*DELAYED TEMPORAL DISCRIMINATION IN PIGEONS:
A COMPARISON OF TWO PROCEDURES*

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A within-subjects comparison was made of pigeons' performance on two temporal discrimination procedures that were signaled by differently colored keylight samples. During stimulus trials, a peck on the key displaying a slanted line was reinforced following short keylight samples, and a peck on the key displaying a horizontal line was reinforced following long keylight samples, regardless of the location of the stimuli on those two choice keys. During position trials, a peck on the left key was reinforced following short keylight samples and a peck on the right key was reinforced following long keylight samples, regardless of which line stimulus appeared on the correct key. Thus, on stimulus trials, the correct choice key could not be discriminated prior to the presentation of the test stimuli, whereas on position trials, the correct choice key could be discriminated during the presentation of the sample stimulus. During Phase 1, with a 0-s delay between sample and choice stimuli, discrimination learning was faster on position trials than on stimulus trials for all 4 birds. During Phase 2, 0-, 0.5-, and 1.0-s delays produced differential loss of stimulus control under the two tasks for 2 birds. Response patterns during the delay intervals provided some evidence for differential mediation of the two delayed discriminations. These between-task differences suggest that the same processes may not mediate performance in each.

Key words: temporal discrimination, delayed discrimination procedures, response mediation, key peck, pigeons

It is well established that systematic behavioral changes accompany variations in the temporal parameters of conditioning experiments. In Pavlovian conditioning, the temporal placement of the unconditional stimulus in relation to the conditional stimulus can be crucial to the acquisition of a conditional response (e.g., Smith, Coleman, & Gormezano, 1969). In operant conditioning, time-related variables also have significant influences on behavior. Examples can be found in the development of distinctive response patterns under various schedules of reinforcement, such as the fixed-interval scallop (Ferster & Skinner, 1957).

However, as Catania (1970) has pointed out, behavioral control by temporal features of the environment—as indicated by orderly changes in operant responding when temporal parameters are manipulated—does not ensure that a temporal discrimination is involved. Although it is tempting to infer temporal dis-

crimination from schedule-controlled behavior, the subject's direct interaction with the schedule precludes a definitive conclusion. The nature of this interaction is obvious in schedules for which response rate strongly determines reinforcement rate (e.g., fixed-ratio and differential-reinforcement-of-low-rate schedules). However, even when this is not the case (e.g., fixed-interval schedules), other dynamic effects may still be operating, including temporal processes other than discrimination *per se*, such as delayed reinforcement effects (Dews, 1962).

It is possible that recent interest in the issue of animals' perception of time (e.g., Gibbon & Allan, 1984) stems from these analytical shortcomings of reinforcement schedules. In any case, it is clear that a critical test of animals' temporal discriminative capabilities requires a procedure in which responses are controlled by a temporal event after it has elapsed (Wasserman, DeLong, & Larew, 1984). A delayed discrimination procedure is ideally suited to this purpose. Two variants of this procedure can be outlined.

Stubbs (1968) trained pigeons to respond differentially after two classes of stimulus durations using a two-response procedure. After

The authors thank Robert E. DeLong for his comments on a preliminary draft of this report and Veronika T. Guttenberger for her technical assistance.

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the offset of a sample stimulus (white key-light), differential reinforcement was arranged for pigeons' pecking one test stimulus after short sample durations (1, 2, 3, 4, or 5 s) and a different test stimulus after long sample durations (6, 7, 8, 9, or 10 s). In this case, the test stimuli were red and green side keylights, illuminated simultaneously, with their positions (left or right) varied nonsystematically. Because reinforcement was not available until after the sample stimulus was terminated, test-key responses provided an unconfounded measure of duration discrimination.

The other delayed-discrimination procedure is much like that used by Stubbs, but differences between the two could be important. Church (1980) arranged differential reinforcement of rats' pressing one lever after short signals (housetlight extinguished or 2 or 3.2 s) and a second lever after long signals (housetlight extinguished for 5 or 8 s). Once again, the correct response was dependent upon the duration of a previous stimulus. Here, though, the correct response was determined by a constant feature of the apparatus (the position of the lever in the chamber) rather than by a variable feature of the apparatus (the changing location of two visual stimuli).

