DISCRIMINABILITY OF FREQUENCY OF FOOD OR STIMULUS PRESENTATIONS IN VARIABLE-TIME SCHEDULES

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Pigeons responded in a two-alternative forced-choice task in which reinforcement was dependent upon the frequency of events that occurred in an immediately preceding schedule sample. On a given trial the events were either brief food presentations or brief visual and auditory stimulus changes. High levels of stimulus control were obtained by food-presentation schedules only. Discriminative control by frequency or stimulus change was absent. Stimulus control by food frequency was decreased by the imposition of a delay period between the schedule sample and the choice. Moreover, stimulus control by food frequency was related to the ratio of food-presentation schedule pairs when novel schedules were presented in a transfer test.

Key words: frequency discrimination, schedule discrimination, temporal stimulus control, equipotentiality, food presentation, stimulus presentation, variable-time schedule, key peck, pigeon

Variation in rate of reinforcement can control behavior not only through its consequences, but through its stimulus properties as well. Rilling (1967) demonstrated that subjects can discriminate between fixed-interval schedules of varying length. Reinforcement frequency has been shown to produce discriminative control with T schedules of varying frequency (Commons, 1979) and with variable-interval schedules of varying frequency (Mandell, 1981). Typically, such procedures allow the subject to respond briefly on a particular schedule sample and then offer the subject a choice between two responses. Reinforcement of choice responding depends on the value of the preceding schedule sample. In all of the above studies, choice responding was brought under the control of the frequency of events in the preceding schedule sample.

It remains to be demonstrated, however, that the lawful performance obtained in the preceding examples would generalize to any events distributed in time or whether it is limited to food-related events only. Although the principle of equipotentiality (Seligman, 1970) would suggest no reason for the rate of food presentation to differ in discriminability from the rate of any other discrete event, several studies in the literature suggest that in fact it is more discriminable. Stubbs, Vautin, Reid, and Delehanty (1978) reported a study in which the discriminability of time intervals signaled by food, brief stimuli, or paired stimuli and food was examined. Pigeons were trained to report whether a short or long period of time had elapsed following the presentation of a brief stimulus or food. Discriminability was found to be greater when the preceding stimulus was food-related. Spetch and Wilkie (1981) studied the discriminability of the durations of food and nonfood events and found that this discriminability was enhanced for food presentations.

In contrast to the above findings, Maki, Moe, and Bierley (1977) reported that performance on delayed matching-to-sample tasks involving "neutral" stimuli as samples was functionally similar to performance on delayed-matching-to-sample tasks involving

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reinforcers or responses as samples. That is, performance on all three tasks was similarly disrupted by variations in illumination during the delay interval and by shortening the intertrial interval.

These sets of findings are not necessarily contradictory. The ease with which stimulus control is established (assessed by the former set of studies) need not be correlated with the resistance of stimulus control, once established, to disruption (assessed by the second set of studies). The present study addresses both of these issues. First, using a within-subject experimental design, the discriminability of schedules differing in event frequency was compared for food-related and nonfood-related events. If sensitivity to the duration of an event is indeed dependent on the nature of that event, it is reasonable to suppose that sensitivity to the frequency of an event will likewise depend on the nature of that event. Pigeons were presented with one of two variable-time (VT) schedules of discrete events that constituted the sample. In different samples the events were either brief food presentations or brief visual and auditory stimulus changes. The subjects were then required to report, in a two-response forced-choice task, whether the events in the preceding samples occurred at a high or low rate. The degree of stimulus control exerted by event frequency was compared for food and nonfood samples. In addition, the functional similarity of choice performance with respect to food and nonfood events was assessed by imposing variable delays between the sample and the choice component of the task and by varying the event frequencies in a transfer test of stimulus control.

METHOD

Subjects

Four White Carneaux pigeons, bred at the University of New Hampshire, served. The subjects, three females and one male, were approximately one year old at the start of the experiment and were experimentally naive. Each was maintained at a minimum

of 85% of its free-feeding body weight by a diet of mixed grain. The food obtained during the experimental session was usually sufficient to maintain body weight at approximately 95% of free-feeding weight. Because all food was obtained in the experimental chamber, performance did not deteriorate even at these high weight levels. Grit and water were freely available in the home cage.

