

Duration Discrimination Is Better with Food Access as the Signal than with Light as the Signal

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In Experiment 1 a go/no-go discrimination procedure was used to compare control of five pigeons' keypecking by food-access duration with control by light duration. Pecks to an illuminated key were reinforced with grain following 10-sec presentations of food access or houselight, but not after 5-sec presentations of either stimulus. Each subject discriminated food-access duration faster and to a greater degree than light duration. In four between-subject replications, pigeons discriminated food-access duration better than the duration of a localized light, the feeder light and a keylight, and with either water or food as reinforcement. In Experiment 2 control by durations of food access and light was compared using a conditional right-left choice procedure (two pigeons), and a delayed symbolic matching-to-sample procedure (six pigeons). Under both, choice accuracy again was higher on food-access trials. The results of Experiment 3, in which two pigeons received generalization trials with durations of food access and light that were intermediate to the training values, confirmed that responding was controlled by the duration dimension of both food access and light. The superior control by food access is consistent with previous evidence that food is an effective and memorable stimulus, possibly because of its biological importance. These results also provided empirical support for the commonly made assumption that stimuli differ in effectiveness. As well, the results show that the stimulus to be discriminated can play an important role in the accuracy of duration discriminations, a fact which has implications for the study of temporal discriminations in animals.

Many investigators assume that certain stimuli acquire control of responding more readily and to greater degree than other stimuli. For example, Mackintosh (1977, p. 483) stated:

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the amount of training required to establish control by a particular stimulus will surely vary from stimulus to stimulus. . . No one would deny that some stimuli appear to be more effective for some subjects than are others.

Although there are some experimental data consistent with this assumption, surprisingly few studies have provided unambiguous evidence for differences in the effectiveness of stimuli.

Several attempts to demonstrate differences in effectiveness between stimuli have involved comparisons across dimensions. For example, Chow (1953) compared monkeys' acquisition of a contour (circle vs square), a color (red vs green), and a pattern (diamonds vs stripes) discrimination and found that the contour discrimination was acquired most rapidly. Carter and Eckerman (1975) compared control by color (red vs green) with control by line tilt (180° vs 90°) in a matching-to-sample task with pigeons. Matching was established faster, and terminal accuracy was higher, with color than with line tilt.

Unfortunately, the results of these studies are somewhat ambiguous. First, it is not clear what dimensions of the stimuli controlled behavior. For example, a discrimination between red and green could reflect control by any or all of a number of dimensions, such as wavelength, intensity, or purity. There is a second more fundamental problem: it is not clear whether the *difference between the two values* selected from each dimension was equal. Such differences are very important because the extent of control acquired by a given dimension varies directly with the difference between the values used as discriminative stimuli. For example, two wavelengths differing by about 20 nm will control pigeons' keypecking readily, whereas two wavelengths differing by about 2 nm do not (Blough, 1972). Therefore, comparisons of different stimuli across stimulus dimensions require one to equate the differences between values from each dimension. One method for doing this would be to use psychophysical procedures to find just noticeable differences (jnds) along each dimension. Then, values from each dimension that differ by the same number of jnds could be selected to compare stimuli.

The effectiveness of stimuli also can be compared by using a dimension common to both stimuli as the basis of the comparison. A few comparisons of this sort have been attempted, but these too have suffered from problems. For example, Jarvik (1953) used wavelength as the common dimension to compare stimuli in a simultaneous discrimination procedure. Control of monkeys' choice behavior by the color of bread was compared to control by the color of squares of celluloid. Under one condition, bread of one color (red or green) was unflavored whereas bread of the other color was quinine adulterated. The monkeys were permitted to choose one of these. The color of bread rapidly controlled choice behavior; the monkeys avoided the quinine-adulterated bread. In a second condition,

the discriminative stimuli were red and green squares of celluloid located in front of pieces of unflavored and quinine-adulterated white bread. The color of the celluloid acquired little control of choice behavior, the monkeys chose the quinine-adulterated bread on almost half of the trials. Because the spatial and temporal contiguity between the stimulus, response, and reinforcer were not the same in the two conditions, it is impossible to determine whether the difference in control by the color of bread vs the color of celluloid was due to the stimuli themselves, or to differences in the nature of the task. Furthermore, the dimensions that controlled responding to the red and green bread or celluloid were not established. It is possible, for example, that the monkeys' responses were controlled by intensity differences between red and green.

A close examination of other reports of differences in effectiveness between stimuli (e.g., Delius & Emmerton, 1978; Dobrzecka, Szwejkowska, & Konorski, 1966; Harrison & Briggs, 1977) reveals that these studies also did not establish which dimension(s) of the stimuli controlled responding.

Thus, comparisons among different stimuli are not as easy as one might first imagine. First, a dimension common to each stimulus must be selected, or isometric scaling must be conducted if different dimensions are used. Second, evidence must be provided that the nominal dimension(s), actually control(s) responding. This latter requirement is discussed further in the introduction to Experiment 3.

Many dimensions are common only to a limited range of stimuli. For example, color is common to only some visual stimuli. Some dimensions that are common to stimuli perceived by different sensory modalities are not suitable for comparisons of such stimuli because they are measured in different units for each modality and therefore require rescaling in isometric units. Intensity, for example, is a property of both light and sound; however, one cannot equate a particular sound intensity difference with a particular light intensity difference without elaborate psychophysical studies.

One dimension that is common to all stimuli is duration. The values of this dimension can be equated accurately across stimuli, and can be manipulated easily within an experimental setting. Further, the duration dimension has been studied in a number of species and with a variety of procedures and with a number of stimulus modalities (e.g., Church & Deluty, 1977; Church, Getty, & Lerner, 1976; Elsmore, 1971, 1972; Kinchla, 1970; Perikel, Richell, & Maurissen, 1974; Reynolds & Catania, 1962; Roberts & Church, 1978; Stubbs, 1968, 1976a, 1976b; Zirix & Silberberg, 1978). Although various stimuli have been used in duration discrimination experiments with animals to date, no explicit comparisons of control by the duration of different stimuli have been conducted. Therefore, a comparison of stimuli using the duration dimension is also

relevant to the study of temporal discrimination in animals. Such a comparison might reveal that the nature of the stimulus is an important variable in the temporal control of behavior, a finding consistent with a large body of evidence suggesting that stimulus content influences the perception of temporal intervals in humans (e.g., Ornstein, 1969; Thomas & Brown, 1974).

