JOURNAL OF THE EXPERIMENTAL ANALYSIS OF BEHAVIOR 1971, 16, 81-87 NUMBER 1 (JULY)

CONTROL OF RESPONDING BY STIMULUS DURATION[1]

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Pigeons were trained on a procedure in which the key was white for 30 sec, alternating with periods of darkness, or timeout. In a nondifferential training procedure, timeout duration was held constant at either 9 or 21 sec for different animals, and pecks on the white key were reinforced on a variable-interval 36-sec schedule. After 30 sessions an extinction generalization test was conducted where the duration of the timeout was varied from 3 to 27 sec. This test showed no differences in responding following timeouts of different durations. In a differential training procedure, timeout durations of either 9 or 21 sec were randomly scheduled for each animal. The variable-internal schedule was in effect following the same timeout duration as in the prior nondifferential procedure. No pecks were reinforced after the other timeout duration. In 40 sessions, differences in response rates following the two durations gradually developed. A maintained generalization procedure was then imposed in which timeout durations were varied from 3 to 27 sec, with the variable-interval schedule in effect following only the same duration as in the previous procedures. The first maintained generalization session showed that the prior differential training had established control of the animals' behavior by the timeout duration. In continued training on the maintained generalization procedure, control by the timeout duration decreased.

The concept of behavior controlled by the temporal properties of a stimulus has played an important part in the analysis of performance on schedules of reinforcement (Anger, 1956; Morse, 1966). There have been, however, very few studies directly concerned with control of behavior by the temporal properties of events. Several early investigators (*e.g.*, Cowles and Finan, 1941; Woodrow, 1928) demonstrated the discriminability of the duration of an event. Generalization of control by the duration of an event was demonstrated by Reynolds and Catania (1962) and a psychophysical study of event duration was conducted by Stubbs (1968). Judging from the importance of temporal discriminations in theories of reinforcement schedules, demonstration of additional phenomena of stimulus control with event duration as the relevant dimension would seem to be in order, with the aim of strengthening the view that the duration of an event can control behavior in similar fashion to other more commonly studied stimulus dimensions.

The present study examined the effects of discrimination training upon generalization of control by stimulus duration. The precedure was similar to that used by Reynolds and Catania (1962), in which the duration of a timeout that preceded opportunities for the animals to respond, was the relevant stimulus dimension. With this procedure, behavior is reinforced following a stimulus of one duration, and not reinforced following stimuli of other durations. The present experiment examined the effects of nondifferential and differential training procedures on generalization gradients of stimulus duration. The effects of a maintained generalization procedure (Pierrel, 1958) were also investigated.

METHOD

Subjects

Four experimentally naive Silver King pigeons were maintained at about 80% of their free-feeding weights by the grain obtained

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[1] This paper is based in part on a thesis submitted in partial fulfillment of the requirements for the Ph.D. degree to the Department of Psychology, Arizona State University. I wish to thank Aaron Brownstein and Fred Hegge for their helpful suggestions regarding the conduct of the experiments. The research was supported by an NASA predoctoral traineeship. Reprints may be obtained from the author, Department of Experimental Psychology, Walter Reed Army Institute of Research, Washington, D.C. 20012.

during experimental sessions and supplementary feedings as required.

In conducting this research, the investigators adhered to the "Guide for Laboratory Animal Facilities and Care", as promulgated by the Committee on Revision of the Guide for Laboratory Animal Facilities and Care of the Institute of Laboratory Animal Resources, National Academy of Science, National Research Council.

Apparatus

The experimental chamber was a plywood box with inside dimensions of 14 in. high by 18 in. wide by 12 in. deep (35 by 45 by 30 cm). An aluminum intelligence panel contained a Lehigh Valley Electronics translucent pigeon key at a height of 10 in. (25 cm). The key could be transilluminated with white light and required a force of 0.147 N to operate. Directly below the key was a hopper for delivering mixed grain. A white houselight provided general illumination. The experimental chamber also contained a small relay that could be operated after key pecks to provide auditory feedback, and a speaker that presented masking noise continuously during experimental sessions. Experimental contingencies were controlled by standard relays, timers, and stepping switches, and data were collected with electro-mechanical impulse counters, printout counters, a four-pen event recorder, and a cumulative recorder.

