing the red with purple in Component 7.

| Condition   | Bird 1633 |       |        |        |      | Bird 1635 |       |      |      |       | Bird 1914 |      |      |      |       | Bird 1963 |      |      |       |      |
|-------------|-----------|-------|--------|--------|------|-----------|-------|------|------|-------|-----------|------|------|------|-------|-----------|------|------|-------|------|
|             | 1-4       | 5     | 6      | 7      | 1-4  | 5         | 6     | 7    | 1-4  | 5     | 6         | 7    | 1-4  | 5    | 6     | 7         | 1-4  | 5    | 6     | 7    |
| 3 Baseline  | 3.07      | 31.71 | 112.50 | 170.37 | 1.07 | 6.38      | 24.95 | 6.47 | 3.45 | 13.50 | 15.23     | 4.80 | 0.03 | 0.44 | 6.91  | 8.38      | 0.00 | 0.15 | 10.09 | 5.14 |
|             | 4.25      | 26.44 | 130.12 | 165.69 | 6.09 | 4.43      | 31.72 | 6.28 | 3.41 | 8.61  | 24.84     | 3.85 | 0.00 | 0.15 | 10.09 | 5.14      | 0.00 | 0.32 | 10.40 | 7.21 |
| 4 6 Dark    | 17.55     | 34.15 | 112.80 | 167.06 | 1.41 | 2.24      | 30.34 | 5.91 | 5.84 | 4.42  | 18.22     | 2.58 | 0.00 | 0.00 | 0.00  | 2.96      | 0.00 | 0.00 | 3.55  | 4.92 |
|             | 5.96      | 19.89 | 33.45  | 136.68 | 0.88 | 4.48      | 11.85 | 5.67 | 4.66 | 2.70  | 0.11      | 1.70 | 0.00 | 0.00 | 0.00  | 4.75      | 0.00 | 0.00 | 10.77 | 5.61 |
|             | 3.76      | 21.57 | 76.08  | 162.70 | 1.64 | 6.33      | 11.63 | 5.82 | 7.39 | 1.77  | 0.23      | 1.54 | 0.00 | 0.00 | 0.00  | 4.75      | 0.00 | 0.00 | 10.77 | 5.61 |
| 5 Baseline  | 2.99      | 31.88 | 112.16 | 192.51 | 1.74 | 5.72      | 18.12 | 5.88 | 5.66 | 1.45  | 0.56      | 0.64 | 0.00 | 0.00 | 0.00  | 4.75      | 0.00 | 0.00 | 10.77 | 5.61 |
|             | 1.74      | 24.36 | 102.72 | 172.76 | 0.76 | 4.96      | 44.47 | 6.48 | 2.88 | 1.53  | 18.74     | 1.79 | 0.00 | 0.00 | 0.00  | 4.75      | 0.00 | 0.00 | 10.77 | 5.61 |
|             | 2.16      | 23.70 | 91.85  | 157.28 | 0.64 | 5.17      | 32.53 | 4.41 | 5.26 | 1.84  | 20.71     | 1.91 | 0.00 | 0.00 | 0.00  | 2.59      | 0.00 | 0.00 | 2.59  | 4.51 |
| 6 1-4 Dark  | 2.56      | 20.90 | 101.90 | 140.98 | 1.14 | 5.01      | 21.03 | 2.37 | 2.76 | 0.88  | 7.46      | 1.40 | 0.00 | 0.00 | 0.00  | 3.64      | 0.00 | 0.00 | 3.64  | 3.95 |
|             | 15.69     | 27.20 | 92.76  | 124.38 | 0.91 | 16.94     | 29.78 | 2.41 | 0.00 | 5.32  | 16.50     | 1.58 | 0.00 | 0.15 | 6.94  | 4.38      | 0.00 | 0.15 | 6.94  | 4.38 |
|             | 3.15      | 21.56 | 112.39 | 124.61 | 0.18 | 19.72     | 21.95 | 2.30 | 0.00 | 2.84  | 8.65      | 1.24 | 0.00 | 0.00 | 5.98  | 3.20      | 0.00 | 0.00 | 5.98  | 3.20 |
| 9 Baseline  | 0.49      | 20.69 | 137.46 | 139.46 | 0.00 | 15.96     | 16.67 | 1.42 | 0.00 | 1.53  | 8.76      | 0.91 | 0.00 | 0.00 | 5.98  | 3.45      | 0.00 | 0.00 | 5.98  | 3.45 |
|             | 1.87      | 14.07 | 115.59 | 143.75 | 0.75 | 9.90      | 9.60  | 1.37 | 2.80 | 0.71  | 10.69     | 0.93 | 0.30 | 0.22 | 4.04  | 2.55      | 0.30 | 0.22 | 4.04  | 2.55 |
|             | 1.11      | 10.02 | 91.14  | 132.85 | 0.43 | 10.33     | 8.59  | 1.85 | 0.56 | 1.14  | 12.29     | 1.08 | 0.35 | 0.35 | 4.26  | 3.34      | 0.35 | 0.35 | 4.26  | 3.34 |
|             | 0.75      | 7.39  | 82.94  | 116.46 | 0.71 | 10.91     | 9.78  | 2.47 | 0.36 | 0.58  | 12.14     | 1.40 | 0.26 | 0.45 | 5.48  | 3.97      | 0.26 | 0.45 | 5.48  | 3.97 |
| 10 7 Dark   | 1.70      | 10.00 | 90.50  | 75.60  | 0.13 | 7.46      | 3.59  | 0.96 | 0.28 | 0.24  | 3.25      | 0.21 | 0.00 | 0.06 | 0.71  | 1.07      | 0.00 | 0.06 | 0.71  | 1.07 |
|             | 0.55      | 5.18  | 76.98  | 49.54  | 0.09 | 5.24      | 2.81  | 0.74 | 0.13 | 0.24  | 1.23      | 0.15 | 0.00 | 0.11 | 3.16  | 0.84      | 0.00 | 0.11 | 3.16  | 0.84 |
|             | 0.44      | 6.92  | 51.55  | 39.34  | 0.08 | 6.14      | 2.93  | 1.41 | 0.25 | 0.21  | 2.75      | 0.35 | 0.00 | 0.24 | 1.72  | 0.85      | 0.00 | 0.24 | 1.72  | 0.85 |
| 11 7 Purple | 0.23      | 4.27  | 62.33  | 102.85 | 0.03 | 3.18      | 2.28  | 0.69 | 0.49 | 0.44  | 7.30      | 1.18 | 0.00 | 0.00 | 2.05  | 4.49      | 0.00 | 0.00 | 2.05  | 4.49 |
|             | 0.27      | 3.80  | 47.40  | 91.01  | 0.39 | 2.92      | 1.87  | 0.46 | 0.26 | 1.55  | 5.89      | 0.52 | 0.00 | 0.22 | 2.45  | 5.30      | 0.00 | 0.22 | 2.45  | 5.30 |
|             | 0.28      | 4.83  | 47.09  | 95.56  | 0.83 | 2.96      | 3.17  | 0.86 | 0.28 | 1.70  | 6.50      | 0.76 | 0.00 | 0.14 | 3.37  | 3.23      | 0.00 | 0.14 | 3.37  | 3.23 |
|             | 0.22      | 3.38  | 65.33  | 84.47  | 0.79 | 2.37      | 4.84  | 0.58 | 0.10 | 0.44  | 3.95      | 0.64 | 0.00 | 0.00 | 2.08  | 3.46      | 0.00 | 0.00 | 2.08  | 3.46 |