If stimuli do differ in effectiveness, it seems possible that the largest differences might emerge between stimuli that differ substantially in terms of their biological importance to the organism. Stimuli important for survival, such as food or water, commonly are used to reinforce behavior; it would not be surprising if such stimuli also were very effective as discriminative stimuli (cf. Staddon, 1974).

Evidence from studies that have investigated stimulus control by food or water supports the assumption that these stimuli readily control behavior and are very memorable. For example, there is considerable evidence that the occurrence or nonoccurrence of food is a memorable event for hungry animals. Numerous reward alternation studies have demonstrated that the presence or absence of food reward will control rats' running speeds (e.g., Capaldi, 1967) and bar-press latencies (e.g., Wall & Goodrich, 1964) on the next trial, even when the trials are separated by up to 24 hr (e.g., Capaldi & Spivey, 1964). Similarly, the presence or absence of grain has controlled pigeons' keypecking over long delays in both delayed symbolic matching-to-sample tasks (Maki, Moe, & Bierly, 1977; Wilkie, 1978) and a response-independent go/no-go discrimination task (Botjer & Hearst, 1979). Studies of reward alternation also have demonstrated that magnitude of food reward can be remembered over long delays (Wolach, Sayeed, & Foster, 1972).

Several studies have shown that qualitative properties of reward also control behavior readily. For example, Pschirrer (1972) found that type of reward (milk vs food pellets) controlled rats' running speeds in an alternation paradigm, as well as their choice between two runways. Cruse, Vitulli, and Dertke (1966) used a procedure in which a standard food pellet initiated one schedule of reinforcement, and a sucrose pellet initiated a different schedule, and found good control of rats' bar-press rates and choice responses by the type of reward.

In view of this growing body of evidence that reinforcing stimuli are very effective in controlling conditioned behavior, it seemed worthwhile to compare control by such stimuli with control by a more "neutral" stimulus. Therefore, the present experiments selected food access and light as stimuli to compare. The duration dimension served as the basis for this comparison.

EXPERIMENT 1

Food-deprived pigeons were exposed to an elaboration of the go/no-go duration discrimination procedure used by Reynolds and Catania (1962).

Pecks to an illuminated key were reinforced with grain when the key illumination was preceded by one stimulus duration, but not when it was preceded by another stimulus duration. A grain-filled feeder (food access) served as the stimulus on half of the trials; the houselight served as the stimulus on the remaining trials. This procedure allowed within-subject comparisons of the acquisition of control by food-access duration and houselight duration.

In subsequent replications, control by food-access duration was compared to control by the duration of a localized light, a keylight, and the feeder light. These replications were included to determine whether control by food-access duration would differ in a consistent way from control by the duration of various forms of light. In two of these replications, keypecks were reinforced with water instead of food, to assess the possibility that such differences in control might be specific to food reinforced behaviors.

Method

Subjects

The subjects were six Silver King (Birds 1, 2, 6, 7, 8, and 9) and five White King (Birds 3, 4, 5, 10, and 11) pigeons. Bird 7 was experimentally naive; Birds 3 and 4 had received only autoshaping training prior to this experiment. The remaining subjects had varied experimental histories.

All subjects were deprived of food until they were between 80 and 85% of their free-feeding weights. They were maintained at these weights throughout the study by the mixed grain obtained during the experimental sessions, and post-session feedings of maple peas. Some subjects also were water deprived (see Table 1) and each day received only the 15 to 20 ml obtained during the experimental session.

All birds were housed in large individual homecages in which health grit always was available. Subjects that were not water deprived had unlimited access to water in their homecages.

Apparatus

A one-key pigeon chamber was used during the main experiment and Replications 1, 2, and 3. The clear plastic pecking key, which required a force of about 0.2 N to operate, was located on the center of one wall. An Industrial Electronics Engineers' Series 10 stimulus projector containing 2.8-W lamps was mounted behind the key and illuminated the key with a uniform field of green light. A BSR/LVE Model 114-10 solenoid-operated grain feeder that allowed access to mixed grain was located directly below the key. Feeder operations were accompanied by illumination of a 2.8-W lamp in the hopper. A solenoid-operated water dispenser was mounted on the wall to the left of the feeder. A plastic container, 3.5 cm in diameter, was mounted on the wall below the water dispenser. This served as a

receptacle into which a measured volume of water could be dispensed. A 4.8-W lamp was mounted on the wall 3 cm to the left of the water receptacle. The houselight consisted of two 2.8-W lamps mounted behind a metal panel above the key. When these were lit, reflected light from the panel to the white ceiling provided diffuse illumination of the entire chamber.

A two-key pigeon chamber was used during Replication 4. The two clear plastic keys, which required a force of about 0.2 N to operate, were located on one wall 18 cm apart. An Electronics Engineers' Series 10 projector, containing 2.8-W lamps, was mounted behind each key. These illuminated the left key with a uniform field of white light, and the right key with a uniform field of red light. A solenoid-operated grain feeder was centered on the same wall between and below the two pecking keys. Feeder operations were accompanied by illumination of a 2.8-W lamp in the hopper. Houselights were never used for this replication.

Experimental conditions and data recording were controlled by standard solid-state and electromechanical circuits.

Procedure

Preliminary training. The preliminary training for a given subject depended upon its prior experimental experience and the experimental condition under which it would be tested. At the end of training, each bird reliably: (a) ate from the raised illuminated hopper; (b) drank from the illuminated water receptacle (Replications 2 and 3 only); and (c) pecked at the illuminated response key at a high and stable rate.

Discrimination training—main experiment. A go/no-go discrimination procedure was used. Four types of trials were arranged that began with either houselight or feeder operation (food access). These stimuli remained on for either 10 or 5 sec. A 1.4-sec delay, which was spent in the dark, followed. Then the pecking key was illuminated with green light for 10 sec. Pecks were recorded but were without consequence for the first 8 sec of key illumination. A peck that occurred during the last 2 sec produced reinforcement (5 sec of grain access) if the preceding stimulus, either houselight or food access, had been 10 sec in duration (S^+). Pecks following 5-sec durations (S^-) of food access or houselight were never reinforced. An interval of 50 sec, again spent in the dark, separated trials. The four types of trials occurred equally often (approximately 10 times) in mixed order within a session. Sessions were arranged daily at about the same time.