Procedure

The subjects were magazine trained and key pecking was shaped. On the next two days there were 50 reinforcements on a continuous reinforcement schedule, followed by two days of training in which 50 reinforcements occurred each day on a variable-interval schedule with a mean interreinforcement interval of 18 sec (VI 18-sec). Each reinforcer in this initial training and all subsequent experimental procedures consisted of 3-sec access to mixed grain. During reinforcement, all lights in the chamber were extinguished, and the grain hopper illuminated. After the initial training, all subsequent training and test conditions consisted of 30-sec periods during which the key and houselights were on alternating with periods of timeout in which the chamber was totally dark. When the key was white, all pecks on the key produced a click by the relay mounted behind the intelligence panel. During timeout, pecks had no scheduled effect. When reinforcement could occur, it was scheduled according to a VI 36-sec schedule, with the interreinforcement intervals arranged according to the formula of Fleshler and Hoffman (1962) to provide an approximately constant probability of reinforcement as a function of time since the last reinforcement.[2] The VI tape did not run during timeouts or during white-key intervals in which reinforcement was not scheduled. Reinforcements that had been "set up" but not delivered by the start of the next timeout were not available the next time the VI schedule was in effect. All sessions began with the key white. The first response on the white key was reinforced, and the VI schedule was in effect. In each white-key interval, the time to the first response, number of responses, and number of reinforcements were recorded.

The first procedure was a nondifferential training procedure in which each session consisted of 50 timeout-white key cycles with the duration of the timeout constant for each animal and the VI schedule in effect when the key was white. The timeout durations were 9 sec for Birds 1 and 2 and 21 sec for Birds 3 and 4. After 30 nondifferential training sessions an extinction generalization test was given. The test session began with three nondifferential training cycles, after which reinforcement was discontinued. The test itself consisted of nine different timeout durations ranging from 3 to 27 sec in 3-sec increments alternated with 30-sec white-key intervals. Each duration was presented 12 times in a quasi-random series consisting of two repetitions of a six-block sequence. Each block in the sequence contained each of the nine timeout durations in a different irregular order. The sequence was therefore 54 cycles long and the test was 108 cycles long. After the generalization test session, 10 sessions of retraining on the nondifferential procedure were conducted.

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[2] The VI tape contained three blocks of 12 interreinforcement intervals, each block being a different randomization of 12 intervals determined by the formula of Fleshler and Hoffman (1962). The intervals, in seconds, were as follows, with the blocks separated by a slash: 35.4, 16.9, 56.7, 22.1, 4.8, 1.6, 12.5, 75.5, 28.2, 125.5, 8.4, 44.5, / 75.5, 12.5, 16.9, 4.8, 28.2, 35.4, 8.4, 22.1, 1.6, 125.5, 44.5, 56.7, / 44.5, 8.4, 35.4, 4.8, 56.7, 28.2, 16.9, 125.5, 12.5, 1.6, 22.1, 75.5 /.

Table 1

Summary of Experimental Procedures

	S^D Duration		*S^Δ Duration(s)*		
	Birds 1 and 2	*Birds 3 and 4*	*Birds 1 and 2*	*Birds 3 and 4*	*Sessions*
Nondifferential training	9 sec	21 sec	—	—	30
Extinction generalization test	—	—	3 sec-27 sec	3 sec-27 sec	1
Nondifferential retraining	9 sec	21 sec	—	—	10
Differential training	9 sec	21 sec	21 sec	9 sec	40
Maintained generalization	9 sec	21 sec	3 sec-27 sec (excluding 9 sec)	3 sec-27 sec (excluding 21 sec)	21

In the second training procedure, two different timeout durations were scheduled, and whether the VI schedule was in effect or not after a timeout depended on the duration of the timeout. For Birds 1 and 2, the VI schedule was in effect following timeouts of 9 sec, and an extinction schedule was in effect following timeouts of 21 sec. These conditions were reversed for birds 3 and 4. For simplicity, the terms S^D and S^Δ will be used to designate timeouts following which the VI schedule was or was not in effect, respectively. Thus, each bird had the same S^D as in the previous nondifferential training procedure. Each session consisted of 100 cycles, with the sequence of durations determined by a Gellerman (1933) series. Three different sequences were used and the sequence was changed daily. This procedure was initiated on the day following the last nondifferential retraining session, and was in effect for 40 days.