### Summary

The purpose of Experiment 1 was to examine the effect on the rate of pecking of darkening the key during various portions of the interval between deliveries of grain. This manipulation was introduced on three separate occasions at three different points within the interval. In almost all instances, for all birds and all components, this procedure reduced the rate of pecking in that part of the interval during which the key was darkened. When it was the final stimulus in the series that was replaced by the darkened key, the rate also declined during earlier portions of the interval. The data confirm the immediate hypothesis that darkening the key reduces the rate of pecking. In turn, this form of suppression provides a plausible explanation for the temporal distribution of pecking under standard autoshaping procedures, where it is largely confined to periods when the conditional stimulus (normally a lighted key) is present.

### EXPERIMENT 2

The data obtained in the first experiment indicated that darkening the key during one component produced a decrement in the rate of pecking during that, and sometimes other, components of the sequence. But it was not clear whether the decremental effect was specific to the particular physical stimulus of a darkened key or was more general, that is, characteristic of other changes in stimulation as well. When we replaced darkening of the key in the last component of the sequence with a novel illumination, purple, we did not get a complete recovery of the previous baseline performance (Block 11). Aside from confirming the effect of darkening the key, the main purpose of the second experiment was to determine whether the incomplete nature of the recovery observed in Block 11 should be attributed to a suppressive effect produced by the new color or whether it represented a continuing, not readily reversible, consequence of the earlier darkening of the key. Therefore, in Experiment 2, we introduced the change in color before rather than after the darkening of the key.