Both researchers found that differential responding was a function of the duration of the sample stimulus, providing strong evidence for temporal discrimination, as well as impetus for defining limits, isolating influential variables, and describing mathematical functions that relate subjective time to objective time. However, potentially important procedural differences may limit the generality of conclusions from one experiment to the other. Although the above two delayed-discrimination tasks are similar in that reinforcement is made available on each trial given a correct response, different rules are used for designating correct responses in each. With the procedure used by Church, a correct rule might be "respond on the right lever after a short stimulus; respond on the left lever after a long stimulus." On the other hand, with the procedure used by Stubbs, the rule might be "peck red after a short stimulus; peck green after a long stimulus." This is not a trivial distinction if one considers that, in the former task, the subject can correctly choose where to respond even before the options are made available. For example, in Church's experiment, if a rat were to adopt a temporal

cutoff between 3.2 and 5 s for distinguishing short signals from long signals, it could immediately orient toward the "correct" lever as soon as the cutoff interval had been reached, even though pressing would not be reinforced until later. In Stubbs' procedure, however, position-oriented responses before the time of the test would have only a chance relation to the side where reinforcement would occur, because the latter would be correlated with the visual properties of the test stimuli, rather than with fixed positions.

Furthermore, there is some suggestion in the literature concerning stimulus dimensions other than time, that these two delayed-discrimination tasks might lead to performance differences. Smith (1967) observed that pigeons' discrimination learning was more rapid and terminal performance was more accurate with a position task like Church's than with a stimulus task like Stubbs'. Unfortunately, the strength of Smith's conclusions is reduced because his design failed to control for possible confounding effects due to differences in the discriminability of the sample stimuli in the two tasks. Under better equated experimental conditions, Honig and Wasserman (1981) found that stimulus control developed faster and dissipated less quickly when a go/no go discrimination was learned solely on the basis of the sample stimulus than when learning was necessarily based upon both the sample and the later test stimuli. Moreover, using a choice procedure, Chatlosh, Guttenger, and Morgan (cited in Wasserman, 1985) found that increasing sample stimulus durations had a much greater effect on the retention of stimulus discriminations in procedures like that of Stubbs than on the retention of position discriminations in procedures like that of Church. The proposal generated by these findings—that observed performance differences may indicate different bases for the discriminations—can be applied here as well. This possibility exemplifies the need for careful examination of experimental procedures before attempting to integrate available research findings.

The present study was designed to assess whether two delayed-discrimination procedures, similar to those used by Stubbs (1968) and Church (1980), generate reliable differences in pigeons' acquisition of a duration discrimination and/or maintained performance when interstimulus delays subsequently are

added to the procedures. In the first phase, experimentally naive birds each were trained with two types of delayed-discrimination problems, differing with respect to the designation of correct responses. The color of a sample stimulus signaled the problem type for each trial. On all trials, the sample stimulus was presented for either a short or a long fixed duration, after which two line-orientation stimuli were presented simultaneously. On half of the trials, the *position* task, the duration of the sample stimulus indicated where the bird must peck if it is to obtain a reinforcer: to the right or to the left test stimulus, regardless of line orientation. On the other half of the trials, the *stimulus* task, the duration of the sample stimulus indicated which test stimulus the bird must peck if it is to obtain a reinforcer: the horizontal-line or the slanted-line stimulus, regardless of key location. In both tasks, the correct response depends upon the previous sample stimulus duration. But, in the position task, unlike in the stimulus task, the correct response does not depend upon the specific features of the test stimuli; rather, components of the correct differential response can be made during the presentation of the sample stimulus. Because of this difference, we predicted that correct differential responding would develop more quickly on position-task trials than on stimulus-task trials.

In the second phase of the experiment, time intervals were interpolated between the sample and the test stimuli. This was an important manipulation because it seemed likely that the position task—due to the possible emergence of correct orienting responses prior to the onset of the test stimuli—would more effectively control behavior across delays than would the stimulus task. Therefore, we hypothesized that discriminative performance would be more strongly disrupted by the interstimulus delays on stimulus trials than on position trials.