Apparatus

A Gerbrands Model G7410 chamber was used. It was equipped with three Model G6315 response keys, three stimulus light assemblies, and a Model G5610 feeder that dispensed mixed grain. The feeder, key-lights, and keys were located on one wall of the chamber such that the keys were spaced horizontally 6 cm apart, 12 cm above the feeder that was located centrally. A sonalert, located in the lower righthand corner of the response panel, produced a pure tone that was clearly audible to the experimenter. The chamber was housed in a sound-attenuating enclosure (see Weiss, 1970). A blower mounted outside the chamber provided masking noise and ventilation.

The experiment was controlled by a TRS 80/I microprocessor using MMS Forth, a time-sharing system designed by D. Lea, and interfacing designed by the LVB corporation.

Procedure

The procedures were designed to train the subjects to report on the rates at which events occurred in time. In the final training procedure subjects were presented a series of trials, each consisting of a schedule sample in which events occurred at a low rate (called low-frequency schedule) or at a high rate (called high-frequency schedule), followed by a forced-choice task in which reinforcement followed left- or right-key pecks, depending on event frequency in the preceding schedule sample. The descriptions that follow present details of this procedure, the methods used to shape final performance, the sequence in which the various

Fig. 1. Schematic diagram of procedure.

conditions and parameters were employed, and the final series of tests.

The final training procedure is schematized in Figure 1. Schedule samples were initiated following a 20-s intertrial interval (ITI) and were signaled by the illumination of the center key with a white light. A schedule sample consisted of three possible intervals, each terminating in a discriminable event, arranged as follows: The middle interval was equal to the nominal schedule value. Thus, for a VT 15-s schedule the middle interval equaled 15 s. The shorter interval was one half the nominal schedule value (7.5 s in this example) and the longer one was one and one half times the length of the nominal schedule value (22.5 s in this example.) The arithmetic mean of these intervals therefore was equal to the nominal value of the schedule. These intervals were arranged randomly in blocks of three, and between one and six blocks were presented on any given sample. A one-block sample consisted then of the three intervals—short, middle, and long—in random order, with each interval followed by an event. Larger samples consisted of multiples of the one-

block sample with the order of the intervals in each block determined independently on each repetition. Averaged over time, the number of events presented on the high-frequency schedule was equal to the number of events on the low-frequency schedule. A consequence of this procedure was that the samples were of variable duration, and distributions of sample durations for the high-frequency and low-frequency schedules were overlapping. For example, when the schedules were in a ratio of 3:1, the duration of a single-block sample of the low-frequency schedule was equal to that of a three-block sample of the high-frequency schedule. Similarly, a two-block sample of the low-frequency schedule was equal in duration to a six-block sample of the high-frequency schedule. Thus, neither the duration of the schedule sample nor the number of events could, in itself, predict schedule value.

The events presented at the end of each interval occurred independent of responding on the center key—that is, according to a VT schedule. The event was either a 1.5-s stimulus change or a 1.5-s hopper presentation in which the keylight was turned off and the food hopper, illuminated by a white light, was raised. During the first portion of the experiment (called the low-salience condition) the stimulus change consisted of a 1.5-s darkening of the keylight. After several months of training, with little evidence of acquisition, the stimulus events were changed to increase their salience. The 1.5-s hopper presentations were now accompanied by a darkening of the houselight as well as a darkening of the response key, and the 1.5-s stimulus change consisted of a darkening of the houselight, a change in key color from white to green, and presentation of an audible pure tone (called the high-salience condition). On any given sample only one type of event was presented. Thus, in a single session four types of samples were possible: low frequency/food, high frequency/food, low frequency/stimulus change, and high frequency/stimulus change. The sequence of sample types was random. After the last scheduled event the forced-choice component of the trial began.

The forced-choice segment was initiated with the illumination with red light of the two side keys of the chamber. The keylights remained on until a response occurred. Left-key responses following low-frequency samples and right-key responses following high-frequency samples (correct responses) resulted in 5-s food presentations followed by the intertrial interval. Grain presentations following correct choice responses were accompanied by a red hopper-light (to contrast with the white lights of sample reinforcers). Left-key responses following high-frequency schedules or right-key responses following low-frequency schedules (incorrect responses) produced the intertrial interval.

A daily session always began with the intertrial interval and consisted of 20 trials or 90 min. The houselight remained on during the entire session except as noted above. In the initial training procedure the average values of the low- and high-frequency schedules were 15 s and 5 s, respectively. Changes in these values occurred at various times as will be noted below. Sessions occurred 5 days per week.