A maintained generalization procedure was then begun. Sessions were divided into blocks of 10 cycles, with each block containing each of the nine possible timeout durations from 3 to 27 sec in 3-sec increments. The S^D was repeated twice in each block, but the VI schedule was in effect following only one of these presentations. As in the previous procedures, the S^D for Birds 1 and 2 was 9 sec and the S^D for Birds 3 and 4 was 21 sec. All other timeout durations were S^Δs. Thus, it was possible for pecks to be reinforced on one cycle of each 10-cycle block. Each session consisted of five repetitions of a five-block sequence, with each block of the sequence containing a different irregular order of timeout durations. A session therefore was 250 cycles long. This procedure was in effect for 21 sessions. The order and duration of all experimental procedures is summarized in Table 1.

RESULTS

Figure 1 shows the results of the extinction generalization test given after nondifferential training, and the data from the first 100 cycles of the maintained generalization procedure. All four animals showed no control by timeout duration after nondifferential training (filled circles), with approximately equal response rates following all timeout durations. After differential training, all animals showed a continuous gradient of response rate, with the highest rates occurring near the S^D in the preceding differential training procedure. Animals 1 and 3 showed a clear peak shift in their postdiscrimination gradients, with maxima displaced away from the S^D in a direction opposite the previous S^Δ. Animals 2 and 4 showed approximately equal response rates following all durations on the S^D end of the gradients. Comparison of the top two frames with the bottom two shows that reversal of the training stimulus durations served only to reverse the direction of the gradients and had no other consistent effect.

Figure 2 shows the development of discrimination during the differential training procedure. Acquisition of the discrimination was relatively slow. Animals 2 and 3 showed behavioral contrast, with a considerable increase in their S^D rates over pre-discrimination levels. Neither of these two animals, however, showed much decline in rate following the S^Δ duration. Animals 1 and 4 had an opposite picture of rate change during the formation of the discrimination. That is, the S^Δ rate declined greatly, and the S^D rate also declined, but not as much. No reason was apparent for these two distinct patterns of discrimination formation.

Figure 3 shows performance during the maintained generalization procedure. Each

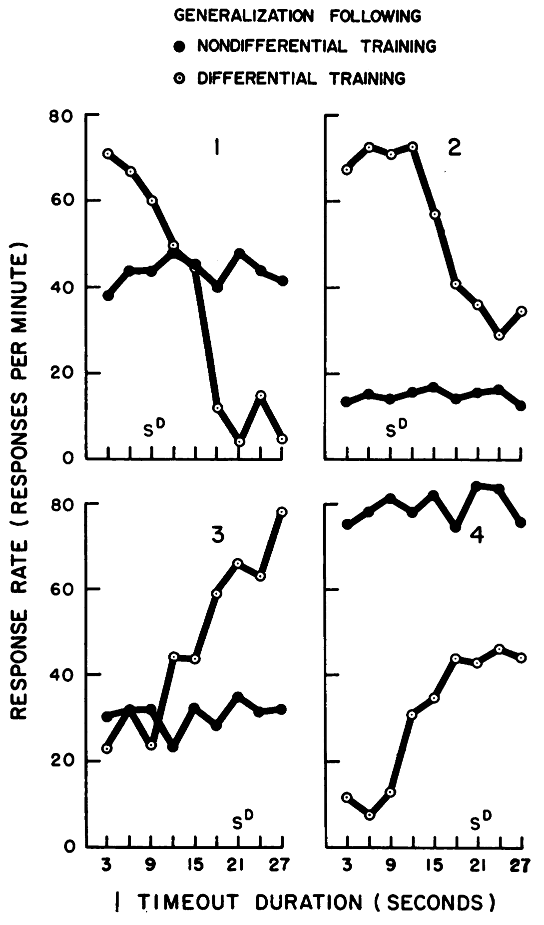

Fig. 1. Response rate is plotted as a function of the preceding timeout duration for both the extinction generalization test that followed the nondifferential training procedure (filled circles), and the first 100 trials of the maintained generalization test that followed the differential training procedure (open circles). Each frame is for a different animal.