### Method

*Subjects.* Three new birds—66, 12773, and 12825—served as subjects. Like the birds in

Table 3

Experiment 2: Number of sessions in each condition and sequence of key colors in Experiment 2. Each of the seven components varied in duration, with a mean of 30 s. Grain was presented at the end of the seventh component.

| Condition | Number of sessions | First four components | Fifth component | Sixth component | Seventh component |
|-----------|--------------------|-----------------------|-----------------|-----------------|-------------------|
| 1         | 29                 | white                 | blue            | red             | green             |
| 2         | 15                 | white                 | blue            | red             | yellow            |
| 3         | 15                 | white                 | blue            | red             | dark              |
| 4         | 15                 | white                 | blue            | red             | green             |
| 5         | 15                 | white                 | red             | red             | red               |
|           | 40                 |                       | feeding         | only            |                   |
| 6         | 15                 | white                 | red             | red             | red               |

the first experiment, they were 7 years old and experimentally naive.

*Apparatus.* The apparatus was the same as that used in Experiment 1.

*Procedure.* The daily routine was the same as in the previous experiment except that this time the baseline color sequence was white, blue, red, and green (see Table 3). Interventions included the substitution of yellow for green in the final component (second condition), darkening of the key in the final component (third condition), restoration of the original green (fourth condition), and the use of a common color (red) throughout the last three components (fifth and sixth conditions). The fifth and sixth conditions were separated by 40 days, during which no experimentation was conducted.

### Results and Discussion

Substantial baseline performances were generated in Birds 66 and 12825, which were trained for 32 and 29 sessions, respectively, on the original sequence of colors. Bird 12773, however, was added as a replacement for a bird that did not peck the key, and it received only 11 sessions of training before time constraints made it necessary to move on to the next experimental condition. Its performance did not appear to have stabilized. The median rates in each component for the last five sessions of training are shown in the first row of Table 4.

*New color during the last component.* In the second experimental condition, we substituted a new key color, not previously seen by these birds (yellow), for the green that had originally



Table 4

Experiment 2: Median number of pecks per minute for five sessions (rows). The interval between deliveries of grain was divided into seven components, each averaging 30 s (columns); under the baseline procedure, the first four components, as a group, and Components 5 through 7 were each accompanied by a different color on the key. Interventions included changing the key to yellow during Component 7, leaving it dark, and turning it back to green. Under the final procedure, the key was white (as usual) during Components 1 through 4 and red during Components 5 through 7.