Shaping the key-peck responses. Although responding was not required during the schedule sample, it was necessary to train the subjects to respond during the choice period. In order to equate experience with hopper presentation and stimulus change, a modification of the typical autoshaping procedure was used. Following a 40-s ITI with neither keylight nor houselight illuminated, the houselight was turned on and either of the two side keys was illuminated with red light. The probability of left- or right-key illumination was 0.5. If no response occurred within a 10-s period, either a 5-s food presentation or a 5-s key darkening followed. If a response occurred, the key was darkened and the scheduled event (feeder presentation or keylight offset) followed immediately. After the event the ITI was initiated. Sixty such trials were given daily until all subjects consistently pecked the red-lighted keys. The probability of food or stimulus change trials was 0.5.

Correction procedure. At the start of training

a correction procedure was instituted to minimize positional key biases. Incorrect responses during the choice period did not produce the ITI and advance the trial as they did in the final training procedure. Rather, they had no scheduled consequences. The trial did not terminate until the subject emitted a correct response, which was then reinforced. To determine accuracy, only the first choice response, correct or incorrect, was recorded during these trials.

Sequence of conditions. After autoshaping, the training procedure was begun using the correction procedure. The nominal value of the low-frequency schedule was 15 s. The nominal value of the high-frequency schedule was 5 s (3:1 ratio). After approximately 100 sessions the correction procedure was eliminated. Due to the failure to demonstrate significant stimulus control after 20 additional days of training without the correction procedure, schedule values were increased to 17.5 s and 3.5 s (5:1 ratio). These values were chosen arbitrarily. After 30 days of training on these values (without the correction procedure) stimulus control was evident, at least for the food schedules, and Delay Test 1 (see below) was instituted.

Because the above procedures did not produce stimulus control for the nonfood schedules, the high-salience condition was instituted. At this time the schedule values were once again changed to a 3:1 ratio. The schedule pair (4.38 s and 13.14 s) was again chosen arbitrarily. After 30 days of training at these values, with no correction procedure, Delay Test 2 (see below) was initiated followed by a 5-day return to baseline and a transfer test (see below). The sequence of conditions, the schedule pairs and their ratios, and the number of sessions at each condition are summarized in Table 1.

Delay Test 1: Delay Test 1 was administered after training on the low-salience condition. During testing a delay interval, signaled by the illumination of the center key with a red light, was inserted between the schedule sample and the choice period. In any single session one of the following delay values was instituted: 0, 1, 2, 4, 8, 16, or

Table 1

Sequence of conditions, schedule values for S1 (low frequency) and S2 (high frequency) and their ratios, the presence or absence of a correction procedure (corr. proc.), the salience of the scheduled events, and the number of sessions completed over the course of training.

Condition	Schedule value		Ratio	Corr. Proc.?	Salience	# of Sessions
	S1	S2				
Training 1	5.00	15.00	3:1	Yes	Low	100
Training 2	5.00	15.00	3:1	No	Low	20
Training 3	3.50	17.50	5:1	No	Low	30
Delay Test 1						12
Training 4	4.38	13.14	3:1	No	High	28
Delay Test 2						60
Training 5	4.38	13.14	3:1	No	High	5
Transfer Test						30

32 s. The delay values were presented first in ascending then in descending order during the course of 14 days. It was observed that during the 0-s delay condition, a 40-ms flash of red light was clearly visible on the center key. This was not the case prior to the delay test.

Delay Test 2. Delay Test 2 was administered after training on the high-salience condition. Unlike Delay Test 1, no keylights were illuminated during the delay interval. Further, instead of presenting a single delay value on a given day, delay values (0, 3, 6, 12, 24, and 48 s) were presented randomly during each session. This condition was in effect for 60 sessions.

Transfer test. After the administration of Delay Test 2, the preceding training condition (high salience, 3:1 schedule ratio) was reestablished for five sessions and the transfer test was instituted. During a given session, a pair of schedule values was chosen such that the ratio was greater than, equal to, or less than the ratio of the final training values (4.38 and 13.13 s). The schedule values were chosen so as to maintain a constant geometric mean value for each pair of schedules (7.58 s). The schedule pairs and their ratios (in parentheses) were: 18.76 and 3.07 s (6:1); 16.01 and 3.55 s (4.5:1); 13.13 and 4.38 s (3:1); 11.42 and 5.04 s (2.25:1); 9.38 and 6.13 s (1.5:1). In addition to variations in average schedule value, the variability of the intervals also was manipulated. On certain days the schedules were pro-

grammed with a short, middle, and long interval, as in training. On other days fixed schedules were employed, with all intervals equal to the nominal schedule value. Each schedule pair was presented three times for both fixed and variable schedules, occupying 30 days in total. During the transfer tests, reinforcement occurred as in training; that is, left-key choices were reinforced following the longer of the two values, and right-key choices were reinforced following the shorter of the two.