METHOD

Subjects

Four experimentally naive pigeons, each maintained at approximately 85% of its free-feeding weight, served as subjects. When required, adjusted food rations of mixed grain were given following daily experimental sessions. Grit and water were continuously avail-

able in individual home cages located in a colony room with 24-hr lighting. Every third day, a dose of poultry vitamins was added to the water.

Apparatus

Four identical three-key pigeon chambers (29.5 by 32.0 by 38.0 cm) with aluminum walls and metal grid floors were used. A force of approximately 0.05 N was required to activate each of the 2.5-cm-diameter response keys. The center key was positioned 12 cm above the solenoid-operated grain hopper (BRS/LVE 114-10) and 4 cm below the houselight. The other two keys were horizontally aligned with respect to the center key, and were positioned 5.7 cm on either side of it. Miniature display projectors (IEE Series 10, CM 44 lamps, 5.5 V dc), mounted behind the clear Plexiglas® keys, transilluminated either a red field, a violet field, a yellow field, or a blue field on the center key, and a white horizontal line or white line slanted 60° from vertical centered on a black field, on each of the side keys. The line stimuli were each 0.2 cm wide and 2.0 cm long. The houselight (CM 44 lamp, 5.5 V dc) was encased in a black metal housing that directed the light toward the ceiling. The hopper opening was 4.9 by 5.5 cm and was illuminated during reinforcement (ESB 24 bulb at 24 V dc). White noise was supplied through speakers, and externally mounted blowers also masked extraneous sounds and provided continuous chamber ventilation. A PDP 8/A® minicomputer (Digital Equipment Corporation), in a separate room, controlled experimental events and data collection via the SKED® software system (Snapper, Stephens, & Lee, 1974).

Procedure

Pretraining. After two hopper-training sessions, the 4 birds' pecking was autoshaped to the three response keys (Brown & Jenkins, 1968). Center keylight stimuli were red, violet, yellow, and blue; right- and left-side keylight stimuli were the horizontal and slanted lines. During autoshaping, one of the eight stimuli was presented on each trial. A stimulus was terminated either when a subject met the response requirement on the lit key or after a fixed duration. The food hopper was raised immediately upon stimulus offset, followed with equal probability by intertrial intervals

(ITIs) of 30, 50, or 70 s. The stimuli were randomly presented, with the restriction that each occur once within every block of eight trials. The birds received six daily sessions of 48 trials (six trials with each of the eight stimuli). Several parameters were varied within and across sessions: Stimulus durations were initially set at 10 s and were later increased to 10 min; response requirements were gradually increased from one peck to 10 pecks, and hopper durations were gradually reduced from 6.00 s to 2.25 s. On the last day of pretraining, all birds rapidly met the final response requirement (10 pecks) on every trial. Phase 1 of the experiment began the next day.

Phase 1. Both types of delayed discrimination trials began with a randomly selected 15-, 20-, or 25-s ITI, during which only the houselight was illuminated. Then a presample stimulus (yellow) was presented on the center key. One peck was required to extinguish the presample and to produce one of the four sample stimuli—a red or violet center keylight presented for either 2 s (short) or 10 s (long). Sample offset was immediately followed by the simultaneous illumination of horizontal and slanted lines on the side keys. These test stimuli appeared equally often in the right and left positions for each trial type. During position trials, the line orientations of the test stimuli were irrelevant. After short samples, pecking the left key was reinforced; after long samples, pecking the right key was reinforced. During stimulus trials, the positions of the two test stimuli were irrelevant and line orientation was the relevant dimension. Short slanted line and long horizontal line sequences were designated correct; short horizontal line and long slanted line sequences were incorrect. With equal probability, reinforcement consisted of either 0.50- or 2.25-s access to the lighted grain hopper, with the houselight turned off. Brief hopper deliveries helped to prevent satiation, thereby permitting a greater number of trials per session. A 0.50-s hopper was followed by 1.75 s of blackout. Incorrect responses resulted in 2.25 s of blackout.

Each of the eight trial types (four sample stimuli $\times$ two positions of the test stimuli) was selected at random, with the restriction that each occur once in every block of eight trials. For Birds 4 and 5, violet signaled a position trial and red signaled a stimulus trial; this specification was reversed for Birds 6 and 7. Daily sessions entailed 72 trials. Three of the

birds were exposed to this procedure for 84 consecutive sessions, then immediately shifted to Phase 2 of training. Bird 7, however, developed a total position preference for the left response key after 40 days of training. Various measures, including a brief return to auto-shaping, were taken to bring its performance back under discriminative control. Because data from these days were excluded, Bird 7 was shifted to the next phase of the experiment 36 days later than the other subjects.