|           |          | Bird 66 |       |       |       | Bird 12773 |       |       |      | Bird 12825 |       |       |      |
|-----------|----------|---------|-------|-------|-------|------------|-------|-------|------|------------|-------|-------|------|
| Condition |          | 1-4     | 5     | 6     | 7     | 1-4        | 5     | 6     | 7    | 1-4        | 5     | 6     | 7    |
| 1         | 7 Green  | 2.88    | 14.30 | 44.03 | 29.17 | 0.00       | 1.55  | 2.29  | 3.89 | 0.31       | 11.55 | 25.32 | 2.01 |
| 2         | 7 Yellow | 2.88    | 18.83 | 50.13 | 9.24  | 0.00       | 8.74  | 12.62 | 2.64 | 0.13       | 6.48  | 25.37 | 0.58 |
|           |          | 2.86    | 12.17 | 49.73 | 39.53 | 0.30       | 11.62 | 21.08 | 3.32 | 0.16       | 7.14  | 21.87 | 1.33 |
|           |          | 2.52    | 9.56  | 36.78 | 25.91 | 0.33       | 9.82  | 25.50 | 3.56 | 0.12       | 4.99  | 27.09 | 2.71 |
| 3         | 7 Dark   | 1.43    | 13.91 | 26.97 | 0.77  | 0.00       | 2.85  | 9.92  | 0.23 | 0.00       | 3.06  | 30.30 | 1.49 |
|           |          | 2.13    | 13.93 | 40.11 | 1.25  | 0.00       | 4.76  | 16.44 | 0.31 | 0.00       | 3.31  | 21.01 | 2.58 |
|           |          | 1.98    | 18.49 | 38.32 | 1.54  | 0.00       | 1.47  | 4.39  | 0.10 | 0.00       | 0.65  | 18.44 | 2.27 |
| 4         | 7 Green  | 5.65    | 19.97 | 45.73 | 20.47 | 0.00       | 3.43  | 5.74  | 1.70 | 0.00       | 0.53  | 12.22 | 0.78 |
|           |          | 2.83    | 11.19 | 21.97 | 3.72  | 0.00       | 3.09  | 7.49  | 1.77 | 0.00       | 0.32  | 16.20 | 1.05 |
|           |          | 1.92    | 9.68  | 18.99 | 6.46  | 0.00       | 1.36  | 7.71  | 0.67 | 0.00       | 0.17  | 9.16  | 0.61 |
| 5         | 5-7 Red  | 2.43    | 13.83 | 4.71  | 3.55  | 0.00       | 2.85  | 0.72  | 0.11 | 0.00       | 2.05  | 0.94  | 0.52 |
|           |          | 2.01    | 9.72  | 2.84  | 1.97  | 0.00       | 1.27  | 0.10  | 0.10 | 0.00       | 2.79  | 0.64  | 0.00 |
|           |          | 4.17    | 12.63 | 6.26  | 5.85  | 0.00       | 1.05  | 0.20  | 0.00 | 0.00       | 4.87  | 0.69  | 0.16 |
| 6         | 5-7 Red  | 0.90    | 15.03 | 6.80  | 4.92  | 0.00       | 3.36  | 0.68  | 0.15 | 0.03       | 5.43  | 0.72  | 0.64 |
|           |          | 2.27    | 32.43 | 40.29 | 16.63 | 0.00       | 4.73  | 1.23  | 0.53 | 0.00       | 1.72  | 1.37  | 0.72 |
|           |          | 1.55    | 15.34 | 5.66  | 2.95  | 0.00       | 1.37  | 0.73  | 0.11 | 0.00       | 2.44  | 0.21  | 0.00 |

been used as the last color in the series. The purpose of this procedure was to provide a control for the possibility that the effect to be produced in the third experimental condition by darkening the key might not be specific to that particular physical stimulus but might be a more general one, such as might be produced by the substitution of any unfamiliar stimulus for the one with which the birds had been trained.

As may be seen in the second row of Table 4 (Component 7) and in the second bars of Figure 2, for the first five sessions after we substituted yellow for green all 3 birds did peck at lower rates during the final component. However, this effect did not last for the remaining sessions under Condition 2. After the initial dip, all 3 birds returned to approximately the same level of performance during subsequent sessions. In none of the birds was there any evidence of a continued suppression that could be attributed to the new color. Therefore, the incomplete nature of the recovery noted in Condition 11 of Experiment 1 does not appear to be a characteristic product of introducing a novel color but presumably represents a long-term effect attributable to the prior sessions with the darkened key.

*Darkened key during the last component.* When the key was darkened during the last component of each cycle (Condition 3), instead of turning green or yellow, Bird 12825 was not greatly affected. For Birds 66 and 12773, however, the rate of pecking during the final component declined to much lower levels (Figure 2 and Table 4). The rate remained low not only for the rest of the time the dark-key procedure was in effect, confirming the results obtained in Condition 10 of Experiment 1, but also during subsequent sessions (Condition 4) when the original color was restored. These data provide confirmatory evidence for the persisting effect of darkening the key, suggesting once again that this was the factor responsible for the incomplete character of the recoveries obtained with the novel color in Condition 11 of Experiment 1. As in Experiment 1, there was also considerable evidence of a reduction in pecking rates in the presence of colors coming earlier in the sequence (Table 4).

The low level of performance when the key is dark for the last part of the interval is consistent with previous data on "trace conditioning" under the autoshaping procedure (e.g., Kaplan & Hearst, 1982; Rescorla, 1982). However, our data indicate that this operation

suppresses responding not only in the presence of the immediately preceding stimulus (the conditional stimulus in trace autoshaping) but also more generally, that is, throughout the entire interval between food deliveries. Extension of the suppressive effect to earlier parts of the interval indicates that the final stimulus must have served some type of mediating function, transmitting the effects of the food deliveries to those portions of the interval. By contrast, when the key was darkened at the beginning of the interval (during Components 1 through 4 under Condition 6 of Experiment 1), rates during the immediately subsequent component shifted, if at all, in the opposite direction.