RESULTS

Throughout this report the acquisition of stimulus control is characterized in two ways. The proportions of left-key responses (P[R1]) following the low-frequency schedule (S1) and those following the high-frequency schedule (S2) are shown. These measures are analogous to the hit and false-alarm probabilities in the Green and Swets (1966) model of signal detectability. The greater the difference between these measures, the greater the accuracy of performance. In addition, for purposes of comparison between the food and stimulus-change conditions, a single measure of accuracy is also presented. Ideally, a measure of accuracy that represents discriminability only and is independent of response bias (such as d' in the detectability model) should be used. Unfortunately, the small number of trials and the frequency with which values of

0.0 or 1.0 were obtained in the present work rendered the use of d' unfeasible. Therefore, overall accuracy has been represented throughout as proportion of correct trials. The reader should note, however, that strong quantitative comparisons should not be made using this index due to the confounding of discriminability and response bias.

Acquisition of discrimination in the initial task was extremely slow. After 100 days of training, little evidence of stimulus control was seen for any subject in either the food or

the stimulus-change condition. The left panels of Figure 2 show the proportion of hits and false alarms during the last five days of the initial low-salience condition (schedules in a ratio of 3:1). There is no consistent separation between the hit and false-alarm functions. The left panels of Figure 3 show the same data replotted in terms of proportion of correct choice responses. Accuracy fluctuated around 0.5 or chance performance. The right panels of Figures 2 and 3 show performances during the subsequent low-salience condition following the increase

Fig. 2. Proportion of R1 (left-key) choices given S1 (low frequency) and S2 (high frequency) during training in the low-salience condition.

Fig. 3. Proportion of correct choices during training in the low-salience condition.

in the schedule ratio (5:1). A substantial improvement in stimulus control in the food condition occurred for all subjects. For Subjects 2 and 3 the change in performance was evident immediately. For the other subjects the change was more gradual, requiring 10 to 15 days of additional training. No increase in accuracy occurred in the stimulus-change condition. Performances remained consistently around chance levels.

The effects of the delays imposed between sample offset and onset of the choice component during Delay Test 1 on choice accuracy (proportion of correct trials) are shown in Figure 4. In the reinforcement condition,

Fig. 4. Proportion of correct choices as a function of the delay interval during Delay Test 1. (Each point represents approximately 10 determinations.)

accuracy tended to deteriorate after as little as 2 s of delay. This is somewhat surprising considering that all of the interreinforcement intervals, which served as stimuli, exceeded that value. Performance in the stimulus-change condition did not change systematically at any delay values.

The pattern of acquisition in the high-salience condition is shown in Figure 5 (hits and false alarms) and Figure 6 (proportion of correct trials). The data are similar to the acquisition data of the low-salience, 5:1 ratio condition. That is, in the food condition accuracy was maintained at high levels. In the stimulus-change condition performance remained at chance, as indicated by the degree

Fig. 5. Proportion of R1 (left-key) choices given S1 (low frequency) and S2 (high frequency) during training in the high-salience condition.

of separation for the hit and false alarm functions as well as the proportion of correct responses.

Although appearances suggested that responding in the food condition was controlled by event frequency, it is nonetheless possible that control was attributable to other factors. These data were therefore analyzed to determine whether variables other than event frequency were contributing to stimulus control. First, the contribution of the total sample duration was considered. Table 2 shows the proportion of correct responses following high- and low-frequency schedules as a function of total sample duration. If sample duration were in fact influencing choice performance, then accuracy should decrease at durations common to both high- and low-frequency schedules (39.42 s and 78.84 s). No such trend is evident in these data, suggesting that sample duration was not a systematic determinant of choice. In addition, responding on the

Fig. 6. Proportion of correct responses during training in the high-salience condition.

center key was examined to determine whether response rates differed (and thus served as cues) during the sample portions of the task. Subjects 1 and 2 did not respond at all during the schedule sample. Subjects 3

Table 2

Proportion of correct responses, given S1 (low frequency) or S2 (high frequency), as a function of total sample duration. .