Discrimination training—replications. In four systematic replications certain features of the discrimination procedure were modified. Replication 1 involved a single subject; Replications 2, 3, and 4 each involved two subjects.

Replication 1. Water reinforcement (1 ml of water was dispensed and

the lamp 3 cm to the left of receptacle was illuminated for 5 sec) was substituted for the food reinforcement.

Replication 2. A localized light (illumination of the lamp located next to the water receptacle) was used in place of the houselight.

Replication 3. The feeder light (illumination of the lamp in the hopper without presentation of grain) was substituted for the houselight, and water was substituted for food as the reinforcement.

Replication 4. A keylight (illumination of the left key with white light) was substituted for the houselight, and the right response key was illuminated with red rather than green light.

Experiments were terminated when discriminative responding appeared to be stable and asymptotic. Table 1 summarizes the various conditions of Experiment 1 and shows the number of sessions received by each subject.

Data Analysis

Control of responding by the duration of the food and the light stimuli was assessed by calculating a separate discrimination ratio for food-

TABLE 1
Subjects and Conditions of the Main Experiment and Four Replications

Experiment	Bird	Stimuli	Reinforcement	Deprivation	Sessions
Main	1	Food access vs houselight	Food	Food	50
	2	Food access vs houselight	Food	Food	70
	3	Food access vs houselight	Food	Food	50
	4	Food access vs houselight	Food	Food	70
	5	Food access vs houselight	Food	Food	70
Replication 1	6	Food access vs houselight	Water	Food and water	70
Replication 2	7	Food access vs localized light	Food	Food	80
	8	Food access vs localized light	Food	Food	100
Replication 3	7	Food access vs feeder light	Water	Food and water	70
	9	Food access vs feeder light	Water	Food and water	70
Replication 4	10	Food access vs keylight	Food	Food	100
	11	Food access vs keylight	Food	Food	100

access and light trials. (Justification for assuming that duration was the controlling dimension is provided by Experiment 3.) Pecks after the S⁺ duration of a stimulus (food or light) were divided by the sum of pecks after the S⁺ and S⁻ durations of that stimulus. Thus, indiscriminate responding after the two durations would produce ratios of .5; these ratios increase as control by the stimulus durations develops. For each subject, these ratios were calculated for blocks of 10 consecutive sessions.

Results

Main Experiment

The discrimination ratios for food access and light as a function of training are shown in Fig. 1. Two main features are apparent in the data. First, the asymptotic discrimination ratios for both the food-access and light stimuli were greater than .5; thus the duration of both stimuli acquired some control of responding. Second, food-access duration clearly was more effective in controlling responding than was houselight duration.

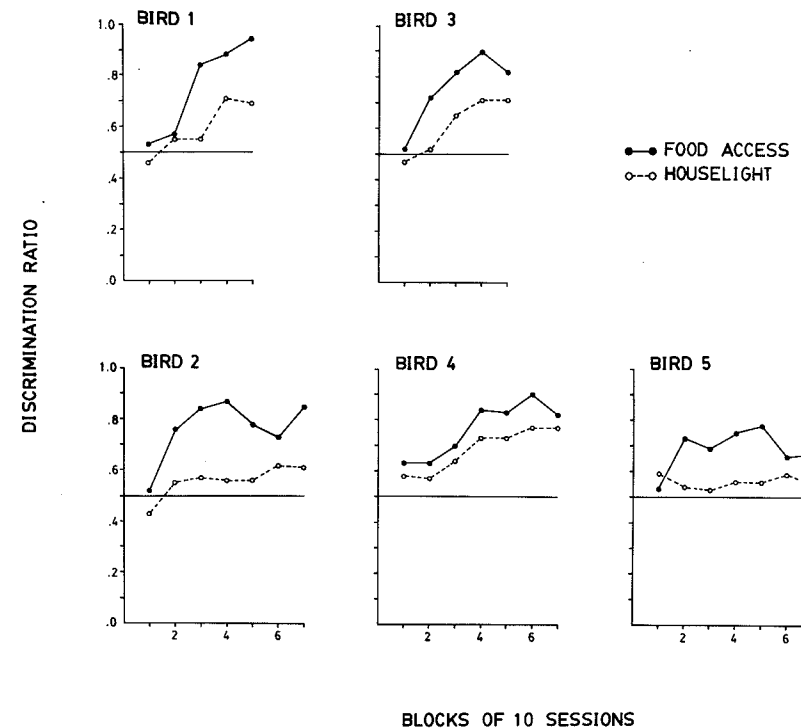


FIG. 1. Discrimination ratios (pecks after S⁺ divided by the sum of pecks after S⁻ and S⁺) on food-access and houselight trials as a function of training for the five birds in Experiment 1.

Replications

Figure 2 shows food-access and light discrimination ratios as a function of training for the four replications. In spite of the difference in types of light, reinforcement, etc., all subjects showed the same pattern of results: control by food duration developed more rapidly and to a greater degree than did control by light duration.

Discussion

Control of pigeons' keypecking by food-access duration was superior to control by light duration. Three features of the results provided evidence for the reliability and the generality of this difference. First, the superior control by food-access duration was replicated in every subject studied. Second, these differences in control were not restricted to food-reinforced behaviors. Water-reinforced keypecks (Replications 1 and 3) also were controlled more readily by food-access duration than by light duration. Third, the comparisons between food access and the four light stimuli yielded comparable results even though these lights differed in such features as intensity, localizability, size, and location in the chamber.

In Replication 3 (food access vs feeder light), all features of the two stimuli were identical, except the presence and absence of food. Therefore, the large difference in control by the duration of these stimuli seems to be due to some property(ies) of food.

EXPERIMENT 2

Although Experiment 1 demonstrated that pigeons' keypecking in a go/no-go discrimination task was controlled more readily by food-access than by light duration, the generality of this finding across procedures had to be investigated before general conclusions could be made about the relative effectiveness of these stimuli for pigeons. In fact, there is some suggestion that the relative effectiveness of stimuli can vary with different discrimination procedures. For example, investigators (e.g., Dobrzecka *et al.*, 1966; Lawicka, 1964) have reported that the position, but not the quality, of two auditory stimuli (buzzer vs metronome) readily controls dogs' right-left response differentiation, whereas dogs' go/no-go response differentiation is controlled more readily by quality than by position. Because it seemed possible that the relative control of pigeons' keypecking by food-access and light duration also might vary across discrimination tasks, the present experiments were designed to replicate the go/no-go results using choice measures of discrimination.