Phase 2. Phase 2 training conditions were identical to those of Phase 1 except that a 0.0-, 0.5-, or 1.0-s interval was inserted between sample stimulus offset and presentation of the test stimuli on each trial. This "retention interval" for a given trial was chosen randomly, with the restriction that each occur once, for each of the eight trial types of Phase 1, in every block of 24 trials. Note that 0.0-s interval trials were identical to Phase 1 trials. Sessions of 72 trials continued for 28 consecutive days for 3 of the birds. Bird 7 also received 28 sessions; however, due to occasional equipment failures, these sessions were not always on consecutive days.

RESULTS

Phase 1

Individual acquisition data are presented in Figure 1. The percentage of correct responses, in 4-day blocks, is plotted separately for position- and for stimulus-trial types. By the end of Block 5, all birds had attained or surpassed a 90% correct accuracy level at least once on position trials, whereas differential responding on stimulus trials remained at near-chance levels. Thus, for all birds, acquisition of the temporal discrimination was far faster when the sample duration indicated where to respond during the test component than when it indicated to which line stimulus to respond.

After extensive additional training, 2 of the birds performed with comparable accuracy on position- and stimulus-trial types. For Bird 4, the nearly equal terminal accuracy levels resulted from a gradual rise in accuracy on stimulus trials and a concomitant decline in accuracy on position trials, after which performance remained stable (Blocks 15 to 21). For Bird 5, however, the similar accuracy levels for position and stimulus trials, exhibited by the end of Block 9, were primarily due to increased accuracy on stimulus trials.

At the end of training, the other 2 birds were still responding more accurately on the position task than on the stimulus task. Bird 6 performed at near-chance levels on stimulus trials until Block 16, when accuracy began to increase, although it never reached the high level of performance maintained on the position task. Bird 7 demonstrated a very gradual rise in percentage of correct choices on stimulus trials that terminated at a level well below that of position trials. Thus, by the end of 21 blocks of training, stimulus task performance caught up with position task performance for 2 birds, but it failed to do so for the other 2.

Phase 2

Performance functions for each of the birds, with the sample test delays of Phase 2 training, are presented in Figure 2. The mean percentage of correct responses, for seven 4-day blocks, at 0-, 0.5-, and 1.0-s retention intervals, is plotted separately for both position- and stimulus-trial types. For Birds 5 and 6, the introduction of delays between sample and test stimuli differentially affected performance on the two tasks. Discriminative performance on position trials was virtually uninfluenced by 0.5- and 1.0-s delays, whereas the same delays considerably disrupted accuracy on stimulus trials. Bird 4, which performed the two tasks with equal mediocrity by the end of Phase 1, continued to exhibit no between-task differences during Phase 2; delayed presentation of the test stimuli did not interfere with either position task performance or stimulus task performance. For Bird 7, accuracy remained much higher on position trials than on stimulus trials in Phase 2, with the 1.0-s delay producing a slight, nondifferential decrease in accuracy on both tasks. Thus, 2 of the 4 subjects behaved in accord with our predictions. That is, when differential responding depended upon features of the test stimuli as well as upon the duration of the sample stimulus, performance was disrupted by insertion of delays between the sample and the test stimuli; but, when differential responding did not depend upon specific features of the test stimuli, no detrimental effects of the delays were observed.

Retention-Interval Responding

Delayed-discrimination tasks sometimes lead to the development of stereotyped responses during the delay interval. When these responses are effective in the control of choice

Fig. 1. Percentage of correct responses during acquisition (0-s retention interval) on position and stimulus trials, in 4-day training blocks, for individual subjects.

responding and increase the rate of reinforcement, they are called mediating responses (Riley, Cook, & Lamb, 1981). Mediating responses are thought to bridge the gap between sample and test stimuli. Using a delayed-matching paradigm, Blough (1959) found that 2 of 4 birds responded differentially during the delays following steady versus flickering sample stimuli. For these birds, the topography of the intervening responses appeared to determine choice responding rather than the sample stimuli per se, so that incorrect choices usually followed atypical retention-interval responses. Blough also reported that as the responses fol-