Although the stimulation during our equivalent of the intertrial interval (Components 1 through 4) differed from that in the gap (the dark key in the final component), it did not overlap in time with either of the later components. Therefore, there was no "local context," as defined by Kaplan and Hearst (1982), to facilitate approach to or pecking of the key.

*Return to the original color.* The pigeons serving as subjects in Experiment 1 were also exposed to a condition in which the key was darkened during the last component (Condition 10). When the dark key was replaced by a novel color (Condition 11), 3 of the 4 birds showed at least partial recovery. However, in most cases they did not return to the previous rate of pecking either in the final component or in earlier parts of the interval. In Experiment 1, it was not clear whether the incomplete nature of the recovery was related to the unfamiliarity of the new color or was a persisting effect of the prior experience with the darkened key. This time, having already tested the effect of substituting an unfamiliar color and having found the effect to be limited in duration, we returned to the original training color (Condition 4) to see whether pecking would return to its previous level.

Even though green was familiar to the birds, pecking remained lower in its presence than it had been immediately before the sessions with the darkened key (Figure 2 and Table 4). Although Bird 66, which showed the least initial reduction during the earlier components of the interval, may have recovered its previous level of performance, Birds 12773 and 12825 did not (Table 4). The incomplete recovery, first noted in Experiment 1, does not appear

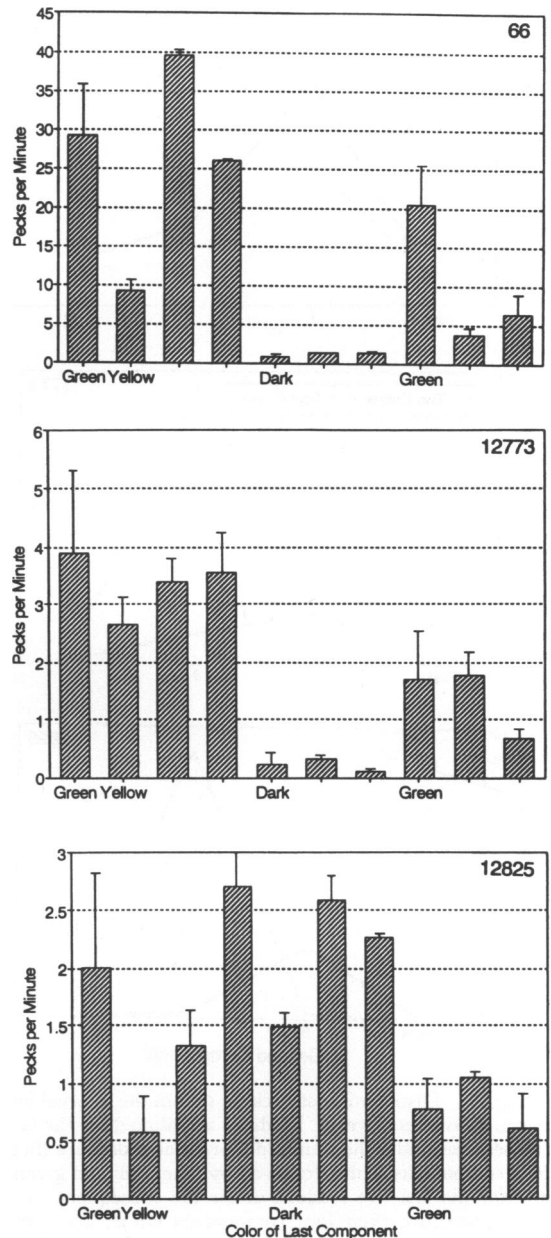


Fig. 2. Successive 5-day medians for rate of pecking during the final segment of the interval between food deliveries when the key was green (end of acquisition), yellow (novel color), dark, and green again (return to baseline). The vertical lines indicate the semiinterquartile range. The novel color produced an initial decrement, followed by a recovery; darkening the key produced a severe decrement in 2 of the birds but had little effect on the 3rd; and the rate when green was restored did not reach the level it had attained at the end of acquisition.