In Experiment 2A, food deprived pigeons served under a right-left choice procedure similar to that used in previous duration experiments (e.g., Church & Deluty, 1977; Kinchla, 1970). Trials began with either a short or a long duration of food access or houselight presentation, fol-

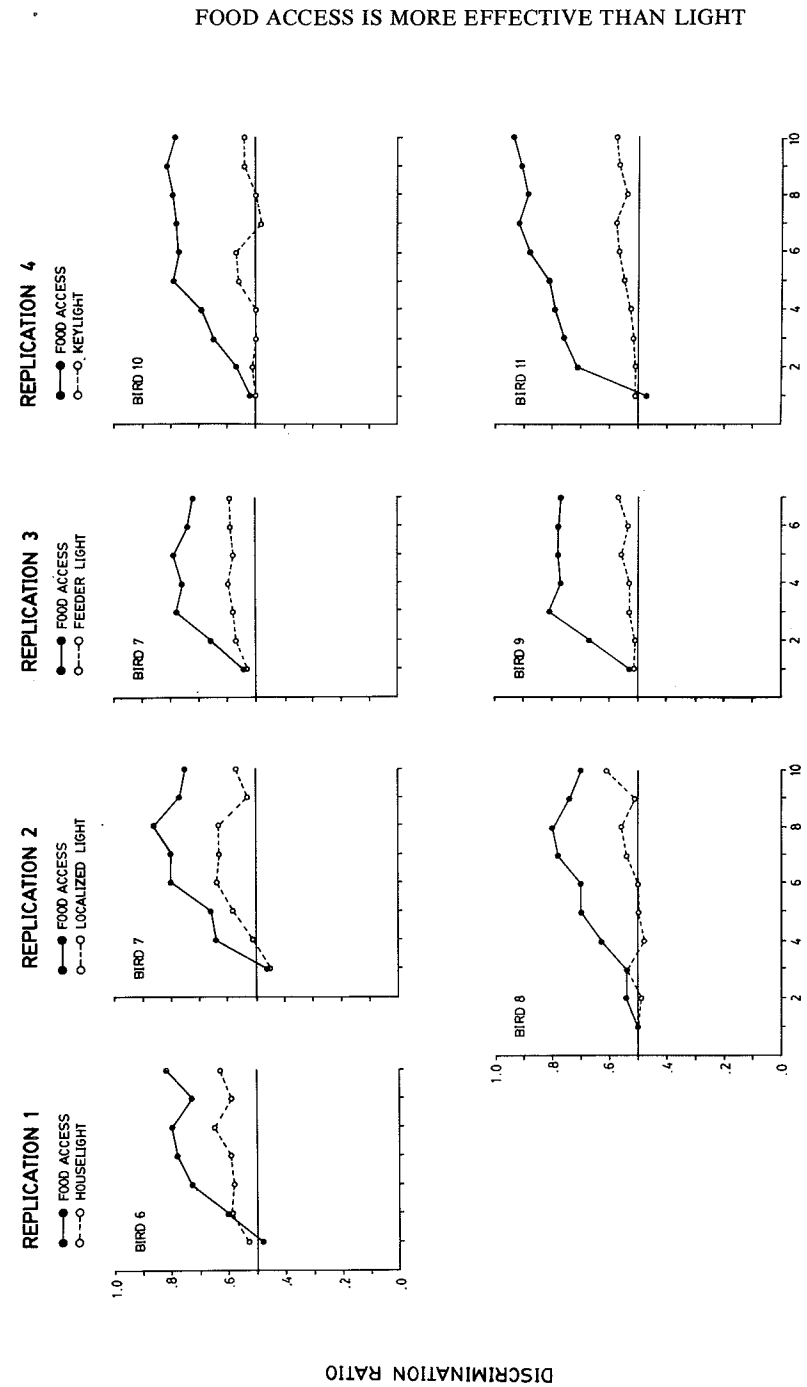


Fig. 2. Discrimination ratios (pecks after S^+ divided by the sum of pecks after S^- and S^+) on food-access and light trials as a function of training for birds in the four replications of Experiment 1.

owed by illumination of two side keys with green light. Pecks to the left key were reinforced following the short duration of food access or light; right-key pecks were reinforced after the long duration of either stimulus.

An elaboration of the delayed symbolic matching-to-sample procedure was used in Experiment 2B. Here, pigeons were exposed to trials that again began with one of two durations of food access or light. Following this, the two side keys were illuminated, one with red light and one with green, the right-left position of red and green varying across trials. Reinforcement was provided for a peck to red following the short duration, and for a peck to green following the longer duration of either stimulus.

These procedures differed from the go/no-go paradigm of Experiment 1 in two important ways. First, stimulus control was assessed by the accuracy of choice behavior rather than by differential response rates. Second, both long and short durations served as a cue for the availability of reinforcement.

EXPERIMENT 2A

Method

Subjects

Two Silver King Pigeons (Birds 12 and 13), housed and treated in the same manner as the birds in Experiment 1, served as the subjects. Bird 12 was experimentally naive; Bird 13 had served in a variety of previous experiments.

Apparatus

A BRS-Foringer Model PS-004 pigeon chamber was used. One wall contained a horizontal row of three clear plastic pecking keys that each required a force of 0.2 N to operate. An Industrial Electronics Engineers' Series 10 stimulus projector was mounted behind each key; these illuminated the keys with a uniform field of colored light. Centered below the keys was a Gerbrands Model G5610 solenoid-operated feeder that permitted timed access to mixed grain. A 2.8-W lamp located within the hopper served to illuminate the grain presentations. The houselight consisted of two 2.8-W lamps hidden behind a plastic reflector above the keys; these provided a diffuse illumination of the chamber.

Control of experimental conditions and collection of data were performed by a Data General Nova 3 computer.

Procedure

Preliminary training. At the end of preliminary training, both birds reliably ate from the raised illuminated grain feeder, and pecked at both the left- and right-hand illuminated response keys.