Fig. 2. Mean percentage of correct responses (across seven 4-day training blocks) on position and stimulus trials with 0-, 0.5-, and 1.0-s retention intervals for individual subjects. Mean standard deviations (across retention intervals) on the position and stimulus tasks, respectively, were, for Bird 4, 0.03 and 0.04; for Bird 5, 0.02 and 0.07; for Bird 6, 0.02 and 0.07; and for Bird 7, 0.05 and 0.05.

lowing each of the sample stimuli became more clearly differentiated, accuracy increased.

In the present experiment, both the position and the stimulus tasks of Phase 2 involved delayed temporal discriminations, and choice performance may, therefore, have come to be

mediated by retention-interval responding in both. However, the nature of the position task, unlike the stimulus task, makes it possible to determine, prior to the delay interval, whether a peck on the left or on the right test stimulus will be reinforced later. Therefore, although

in principle mediating behavior need not take the form of a key peck, the position task provides the opportunity for effective mediation via pecks at the same location where a response will subsequently be reinforced, whereas the stimulus task does not. This analysis suggests the possibility that, in cases where delays had no effect on accuracy during position trials but adversely affected accuracy during stimulus trials, the delays of position trials were mediated by subjects' differential allocation of retention-interval responses to the three keys after short versus long sample durations.

Table 1 gives each bird's pecking rate on each of the three response keys during 1.0-s retention intervals for both position and stimulus trials. The 1.0-s retention-interval data are presented because of the greater opportunity for response mediation during these trials. Rates were determined from the 336 s of 1.0-s retention interval trials on each task, accumulated over the entirety of Phase 2 training.

Recall that on position trials, a short sample stimulus indicated that a peck on the left test stimulus would be reinforced, whereas a long sample stimulus indicated that a peck on the right test stimulus would be reinforced. If key pecks were mediating the delays, one might expect more pecks on the left key than on the right key following short sample stimuli and more pecks on the right key than on the left key following long sample stimuli. Similarly, one also would expect more left-key responses after short sample stimuli than after long sample stimuli and more right-key responses after long sample stimuli than after short sample stimuli. Although the response patterns of Birds 5 and 6 (the subjects whose performance on the two tasks was differentially affected by retention intervals—see Figure 2) conform to these basic expectations, the rate differences were very slight because there was a general lack of responding on the left key, regardless of the sample duration. When sample stimuli were short, both birds most often pecked the center key, not the left key. Center-key responses occurred less frequently after long sample stimuli. The behavior of Bird 6 provided the strongest indication of differential responding and possible response mediation. High pecking rates on the center key and on the right key were almost exclusively correlated with short and long sample stimuli, re-

Table 1
Retention-interval response rates (per second) on left (L), center (C), and right (R) keys.

Subject	Sample duration	Position task			Stimulus task		
		L	C	R	L	C	R
4	short	0.01	0.04	0	0	0	0
	long	0	0.01	0	0	0	0
5	short	0.01	0.18	0	0.01	0.13	0
	long	0	0.03	0.05	0	0	0.01
6	short	0.03	1.00	0	0.18	0.36	0.01
	long	0.01	0.01	1.32	0.01	0.84	0.10
7	short	0	0.07	0	0.01	0	0
	long	0.01	0	0.22	0.02	0	0.01

Note. Rates are based on the total 336 s of the 1.0-s retention interval trials. For the position task, L was correct after short sample durations and R was correct after long sample durations; for the stimulus task, the position of the key was irrelevant to the correct choice (see text).

spectively. The position task data for Bird 5 follow this same general pattern, although to a lesser degree and with lower response rates.

During stimulus-trial retention intervals, Birds 5 and 6 repoded most often on the center response key. This was to be expected because the task makes it impossible for the subject to discriminate where a response will later be reinforced until the choice stimuli are presented. Responding on a side key during a retention interval could not only necessitate a move to the other side key at the time of the test (possibly further delaying reinforcement), but it might also cancel reinforcement for that trial if, for example, a burst of retention-interval pecks extended into the choice component of the trial. Bird 5 restricted center-key responding to retention intervals following short sample stimuli. Bird 6 also showed differential retention-interval responding during stimulus trials. But, unlike Bird 5, this was not an all-or-none difference; rather, long sample stimuli controlled higher rates of center-key responding than did short sample stimuli. Whereas Bird 5 seldom pecked the side keys, Bird 6 maintained low response rates on the left and right response keys after short and long sample stimuli, respectively.