Sample Duration	Subject Number							
	1		2		3		4	
	S1	S2	S1	S2	S1	S2	S1	S2
13.14 s	.67		.60		.40		1.00	
26.28 s	1.00		.57		.40		1.00	
39.42 s	1.00	.60	1.00	.50	.33	1.00	1.00	.87
52.56 s	1.00		1.00		.40		1.00	
65.70 s	1.00		1.00		.50		.89	
78.84 s	.89	1.00	.80	.85	.50	1.00	1.00	1.00
118.26 s		1.00		.90		.80		.67
157.68 s		1.00		1.00		1.00		1.00
197.10 s		.70		.75		1.00		.46
236.52 s		.80		1.00		.85		.40

and 4 responded more quickly during the high-frequency sample (0.66 and 3.22 responses/s, respectively, during the low- and high-frequency samples for Subject 3; 1.92 and 3.41 reponses/s during the low- and high-frequency samples for Subject 4). Thus, it is possible that responding during the sample was controlled by event frequency, and that choice was mediated by the subjects' own responding.

It should be noted, however, that although response rates in the stimulus-change condition were somewhat lower than those in the food condition, they were also differential with respect to the rate of events (0.13 and 1.15 responses/s in the low- and high-frequency conditions for Subject 3; 0.57 and 3.11 responses/s in the low- and high-frequency conditions for Subject 4). The fact, therefore, that stimulus control of choice responding was not achieved in the stimulus-change condition suggests that response rate was not a mediator of choice irrespective of the nature of the events that were presented.

The results of Delay Test 2 (mixed delays), shown in Figure 7, reveal a decrease in the proportion of correct responses with increasing delays in the food condition for 3 of 4 subjects. More marked, however, is the overall disruption of performance (even performance at zero-delay) when variable delays were instituted. This can be seen by compar-

ing the proportion of correct responses obtained during the five days immediately prior to Delay Test 2 (filled triangles) with the proportion of correct responses obtained with zero-delay values during the test (filled circles). Despite the fact that these trials were procedurally identical, accuracy was reduced on those sessions that included longer delays. This reduction in accuracy might be attributed to a reduced reinforcement rate resulting from the high percentage of long-delay trials over the course of the 60-session delay test. If this were the case, decrements in performance with zero delay might be expected to develop gradually after some loss of reinforcers had occurred. Further, these effects might be expected to persist for some time after the delay was removed. It is important to note, therefore, that the deficit in accuracy in the zero-delay trials did not develop gradually; it was evident immediately upon institution of the delay test. Moreover, the levels of accuracy after delay was removed (indicated by filled squares) reached original levels immediately.

Figure 8 shows the proportion of correct responses during transfer testing as a function of the ratio of long to short schedule values. The stimulus-change condition is shown in the right panels and the food condition in the left panels. If performance were related to the ratio of schedule value, accuracy should increase as the ratio increased.

Fig. 7. Proportion of correct responses at each delay interval during Delay Test 2 (mixed delays). Triangles represent the last 5 days of baseline. Squares represent the first 4 days of recovery.

Fig. 8. Proportion of correct responses on fixed and variable trials during transfer test.

There is evidence of such an increase in the food condition, particularly beyond a ratio of 2.25. Such improvement in performance in the stimulus-change condition did not occur even at ratios of 6:1. Differences in accuracy for variable and fixed schedules (solid and dashed functions, respectively) were also assessed. The overlapping of the functions shown in Figure 8 reveals no differential improvement in performance with either schedule type.

The comparison of responding on fixed- and variable-time schedules also can reveal systematic differences in response bias. If, for example, fixed schedules were treated as less dense than variable schedules, consis-

tently higher proportions of left-key (R1) choices should be observed at all fixed-schedule values. In order to address this issue, the proportion of hits and false alarms made at each of the schedule pairs during the transfer test is shown in Figure 9. Again, variable and fixed schedules are represented by solid and dashed lines. There is no evidence for any subject of a difference in the tendency to choose R1 for fixed and variable schedules. Thus, it would seem that the distribution of intervals comprising the schedules did not affect the stimulus control of responding by reinforcement frequency.