Choice training. Trials began with the presentation of either food access or houselight for a period of 5 or 10 sec. At the end of this period both

side keys were illuminated with green light until one of these was pecked. If the correct key was pecked, a 5-sec grain reinforcer was presented. The left key was designated correct following a 5-sec food access or houselight presentation; the right key was correct following 10-sec stimulus presentations. If the incorrect key was pecked (left after a 10-sec or right after a 5-sec stimulus presentation) the trial was terminated and reinforcement was not presented. A correction procedure was employed; if the pigeon made an incorrect choice, the same initial stimulus was presented again on the next trial. All trials were separated by a 30-sec intertrial interval in which the chamber was dark. Each of the four initial stimuli was presented five times within a session (correction trials excluded) in a randomly determined order.

After 70 sessions with this procedure, the reinforcement schedule for correct responses was changed from continuous to partial reinforcement. This was in preparation for subsequent testing (see Experiment 3). For 20 sessions a 75% reinforcement schedule was in effect; correct responses were reinforced with a probability of .75. During the last 40 sessions for each bird, the reinforcement schedule for correct responses was decreased to 50%. Nonreinforced correct responses had the same outcome as incorrect responses, except that a correction trial did not occur.

Data Analysis

Control by duration was assessed by choice accuracy, defined as the percentage of trials on which the correct side key was pecked. Correction trials were excluded from this analysis. Separate accuracy scores were computed for food-access and houselight trials. Accuracy scores were calculated for blocks of 10 consecutive sessions.

Results

Figure 3 shows accuracy scores on food access and houselight trials as a function of training. Stimulus duration did acquire control of choice behavior, as reflected by the increase in accuracy scores to above chance (50%) level. However, the extent of this control by duration differed for the two stimuli; food-access duration acquired more control than did houselight duration. These results were consistent across birds and reinforcement schedules.

EXPERIMENT 2B

Method

Subjects

The subjects were Birds 3 and 4 from Experiment 1, Bird 12 from Experiment 2A, two additional Silver King pigeons (Birds 14 and 15) and one Homing pigeon (Bird 16). Birds 14, 15 and 16 each had served in a

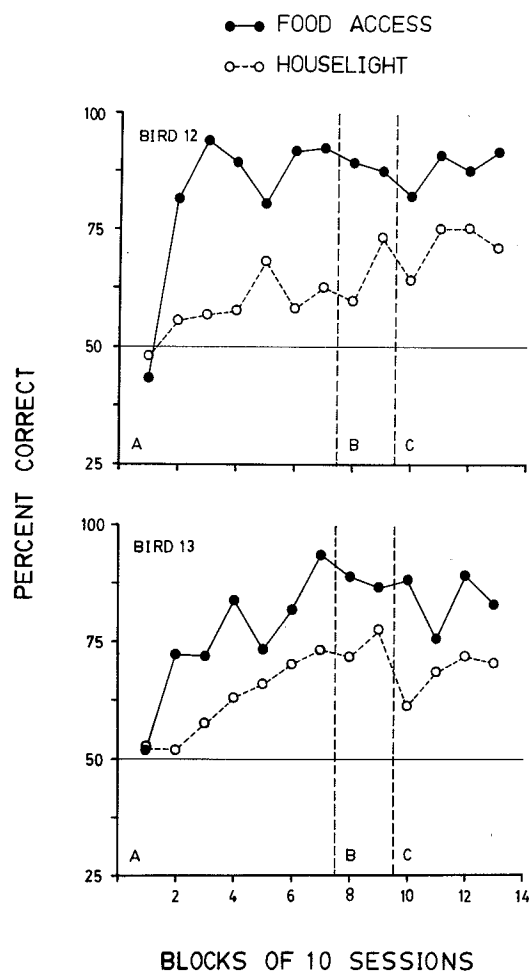


FIG. 3. Choice accuracy (percentage correct) on food-access and light trials as a function of training for the two birds in Experiment 2A. A, B, and C indicate the conditions in which reinforcement for correct responses was available with a probability of 1.0, 7.5, and .5, respectively.

variety of previous experiments. All birds were maintained as in the earlier experiments.

Apparatus

The equipment used was the same as that described for Experiment 2A.

Procedure

No preliminary training was necessary and all subjects were started immediately on the choice procedure.

A variation of the delayed symbolic matching-to-sample paradigm was used. Trials began with the presentation of a sample stimulus (food access or light) for either a short or a long duration. Sample offset was followed immediately by illumination of the side keys with a red and a green comparison stimulus, the position of red and green varying across trials. A peck at the red comparison key after short samples, or at the green key after long samples produced a 5-sec grain reinforcer. A peck at red after long samples or green after short samples terminated both keys and initiated the 30-sec intertrial interval; these incorrect responses always were followed by a correction trial in which the same sample stimulus appeared.

For all birds food access served as the sample on half of the trials; on the remaining trials the sample was houselight for Birds 3, 4, and 12, and feeder light for Birds 14, 15, and 16. Initially the short and long samples were 5 and 10 sec, respectively. The short sample later was decreased to 2 sec in an attempt to improve matching performance in preparation for an experiment not reported here. At the time of this change, Birds 3 and 4 had completed the experiment, and Birds 15 and 16 had not yet started. However, Birds 14 and 15 were in the course of training, and consequently received some sessions in which the short sample was 5 sec, followed by sessions in which the short sample was 2 sec.

In each session the four samples were presented five times each (excluding the correction trial presentations) in a randomly determined order. Birds 3, 4, 12, 14, and 15, received 120, 120, 50, 110, and 120, sessions respectively; Bird 16 became ill and received only 30 sessions.

Data Analysis

Control by stimulus duration was assessed by the percentage of trials (excluding correction trials) on which a correct response occurred (matching accuracy). Separate matching accuracy scores were calculated for food-access and light trials. For each, the scores were calculated for blocks of 10 consecutive sessions.

Results

Figure 4 shows matching accuracy for food access and light as a function of training. Again, the same effects as found in the earlier experiments are revealed by these data. The duration of both food access and light controlled responding; however, the control by food-access duration was superior to the control by either houselight duration (Birds 3, 4, and 16) or feeder light duration (Birds 12, 14, and 15). Some of the birds (Birds 3, 4, 15, and 16) performed below chance levels during the initial block of sessions. An examination of the data, however, revealed no consistent choice bias that could account for these initially below chance scores.