For Birds 4 and 7, delays did not differentially affect performance accuracy during position and stimulus trials (see Figure 2). Thus, there is little reason to expect retention-interval response patterns to indicate differ-

ential mediation of the two tasks. Bird 4 exhibited no task differences in accuracy at the end of Phase 1 (Figure 1) nor during Phase 2 (Figure 2); this subject responded infrequently during the retention intervals of position trials and never responded during the retention intervals of stimulus trials, thereby giving no indication of response mediation in either task. Bird 7 maintained a high accuracy level on the position task, whereas its performance on the stimulus task was equally poor across all retention intervals (see Figure 2). Yet, similar to Bird 5, Bird 7 did show some slight signs of differential mediation of the position-trial delays after short versus long sample durations. There was no evidence of differential responding on the stimulus task for Bird 7.

In summary, Table 1 and Figure 2 provide some, but relatively weak, evidence for a relation between the occurrence of differential responding after short and long samples on position trials versus stimulus trials and differential loss of stimulus control on the two tasks. Although the delays between sample and test stimuli differentially disrupted discriminative accuracy on position and stimulus trials for both Birds 5 and 6 (see Figure 2), only Bird 6 showed clear signs of differential mediation. Bird 5 exhibited only slight task-specific differences in retention-interval responding, and within the position task there was only a suggestion of differential allocation of responses to the center and side keys following short and long samples (see Table 1). Furthermore, although Bird 7 also showed slight signs of differential mediation, discriminative accuracy on the two tasks was not differentially disrupted with the short retention intervals used here. However, considering only position trials, it should be noted that Bird 6, whose retention-interval key pecking provided the best evidence for differential response mediation, was also the most accurate at the longest delay (Figure 2); Birds 5 and 7 were only slightly less accurate and also displayed some hint of response mediation; Bird 4 was least accurate and gave the least indication of response mediation. Therefore, differential responding during position-trial delays was correlated with higher accuracy levels on this task.

DISCUSSION

Our results support the earlier conclusion that duration can effectively function as a dis-

criminative stimulus (e.g., Church, 1980; Stubbs, 1968; Wasserman et al., 1984), and several additional findings extend our knowledge of the nature of temporal discrimination. First, acquisition of the duration discrimination was faster when the correct response location could be discriminated prior to the choice test (position task) than when it could not (stimulus task). Similar results were obtained with color discriminations using a go/no go paradigm in which pigeons either could (simple discrimination) or could not (conditional discrimination) discriminate, prior to the test, whether test responding would be reinforced (Honig & Wasserman, 1981), and with triangle-orientation and line-tilt discriminations using a choice procedure (Smith, 1967).

Second, accuracy levels on the stimulus task for 2 birds during Phase 1 never reached the levels achieved on the position task (Figure 1). Similarly, in the Honig and Wasserman study (Experiment 2; Figure 4), the mean terminal performance level on 0-s retention-interval trials was lower for simple color discriminations than for conditional color discriminations. The fact that 2 of our subjects (Birds 4 and 5) performed as well on stimulus trials as on position trials by the end of Phase 1 is not surprising in light of the fact that extensive training (84 days) was given with 0-s retention-interval trials. Experiments using stimulus dimensions other than duration typically have shown that, although more sessions are needed to reach a criterion performance level when the task requires the discrimination of the specific values of both sample and test stimuli, equivalent discrimination levels can be obtained with a 0-s delay (Honig & Wasserman, Experiment 1, 1981; Smith, 1967). Also, in the present study only Bird 4 maintained equivalent performance on the two tasks during Phase 2 (Figure 2).