DISCUSSION

Consistent with earlier studies on duration discrimination, the present work demon-

strated differences in the discriminability of rate of food and nonfood events. Although the rate of food presentation acquired a high level of stimulus control, virtually no control was acquired by equivalent rates of "neutral" stimulus events. Moreover, although increasing the disparity between two rates of events improved performance in the food condition, it did not improve performance in the stimulus-change condition. This is perhaps more dramatic because it has been demonstrated (Heinemann & Avin, 1973) that after discrimination training on a difficult task in which little stimulus control is apparent, subjects manifest control when more disparate stimuli are presented during generalization testing. Such was not the case in the present study. Neutral events appeared to have acquired no differential control of choice responses in any of the tests used.

The possibility that the stimulus changes themselves were not discriminable to the subjects can be eliminated for the following reasons: (1) Many studies have demonstrated that pigeons can easily discriminate key-color changes, and the difference between a white and a green key should be easily detected (e.g., Wright & Cumming, 1971); (2) examination of videotapes of the subjects (made just prior to and during Delay Test 2) showed that not only did subjects tend to orient toward the center key during the stimulus-change samples, but all subjects tended to peck at the green-key flashes. The pecks occurred with fair reliability even when no pecks were directed at the white center key. Thus the green-key flashes were clearly exerting some sort of behavioral control and presumably were discriminable to the subjects.

Although the present study did not attempt to determine the cause of the failure to achieve stimulus control by the frequency of nonfood events, several interpretations of this failure might be considered. To say that the stimulus-change condition was not sufficiently salient is simply to say that there was no stimulus control, unless salience can be defined independently of choice responding. For example, it may be possible to define

Fig. 9. Proportion of R1 (left key) choices given S1 (low frequency) and S2 (high frequency) for fixed and variable schedules during transfer test.

salience in terms of the number of sense modalities stimulated. Certainly food presentations produced visual, auditory, tactile, gustatory, and proprioceptive stimulation, whereas the stimulus-change condition produced merely visual and auditory stimulation. Alternatively, the difference between the conditions may be related to the fact that food presentations reliably produced a particular response (eating), whereas light and sound stimulation did so less consistently. If this is so, it may be that the subjects' own responding is "more salient" than externally presented stimuli. Another alternative concerns the issue of "biological" relevance. Food, being essential to the organism's survival, can be considered biologically relevant. A change in ambient stimulation uncorrelated with any other event produces habituation of the orienting response and can be considered "biologically irrelevant." It is possible that mechanisms concerned in the detection of time may be triggered only by biologically relevant events.

Moreover, it should be noted that the failure to attain stimulus control by neutral stimuli within the present experimental procedure does not imply that such control cannot be attained in any procedure. First, consider that the rate of events was used to predict a large food reinforcer. If another choice of reinforcer had been made (such as shock termination, for example), it is quite possible that the results would have been reversed, as in the conditioned taste-aversion literature in which certain stimuli have been found to be more easily related to particular consequences than to others (Garcia & Koelling, 1966). Also, consider that within this procedure the subjects had numerous potential sources of reinforcement other than those correlated with correct responding in the nonfood condition. First there were the response-independent reinforcers presented during the sample, and second were the large reinforcers presented for correct responding in the food condition. It is quite possible that if the rate of stimulus change were the only reliable predictor of reinforcement in this situation, stimulus

control would have been demonstrated.

The secondary purpose of this paper, a comparison of the functional similarity of stimulus control by food and nonfood events, could not be fulfilled due to the failure to achieve any measurable stimulus control of choice responding by the nonfood events. Nonetheless, several secondary findings emerged from the transfer and delay tests. One point of interest is the similarity of choice functions for fixed and variable schedules. Mandell (1980) demonstrated that fixed- and variable-interval schedules of equal mean value were equally resistant to disruption. This implies, according to Nevin's (1974, 1978) theory of response strength, that the reinforcement value of equal fixed and variable schedules is equal. This finding was surprising in view of the fact that in choice situations variable-interval schedules are generally preferred to fixed schedules of equivalent value (Davison, 1969; Herrnstein, 1964). Mandell (1981) demonstrated that psychophysical judgments of reinforcement frequency in interval schedules were comparable for fixed- and variable-interval schedules of equal mean value, lending support to the notion that the overall frequency of reinforcers is treated as equal by subjects when the rate of reinforcement presentation is equivalent, irrespective of the distribution of reinforcers. The present transfer test confirms this conclusion and extends it to schedules in which reinforcers are delivered independently of responding.