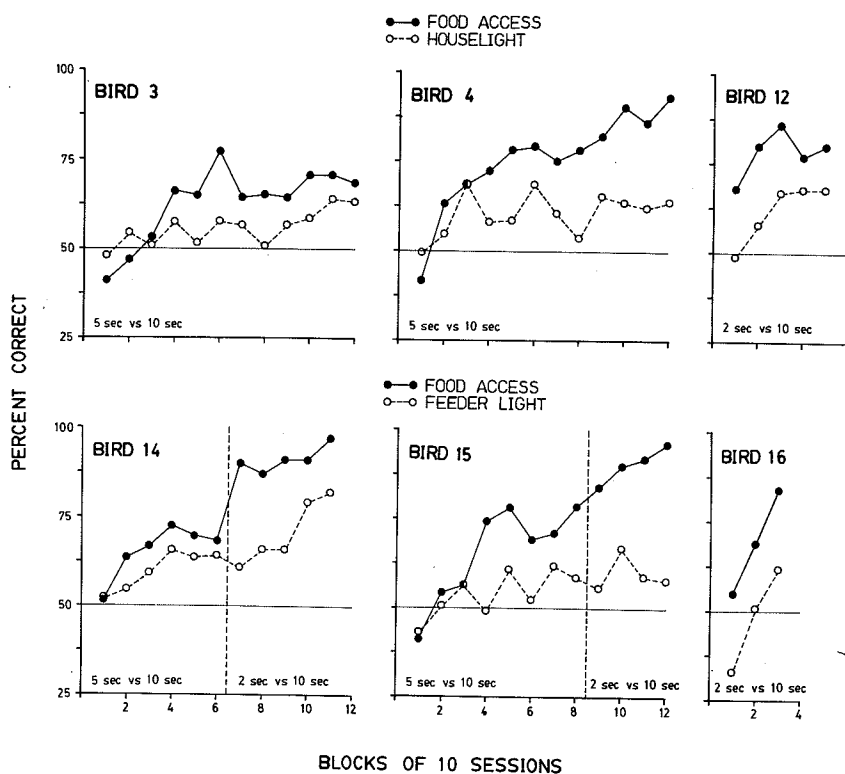


FIG. 4. Matching accuracy (percentage correct) on food-access and light trials as a function of training for birds in Experiment 2B.

Discussion

These two experiments demonstrated the generality of the differences in control by food-access and light duration across discrimination procedures. The results of Experiment 1 were replicated in the present experiments with two choice procedures that differed in a number of ways from each other, and from the go/no-go procedure of Experiment 1. Food-access duration clearly is more effective than light duration in controlling pigeons' keypecking under a variety of conditions.

EXPERIMENT 3

A discrimination between two stimuli selected from a dimension does not always reflect stimulus control by that dimension. For example, a discrimination between red and green may suggest control by wavelength; however, control by some other dimension, such as intensity may also result in differential responding to red and green.

One way to demonstrate control by a dimension after two-value discrimination training, such as that employed in Experiment 1 and 2, is to conduct a generalization test in which new values along the dimension are presented. If the dimension controls behavior, responses to the new stimuli should vary as a systematic function of their position on the continuum.

The main purpose of this experiment was to demonstrate stimulus control by the duration dimension. Such a demonstration was important to the present research for two reasons. First, although previous experiments (e.g., Reynolds & Catania, 1962; Stubbs, 1968) have demonstrated stimulus control by the duration dimension, such control has not been demonstrated with duration of food access. Second, because the present research involves comparisons between stimuli, it must be shown that the same dimension controls responding in both cases.

The present study followed Experiment 2A in which pigeons had received right-left choice discrimination training with 5- and 10-sec durations of food access and houselight. In the present experiment generalization testing was conducted with intermediate durations of these stimuli, and the relationship between generalization duration and choice behavior was investigated.

Previous experimenters have employed this generalization testing procedure as a psychophysical "bisection" procedure; the point at which animals bisect a temporal interval has been used to infer the way in which internal representation of time changes with the duration of an interval (e.g., Church & Deluty, 1977; Church, 1978). For example, Church and Deluty reported that rats bisected temporal intervals at their geometric mean, and suggested that rats' internal representation of time changes as a logarithmic function of real time. Although the present experiment was not designed for this express purpose, it was of interest to see whether the pigeons would bisect the intervals in the same way on food-access and light trials, and whether the bisection points would fall near the geometric mean.

Method

Subjects and Apparatus

These were the same as those described in Experiment 2A.

Procedure

This experiment directly followed the right-left choice training with 5- and 10-sec durations of food access and houselight reported in Experiment 2A. The procedure used here was identical to that of Experiment 2A except that two types of trials were arranged. Training trials occurred

with a probability of .75 and reinforcement for a correct choice on these trials (left after 5-sec and right after 10-sec of both food access and light) occurred with a probability of .75. The remaining trials were generalization trials. During these trials, either food access or houselight was presented for one of nine durations: 5.5, 6.0, 6.5, 7.0, 8.0, 8.5, 9.0, or 9.5 sec. On a given generalization trial, each duration of each stimulus (food or light) occurred with a probability of .056. Following a generalization presentation, both side keys were illuminated and a peck to either key ended the trial but did not produce reinforcement. The correction procedure remained in effect on training trials, but was not used during generalization trials.

Testing was conducted during 120 consecutive sessions by which time each generalization duration of both food access and houselight had been presented at least 25 times.

Data Analysis

For each of the 120 sessions, the percentage of correct choices during training trials, and the number of times that the right and left key was pecked following each generalization duration of the stimuli were recorded. Data from food access and houselight generalization trials were analyzed separately. For each, a function relating the proportion of left-key responses (correct for 5-sec stimulus presentation) to generalization durations of the stimuli was plotted. Each point was the ratio of the number of left-key responses at a generalization stimulus duration divided by the total number of presentations of that generalization stimulus duration. Regression equations and estimated points of bisection (the duration for which probability of choosing right or left key was equal) were found for each of the functions for each of the birds.

Results

Table 2 shows the percentage of correct choices on food access and light training trials in 10 session blocks for the two birds. Bird 12 was more accurate on food-access training trials than on light training trials throughout the experiment. Bird 13 was more accurate on food-access training trials during 10 of the 12 blocks of sessions; this bird's performance on light trials improved with the extended training and the difference in accuracy between food access and light training trials was small by the end of the experiment.

Figure 5 shows the functions relating proportion of left-key responses to generalization durations of the stimuli. The left-key responses of both birds clearly decreased as a function of increases in the durations of the stimuli.