gradient represents pooled data from a block of three sessions. The number of responses emitted after each timeout duration was divided by the total of all responses emitted in the three sessions to obtain a relative rate of response gradient. Data from white-key periods where the VI schedule was in effect were omitted. Gradients for each block of three sessions are successively numbered on the left end of each gradient. The number on the right of each gradient is the mean number of responses per white-key period, averaged across all timeout durations. It is intended to give a measure of the overall rate of response represented in the relative gradients, and could be used to convert the gradients to absolute response rates. These numbers illustrate the fact that there was little systematic change in the overall rates of response as maintained generalization testing continued. A straight line was fitted by the method of least squares to the long limb of each gradient (excluding the point for S^D and the last two points on the S^D end of the gradient) to give a clearer picture of changes in the slope of the gradient during exposure to this procedure. The slope constant for each of these fitted lines is shown above each line. Animals 1 and 2 showed a steady and continuous decline in slope, while Animals 3 and 4 showed a decline followed by a slight recovery. In no case was there a development of sharp control by the S^D duration.

Responses during timeout were recorded throughout the experiment. After the first two or three sessions on the timeout-white-key procedure, responses seldom occurred during the timeout. Those that did occur immediately followed the onset of the timeout, and almost never occurred later in the timeout.

DISCUSSION

The procedure used by Reynolds and Catania (1962) and in the present study clearly allows the study of event duration as a stimulus dimension. The results demonstrate that, in fact, some of the phenomena typically observed with traditional stimulus dimensions, such as wavelength of a light or intensity of a tone, can be observed when the relevant dimension of an event is its duration.

The finding that differential reinforcement on the duration continuum was necessary for that dimension to establish control over the animals' behavior is consistent with a body of literature that shows that some stimulus dimensions behave in this manner, including tone frequency (Jenkins and Harrison, 1960) and angular orientation of a line (Butter and Guttman, 1957). Other dimensions, notably wavelength, require much less (or no) explicit differential reinforcement for the establishment of stimulus control (*e.g.*, Guttman and Kalish, 1956). Baron (1965) accounted for the fact that some dimensions of events do not acquire control of responding without special differential reinforcement in terms of an "attending hierarchy". This conceptualization