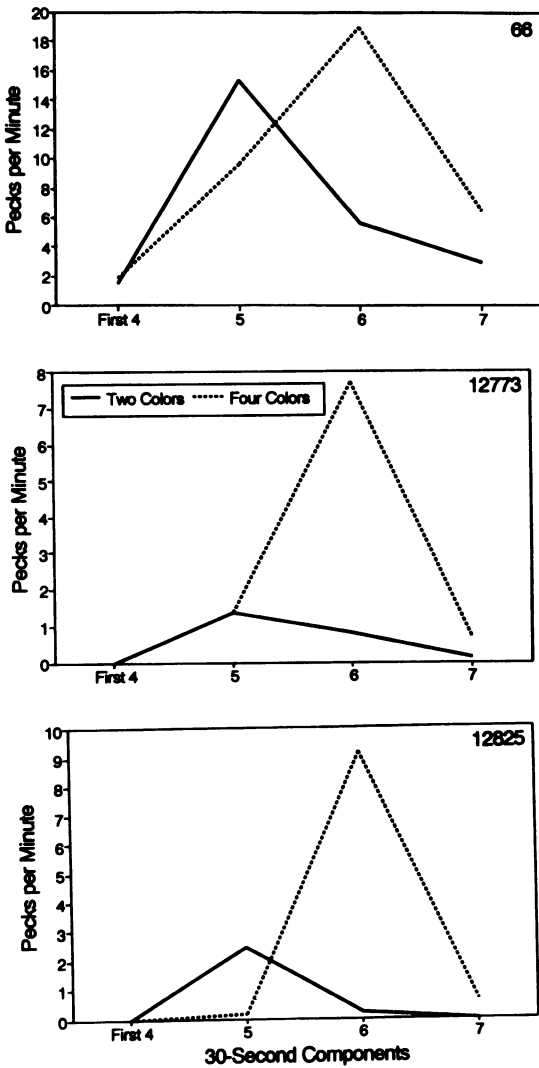


Fig. 3. Distribution of pecking within the interval between deliveries of grain. Medians are plotted for the last five sessions under the standard four-color procedure (first four components white, followed by blue, red, and green) and for the last five sessions under the subsequent two-color procedure (first four components white, last three red). Note that in two of the three cases, pecking in Component 5 increased in absolute rate under the two-color procedure.

to be peculiar to the use of a new color but to be a more general and less avoidable aftereffect of using a darkened key in the final component.

*Same color for last three components.* The procedure used in the last 30 sessions of Experiment 2 was initially devised as a control for some data previously published on the effect of stimulus termination (Dinsmoor *et al.*, 1986) but may have broader implications. This

time we did not terminate any stimuli. As usual, we presented white illumination of the key during Components 1 through 4; then we used a single color for all of the last three components, substituting the red used in Component 6 for the blue and the green originally used in Components 5 and 7.

Reducing the number of stimuli in the sequence profoundly altered the temporal distribution of responding within the interval between food deliveries (see Figure 3 and Table 4). In Components 6 and 7, the rate of pecking declined; in Component 6, the rate for all 3 birds had been substantially higher than in any other component, but now in all three cases it fell well below that in Component 5. One consequence of the drop in Component 6 was a large decrease in the total number of pecks within the interval, even when compared with the already low totals for the previous two experimental conditions. Another change produced by the new procedure was that in 2 of the 3 birds, pecking in Component 5 increased in rate. (In the 3rd bird, it remained the same.) As a result of these opposing changes in Components 5 and 6, the peak rate now came much earlier in the interval than ever before.

A peak in the fifth of seven equal components seems extremely anomalous. Normally, experimenters delivering grain to pigeons after the passage of a substantial amount of time or the emission of a substantial number of responses expect the rate of pecking to reach a maximum just prior to the arrival of the food. When deviations from this rule have been noted (e.g., Caplan, Karpicke, & Rilling, 1973; Dinsmoor *et al.*, 1986; Hendry & Dillow, 1966; Jwaideh, 1973; Kendall, 1972), they have occasioned special comment and in many cases an attempted explanation. Although workers in the Pavlovian tradition are aware that the peak response will normally precede the unconditional stimulus, the expectation is that at least in relative terms it will be close to the end of the interval. But even after 30 sessions, the present data continued to violate these expectations. The peak rate was closer to the beginning of the conditional stimulus than to the arrival of the grain.

For past findings of this nature, several explanations have been proposed. The largest effects have been found in a pair of studies employing observing responses. (The same phenomenon has been noted in similar, unpublished work conducted in this laboratory.)