There were no consistent differences between the functions obtained on

TABLE 2
Percentage of Correct Choices on Food-Access and Light Training Trials in Experiment 3

Bird	Block of sessions	Percentage correct	
		Food access	Light
12	1	84.3	69.1
	2	80.4	71.7
	3	90.3	72.5
	4	92.8	84.4
	5	93.0	68.4
	6	91.6	72.3
	7	95.6	75.8
	8	93.7	77.5
	9	93.6	77.2
	10	90.5	81.6
	11	93.3	68.3
	12	94.8	78.0
	\bar{X}	91.2	74.7
13	1	93.2	79.2
	2	88.4	77.7
	3	92.9	86.5
	4	90.8	89.7
	5	89.9	85.9
	6	90.9	92.0
	7	97.1	95.9
	8	95.1	85.7
	9	91.0	90.7
	10	95.0	96.9
	11	91.2	86.9
	12	91.6	89.8
	\bar{X}	92.3	88.1

food-access trials and those obtained on houselight trials. On food-access trials the regression equations were: Bird 12: proportion of left responses = $2.15 - .22 \times \text{duration (sec)}$; Bird 13: proportion of left responses = $1.9 - .19 \times \text{duration (sec)}$. On light trials the equations were: Bird 12, proportion of left responses = $1.71 - .16 \times \text{duration (sec)}$; Bird 13, proportion of left response = $1.9 - .19 \times \text{duration (sec)}$. The estimated points of bisection for Birds 12 and 13, respectively, were: 7.5 and 7.65 sec on food-access trials; 7.68 and 7.22 sec on light trials. The arithmetic, geometric, and harmonic means of the interval are 7.5, 7.23, and 6.99 sec, respectively. Thus, the bisection points were closest to the arithmetic mean in three of the four cases, and closest to the geometric mean in only one case.

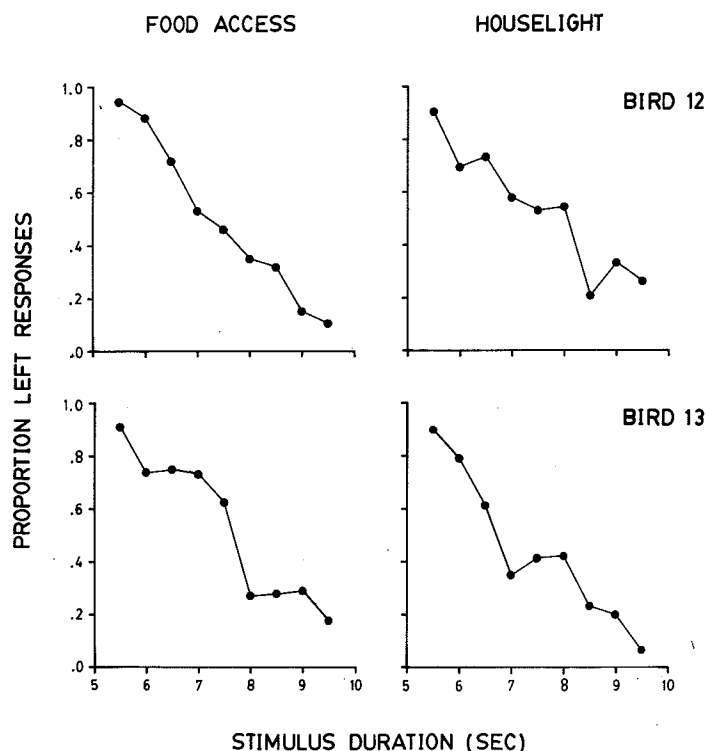


FIG. 5. The proportion of left responses on generalization trials at each duration of food access and houselight for the two birds in Experiment 3.

Discussion

This experiment clearly demonstrated stimulus control by the duration dimension. Choice behavior varied as a function of the generalization durations of both the food access and light. Thus, the difference in control by the training durations of food access and light was not due to different controlling dimensions.

The present results extend other demonstrations of control by the duration dimension (e.g., Church & Deluty, 1977; Reynolds & Catania, 1962; Stubbs, 1968) by showing similar control by the duration of food access.

The present experiment, with only two subjects, is limited with respect to any conclusions that might be drawn about how pigeon's internal representations of time changes as a function of real time. However, since the bisection points in a majority of cases were closer to the arithmetic mean than to the geometric mean, the results seem more consistent with studies suggesting that time processing is linear (cf. Allan, 1979) than with

those suggesting that time is processed logarithmically (e.g., Church & Deluty, 1977; Stubbs, 1976a).

GENERAL DISCUSSION

These experiments clearly demonstrated that control by food-access duration is superior to control by light duration in the pigeon. This difference in stimulus control is reliable, and generalizes to a number of experimental conditions. In Experiments 1 and 2, control by food access was superior to control by light for every subject studied, and these results were not specific to the particular kind of light, to the reinforcer, or to the discrimination procedure employed. Experiment 3 demonstrated that the duration dimension controlled responding on both food-access and light trials.

The Superior Effectiveness of Food

There are a number of mechanisms that may account for the superiority of food-access control. One is response mediation of event duration. Food-access presentations elicited eating; the duration of this behavior likely was highly correlated with the duration of food access. On the other hand, the duration of orienting or other behaviors that occurred during light may not have been as closely correlated with the duration of the light presentations. Thus, if the pigeons discriminated event duration by discriminating the duration of their own behavior, the difference in the accuracy of such discriminations on food access and light trials might be expected. There is considerable evidence that animals are sensitive to several aspects of their behavior. Beninger, Kendall, and Vanderwolf (1974) and Morgan and Nicholas (1979) demonstrated that rats could discriminate between different classes of their own behavior (e.g., rearing, grooming, etc.). Other studies have demonstrated that pigeons can discriminate the number of their keypecks (e.g., Rilling, 1967; Wilkie, Webster, & Leader, 1979), as well as the time between keypecks (Reynolds, 1966). Animals also can discriminate the duration of their responses. Platt, Kuch, and Bitgood (1973) reported that rats learned to emit lever presses of a certain range of durations, and Ziriax and Silberberg (1978) found that pigeons could discriminate between keypeck durations. In view of these findings one might expect that pigeons would readily discriminate their eating times.