Another finding of note concerns the disruptive effects of delay in the delay tests. Many researchers have used similar delays in stimulus-control tasks and have found orderly delay gradients (e.g., Berryman, Cumming, & Nevin 1963). In the present study, however, delay produced nonspecific effects at all values of the delay interval, including zero delay. It is difficult to explain this. Perhaps the task was so difficult that any change in procedure would have produced general disruption. Alternatively, perhaps there was some interaction due to the temporal nature of the task and the temporal nature of the disruption.

In summary, the major point of this study is to demonstrate that differing degrees of temporal stimulus control can be produced by comparable schedules, depending on the nature of the scheduled events. These results add to the already serious doubts about the theory of equipotentiality and suggest that biological constraints may be operative in many, seemingly "neutral," stimulus-control procedures. These results suggest that care must be taken, when studying temporal control, to consider the nature of the temporal stimuli rather than treating them abstractly. This is of particular importance when the conclusions to be drawn concern the nature of temporal processing per se, or involve generalization between experimental situations.

REFERENCES

- Berryman, R., Cumming, W. W., & Nevin, J. A. (1963). Acquisition of delayed matching in the pigeon. *Journal of the Experimental Analysis of Behavior*, 6, 101-107.
- Commons, M. L. (1979). Decision rules and signal detectability in a reinforcement-density discrimination. *Journal of the Experimental Analysis of Behavior*, 32, 101-120.
- Davison, M. C. (1969). Preference for mixed-interval versus fixed-interval schedules. *Journal of the Experimental Analysis of Behavior*, 12, 247-252.
- Garcia, J., & Koelling, R. A. (1966). Relation of cue to consequence in avoidance learning. *Psychonomic Science*, 4, 123-124.
- Green, D. M., & Swets, J. A. (1966). *Signal detection theory and psychophysics*. New York: Wiley.
- Heinemann, E. G., & Avin, E. (1973). On the development of stimulus control. *Journal of the Experimental Analysis of Behavior*, 20, 183-195.
- Herrnstein, R. J. (1964). Aperiodicity as a factor in choice. *Journal of the Experimental Analysis of Behavior*, 7, 179-182.
- Maki, W. S., Jr., Moe, J. C., & Bierley, C. M. (1977). Short-term memory for stimuli, responses, and reinforcers. *Journal of Experimental Psychology: Animal Behavior Processes*, 3, 156-177.
- Mandell, C. (1980). Response strength in multiple periodic and aperiodic schedules. *Journal of the Experimental Analysis of Behavior*, 33, 221-241.
- Mandell, C. (1981). A psychophysical analysis of time-based schedules of reinforcement. In M. L. Commons & J. A. Nevin (Eds.), *Quantitative analyses of behavior: Vol. 1. Discriminative properties of reinforcement schedules* (pp. 31-50). Cambridge, MA: Ballinger.
- Nevin, J. A. (1974). Response strength in multiple schedules. *Journal of the Experimental Analysis of Behavior*, 21, 389-408.
- Nevin, J. A. (1978). Reinforcement schedules and response strength. In M. D. Zeiler & P. Harzem (Eds.), *Advances in analysis of behaviour: Vol. 1. Reinforcement and the organization of behaviour* (pp. 117-158). Chichester: Wiley.
- Rilling, M. (1967). Number of responses as a stimulus in fixed interval and fixed ratio schedules. *Journal of Comparative and Physiological Psychology*, 63, 60-65.
- Seligman, M. E. P. (1970). On the generality of the laws of learning. *Psychological Review*, 77, 406-418.
- Spetch, M. L., & Wilkie, D. M. (1981). Duration discrimination is better with food access as the signal than with light as the signal. *Learning and Motivation*, 12, 40-64.
- Stubbs, D. A., Vautin, S. J., Reid, H. M., & Delehanty, D. L. (1978). Discriminative functions of schedule stimuli and memory: A combination of schedule and choice procedures. *Journal of the Experimental Analysis of Behavior*, 29, 167-180.
- Weiss, S. J. (1970). An effective and economical sound-attenuation chamber. *Journal of the Experimental Analysis of Behavior*, 13, 37-39.
- Wright, A. A., & Cumming, W. W. (1971). Color-naming functions for the pigeon. *Journal of the Experimental Analysis of Behavior*, 15, 7-17.

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