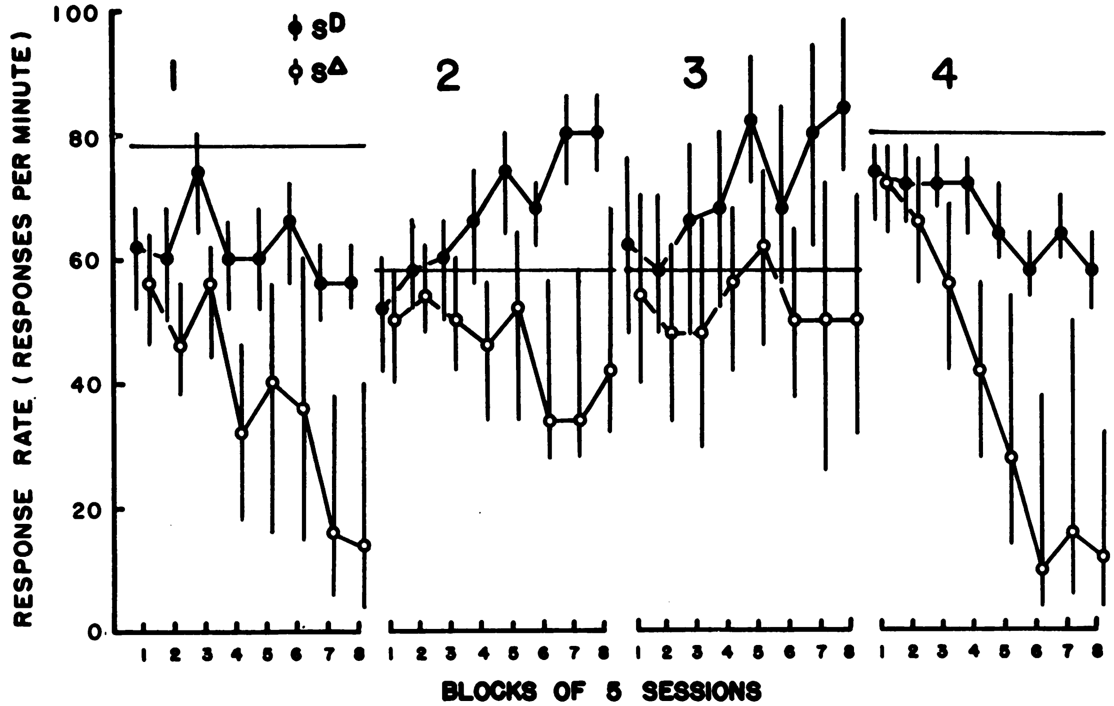

Fig. 2. Median and semiquartile range of response rates following both the S^D (filled circles) and the S^Δ timeout durations are plotted in blocks of five sessions for the entire period of exposure to the differential training procedure. Each frame shows the data for a single animal, and the horizontal line through each frame shows the median response rate from the last five sessions of the immediately preceding nondifferential training procedure.

states that when an organism is brought into an experimental setting, different dimensions of the extroceptive events with which it may be presented are ordered with respect to the ease with which they can come to control the animal's behavior. The position of a given dimension in the hierarchy may be raised through operations of differential reinforcement with respect to that dimension. While perhaps useful in a descriptive sense, this conceptualization does not suggest any possible determinants of the attending hierarchy possessed by an organism when it enters the experimental setting.

Skinner (1966) suggested that there are two important variables in the determination of what events may easily acquire control over the behavior of an organism. The phylogenetic history of the organism may increase the probability of some events acquiring control simply as a function of the evolution of certain sensory systems. The other source of control would be found in the ontogenetic development of the organism. Dimensions of events that have been systematically associated with reinforcement or nonreinforcement in the pre-experimental history of the organism may easily acquire control of the organism's behavior in a new situation. Dimensions that have been equivalently associated with reinforcement and nonreinforcement, or, that have never been presented to the organism, may not acquire control without some special differential reinforcement procedures. Such a formulation is consistent with most of the available data on the acquisition of control by various stimulus dimensions (*e.g.*, Jenkins and Harrison, 1960; Peterson, 1962; Tracy, 1970) and allows some predictions to be made. In the case of the present research, it is unlikely that the behavior had had much differential reinforcement with respect to the duration of events; therefore it would be predicted that the dimension of timeout duration would not acquire control without explicit differential reinforcement procedures.

The finding that behavioral contrast occurred with only two of the four subjects in this study does nothing to clarify the theoretical arguments on the subject of contrast