Attentional mechanisms also might account for the superior effectiveness of food in controlling pigeons' behavior. For example, the rewarding value and/or the response-eliciting properties of food may ensure attention to the stimulus on food-access trials; whereas the pigeons may not always have attended to the light presentations on some trials or for their entire duration. However, the apparent similarity between the points at

which the birds bisected food and light intervals in Experiment 3 would seem to rule out this latter possibility; if the birds attended to the light for only a portion of its duration then one might expect that the bisection point would be shorter for light intervals than for food intervals.

The superior effectiveness of food also could be related to the dimension chosen to compare food and light. For example, theories of selective attention (e.g., Mackintosh, 1974) have suggested that certain dimensions of a stimulus may be more salient than other dimensions and control by the salient dimensions will sometimes interfere with, or overshadow control by the relevant dimension. It is possible that duration is a particularly salient property of food but not of light. The duration of access to food likely is of particular importance to a hungry animal. If other dimensions of light (e.g., intensity) are more salient than its duration, the poorer control by light could be due to greater overshadowing by these non-relevant dimensions.

It is also possible that the greater biological importance of the food-access stimulus for the pigeon contributed to its superior control, perhaps by ensuring attention to food duration, or by affecting response mediation of event timing. Although the present results are consistent with such notions, considerable additional research would be required to demonstrate that animals are predisposed to learn about biologically important events, *as a class*, more readily than about more "neutral" events.

Comparisons among Stimuli

The present results provide direct empirical evidence for the assumption that stimuli differ in their ability to control behavior. The difference in control of pigeons' behavior by food and light was not confounded with differences in the discriminability of the dimensions that controlled the behaviors because: (1) the *same* values from a dimension that was common to both stimuli served as the basis of the comparison, and (2) evidence was provided that this dimension of both stimuli controlled the behaviors.

Procedures such as those used here for comparing stimuli could be fruitfully applied in several areas of investigation within the stimulus control literature. One such area is stimulus-reinforcer specificities. For example, some investigators have reported that visual stimuli are more effective than auditory stimuli in controlling pigeons' food-reinforced behaviors, whereas control by the auditory stimuli is superior in aversive conditioning (e.g., Delius & Emmerton, 1978. Foree & LoLordo, 1973). Foree and LoLordo suggested that such results are consonant with the knowledge that, in nature, pigeons find food by sight, but rely on auditory cues when predators approach. However, in these studies the dimensions of the stimuli that controlled behavior were not specified, and no attempts

were made to equate the values of such dimensions for discriminability. Thus, it is not known whether auditory and visual stimuli per se are differentially effective in appetitive and aversive situations, or whether pigeons' behavior is controlled by different stimulus dimensions in the two situations. It is possible, for example, that pigeons attend to one dimension (e.g., intensity) in avoidance tasks, but to another dimension (e.g., spatial location) in appetitive tasks. Accordingly, the auditory stimulus used may have been more discriminable in terms of intensity, but less discriminable in terms of spatial location than the visual stimulus. Although unlikely, such possibilities cannot be ruled out unless the dimensions controlling behavior are identified, and the stimuli used are equated for discriminability along these dimensions. Perhaps a better way of studying such stimulus-reinforcer specificities is to use a common dimension to compare the stimuli. For example, by using the duration dimension to compare a visual and an auditory stimulus under appetitive and avoidance tasks, one could determine whether the relative effectiveness of the stimuli themselves is specific to the situation.

The Role of the Stimulus in Control by Duration

The present research demonstrated that the stimulus one selects to study duration discrimination can determine the speed of acquisition and perhaps the asymptotic accuracy of such discriminations. This finding has certain implications for the study of temporal discriminations in animals. For example, an animal's accuracy in discriminating the duration of a given stimulus may not accurately reflect the animal's timing abilities, because how accurately the animal discriminates event duration depends in part on the nature of the event.

The present results are relevant to a recent theory of temporal discrimination in animals (Church *et al.*, 1976). This theory proposed three factors that limit an animal's accuracy in estimating temporal intervals: (1) inattention to the signal on some trials; (2) variability in starting to time the duration when the signal begins and/or in stopping to time the duration when the signal ends; and (3) factors relating to the signal duration itself. The present results, which demonstrated that pigeons' accuracy in discriminating durations is limited by the nature of the stimulus, could be interpreted in terms of either of the first two factors proposed by this theory. For example, the presence of food on food-access trials may have ensured attention to the signal on all such trials and/or decreased the variability in starting and stopping to time the duration.

The present results also have implications for theories of timing behavior. The study of timing behavior in humans has been characterized by two main approaches: an "internal timer" approach, and an "event processing" approach (cf. Coren, Porac, & Ward, 1979). The internal

timer approach is based on an assumption that the passage of time is sensed and measured by continuous changes in some biological mechanism that acts as an internal clock. The event processing approach, on the other hand, views time experience as a purely cognitive process, and assumes that the sensation of time is based on how much sensory information is processed during a particular interval. Studies of timing behavior in humans have provided some support for both approaches.

Although many investigations of timing behavior in animals have been largely atheoretical (e.g., Elsmore, 1971; Reynolds & Catania, 1962; Stubbs, 1968), the internal timer hypothesis recently has been applied to the investigation of timing mechanisms in rats (Church, 1978; Church & Deluty, 1977; Roberts & Church, 1978). For example, Roberts and Church (1978) have suggested that rats possess an internal clock that functions in many respects like the familiar stopwatch. One of their explicit assumptions is that the rats' clock, like a stopwatch, measures time independently of modality. As evidence for this, they demonstrated that rats were able to add time spent in light to time spent in sound and respond on the basis of the sum of these times. This was interpreted as evidence that rats time light and sound at the same rate. The present research, which demonstrated that pigeons' duration discrimination depends on the stimulus used as the signal, does not appear to be consistent with this internal clock theory.

The present results may be more amenable to an event processing analysis. In human studies based on this approach it has been found that duration estimation is affected by many nontemporal variables. For example, durations are sensed as being longer the more complex or informative the stimulus (Ornstein, 1969), the larger the number of events that occur during the period (Thomas & Brown, 1974), or the more active or aroused the subject (Falk & Bindra, 1954; Ornstein, 1969). If such effects occurred in animals one might expect that food durations would be perceived as being longer than the corresponding durations of light because of the complex, arousing, etc., aspects of food. If, in addition, ease of discrimination depended upon the *absolute* difference in S⁺ and S⁻ durations, then the superiority in discrimination of food access duration would be expected.

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