In the first of these studies, Hendry and Dillow (1966, p. 344) suggested that "the terminal decline in observing response rate . . . was to be expected if observing behavior were maintained by the temporal significance of the stimuli obtained; once the final stimulus (S1) was observed, no further, different, timing stimulus could be obtained." But the present case seems quite different: Although the red illumination of the key could still be treated as a clock stimulus, pecking is not reinforced by production of that stimulus but occurs in its presence. In another study, Kendall (1972) suggested that the lowered rate of pecking on the observing key when the third and final clock stimulus was being produced might be attributable either to competition with food-reinforced pecking on another key or to the requirement that at least 3 s must have elapsed since the last observing response before the grain was delivered. In our work, we had a similar delay provision, but that provision was also in effect during earlier sessions when we did not find such an early peak.

It is tempting to relate the current finding to the sometimes suppressive effect of a CS followed by response-independent food on an operant baseline ("positive conditioned suppression"), but the study that appears to approximate the present conditions most closely as to species, response, locus of stimulus, and temporal parameters is one by Smith (1974). When the stimulus was imposed on low baseline rates, Smith typically found no effect at a CS duration of 120 s and very small positive effects on the rate of pecking at 30 and 60 s (Figure 1, p. 218).

Jwaideh (1973) noted a reduction in rate of pecking before the completion of the response requirement under a chained fixed-ratio (or block counter) procedure and suggested that "a possible explanation is that the bird slowed down toward the end of the ratio run in order to get ready to begin eating" (p. 266). The same interpretation has frequently been advanced in the autoshaping literature. But these effects have extended over only a few seconds before the arrival of the grain, and it seems unlikely that such a mechanism could account for pigeons slowing down for the last 60 s or so of a stimulus that typically appears some 90 s before the delivery of the grain.

In autoshaping, it has been suggested (e.g., Lucas, Deich, & Wasserman, 1981; Wasserman, 1973) that pecking is more effectively

elicited by the onset of a stimulus than by its continuation, but a pattern of deceleration in the presence of the CS is by no means universal. In fact, using a trace conditioning procedure, Gibbon, Farrell, Locurto, Duncan, and Terrace (1980) found a positive acceleration throughout the period of CS presentation. If a negative acceleration should prove to be more typical, such a finding would raise a question as to how well autoshaping data may be said to conform to the normal Pavlovian model.

On the basis of data currently available, then, the phenomenon of an early peak in the rate of pecking remains difficult to explain.

### *Summary*

When a novel color was substituted for the last stimulus in the sequence leading to food, the disruption in performance was only temporary. But when the key was darkened for the corresponding period, pecking was more broadly and more lastingly suppressed. Even when the original color was restored, the rate of pecking did not return all the way to its pervious value. This result encourages us to continue thinking of the standard autoshaping procedure as a variant of the block clock in which responding has been suppressed throughout a large part of the interval between deliveries of grain by darkening the key. In particular, it suggests that the poor performance observed under trace autoshaping procedures (Kaplan & Hearst, 1982; Rescorla, 1982) may be attributed in part to the suppressive effects of a particular physical stimulus presented during a critical portion of that interval, just prior to the food.

Reducing the number of clock stimuli from four to two also reduced the total number of pecks per session, but further work is needed to tease out the relevant parameters. A peak in the rate of pecking during the first third of the second stimulus, followed by a lower rate during the final 60 s (on average) before the delivery of the food, may represent a pervasive phenomenon but one that does not seem predictable from existing theoretical accounts.

### CONCLUSIONS

The experiments reported here were conducted as an initial test of the feasibility of treating conventional autoshaping as a fragmentary version of the block clock procedure in which only one of the successive colors or

patterns is presented and pecking at other times is discouraged by darkening the key. The results confirmed our expectations. We found that in most cases, turning off the illumination behind the key did reduce the rate of pecking and that this effect was broader and longer lasting than that produced by other changes in stimulation, such as substituting a novel color. As a specific physical stimulus, a darkened key has behavioral properties that differ from those possessed by keys that are lighted. Although not all subjects are necessarily affected, these properties account, at least in part, for differences in the average number of pecks generated by the two procedures. Our data also suggest that the number of stimuli may play a role, but it will be difficult to manipulate this factor without changing other parameters. The suppressive properties of the darkened key also account in some part for the familiar pattern of results in which autoshaped pecking is largely restricted to times when the conditional stimulus is present. Although the present findings are limited in scope, they provide initial support for the fruitfulness of the current approach and suggest that it may be desirable to continue developing and testing other implications of treating autoshaping in this fashion.

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