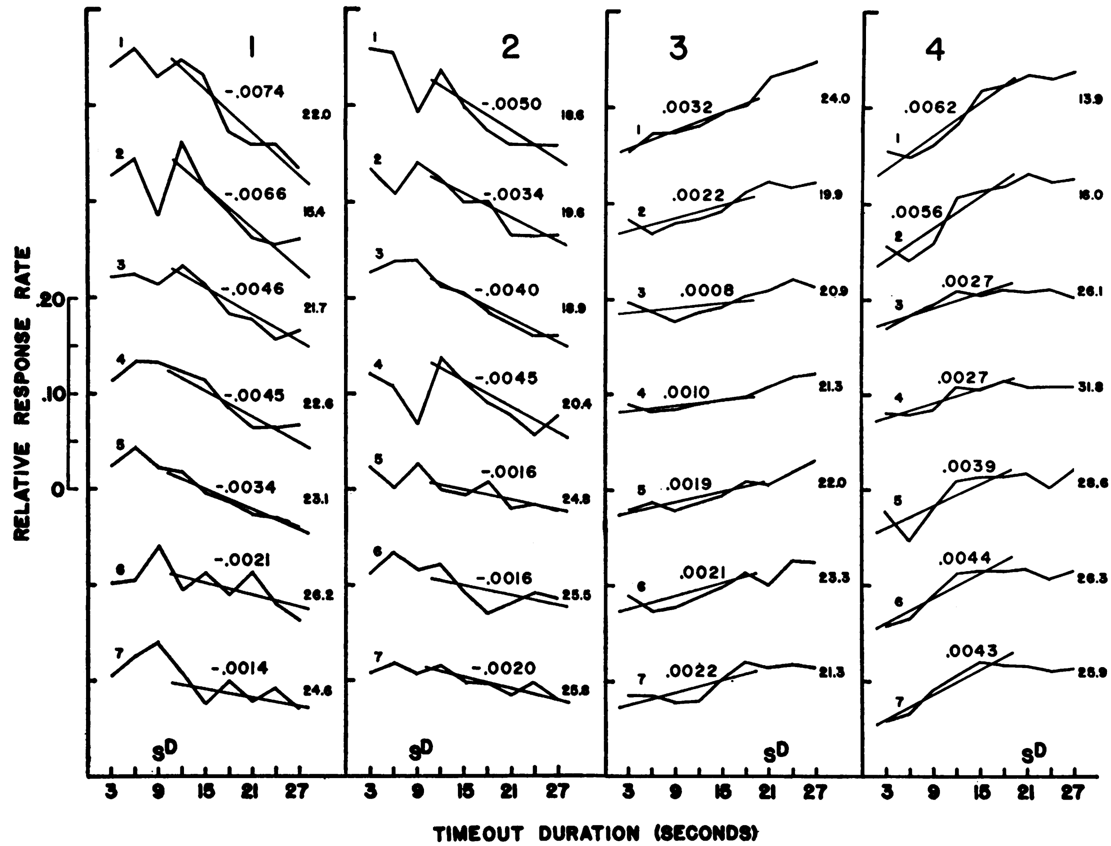

Fig. 3. Relative response rates for all animals are plotted as a function of the duration of the immediately preceding timeout. Each gradient is for a block of three maintained generalization training sessions, with the order of blocks indicated by the small number to the left of each gradient. The number to the right of each gradient indicates the mean number of responses per white-key period for that gradient. The straight lines are least squares fits to the six points on that side of the gradient, and the numbers above the gradients are the slope constants of the fitted lines.

(Reynolds, 1961; Terrace, 1968), and merely serves to demonstrate that the contrast phenomenon is not restricted to the auditory and visual modalities with which it has primarily been studied. This finding strengthens the view that behavioral contrast is a general characteristic of all discrimination learning.

Perhaps the most interesting result of the present study is the loss of control that was observed during the maintained generalization training procedure. This finding is in contrast to the many published studies of maintained generalization (*e.g.*, Blough, 1961; Pierrel, 1958), which typically show a sharpening of control when responding continues to be reinforced in the presence of one S^D and extinguished in the presence of several S^Δs. Perhaps the explanation for this difference lies in the term "presence" of a stimulus. In traditional studies of stimulus control, the stimuli relevant to the discrimination are, in fact, present in the exteroceptive environment while the organism's responses are reinforced or extinguished. That is, the lights are on or the sound is present in the chamber, and these stimuli are different during the S^D and the S^Δs. In the present experiment, this was not the case. In fact, the exteroceptive environment was exactly the same for the bird during all opportunities to respond. The only events available to the organism as a basis for discrimination were necessarily generated by the organism itself. This is a property of all temporal discrimination procedures, and is unavoidable due simply to the fact that "time" does not change the exteroceptive environment, at least within the confines of the experimental chamber.

The fact that these organism-generated events are neither observed nor controlled by the experimenter means that these events are only accidentally correlated with reinforcement or non-reinforcement. If the organism-generated events are perfectly correlated with time, the temporal discrimination will be quite stable. If, on the other hand, the organism-generated events are variable, the discrimination must necessarily "drift" (Herrnstein, 1966). Thus, although some typical stimulus control phenomena can be observed with the duration of an event as the relevant stimulus dimension, differences that are observed between "temporal discriminations" and discriminations of visual and auditory events may be due to the fact that temporal discriminations must necessarily be based upon events not under experimental control, and are therefore free to drift.

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Received 28 October 1970.