Third, for Birds 5 and 6, the sample-test delays of Phase 2 differentially affected performance on the two temporal discrimination tasks; performance on position trials was better maintained than was performance on stimulus trials (Figure 2). This result, too, has been obtained previously with stimulus dimensions other than duration (Chatlosh et al., cited in Wasserman, 1985; Honig & Wasserman, 1981; Smith, 1967). The fact that half of our subjects exhibited differential loss of stimulus control and half did not suggests that perhaps this discrepancy among individuals could be traced

to individual differences in response patterns during the retention intervals of position and stimulus trials. Parsons, Taylor, and Joyce (1981) found that children who were required to make sample-specific collateral responses during delays in a matching-to-sample problem matched more accurately than either those required to make the same collateral response after each sample stimulus or those required to make any collateral response after each sample stimulus. Furthermore, the performance of the latter two groups deteriorated with increasing delays, whereas subjects who were required to respond differentially maintained high accuracy levels. In the present study, although not required, Bird 6 clearly did peck differentially on the three response keys during the delays in position trials, in a pattern distinct from that of stimulus trials (Table 1). This bird also evidenced differential loss of stimulus control on the two temporal tasks. In general, the retention-interval responses of Birds 5 and 7 followed a similar pattern, but the differences are too slight to conclude that these responses mediated their test performances. Furthermore, for Bird 7, accuracy on the two discrimination tasks did not decline across delays; it is possible that longer retention intervals would have produced differential gradients. Because response rates during retention intervals generally were low, an interesting manipulation would be to require a single delay response on any of the three keys in both position and stimulus trials. This requirement might promote more clearly differentiated response patterns during each of the two tasks, and perhaps give a better understanding of between-task differences (Kojima, 1980).

Looking only at position-task performance, there was some relation between differential retention-interval responding and accuracy during Phase 2 (Table 1 and Figure 2). The degree to which subjects responded differentially after short and long samples was correlated with their accuracy levels on 1.0-s delay trials. This result is also consistent with other delayed discrimination studies that have used color as the relevant stimulus dimension. For example, when Kojima (1980) required rhesus monkeys to make a response during the retention intervals in a delayed positional (left or right) response task, but did not specify the location of this response, the animals most often responded on the key leading to food and main-

tained a high level of accuracy even with long delays. However, when a center-key response was required during delays, thereby disrupting mediating responses on the side keys, accuracy dropped with increasing delays in 2 of the 3 animals. Similarly, Jans and Catania (1980) found that pigeons' performances on a delayed position discrimination was generally worse on trials in which the feeder was operated during the delays than when no events were scheduled during the delays. The authors attributed this difference to the interruption of mediational processes by the operation of the feeder. In a subsequent experiment, illumination of the response keys during the delays produced differential responding on the right and left side keys, depending on the location of a correct test response. Interestingly, this pattern of delay responding then transferred to trials in which the keys remained dark during retention intervals. Thus, if we were first to require our pigeons to respond during retention intervals, we might expect differential maintenance of this behavior during position and stimulus tasks when the response requirement was later removed.

We have seen that, although duration is unique in that it is a characteristic of all stimuli, its discrimination is similarly affected by a variable that influences other stimulus discriminations. Furthermore, as with other delayed discriminations, when the task enables pretest discrimination of correct response locations, differential retention-interval behavior is correlated with greater accuracy on duration discriminations. However, we have yet to address the implications of the observed performance differences on the position and stimulus tasks for temporal discrimination.

Our data indicate that discriminative control by duration may be enhanced or impaired depending on the procedure used to measure it. The position and stimulus discriminations were acquired at different speeds, and for 2 subjects, an independent variable (i.e., retention interval) differentially affected accuracy levels for the two discrimination tasks. Given that rather subtle differences between the response rules of the position and stimulus tasks can lead to rather dramatic performance differences, it is likely that other procedural variables also may influence the amount of behavioral control exercised by temporal stimuli.

In fact, Spetch and Wilkie (1981) have reported that the qualitative nature of the stimuli

used to demarcate sample durations also is an important factor affecting pigeons' discrimination performance. Using a go/no go procedure (Experiment 1), a position procedure (Experiment 2A), and a stimulus procedure (Experiment 2B), they found that pigeons' discrimination performance was more accurate when the sample stimuli were durations of food availability than when they were houselight durations. Although several possible mechanisms were suggested to account for these differences in the effectiveness of specific duration stimuli, Spetch and Wilkie aptly pointed out that, regardless of the reason for the differences, the conclusion remains that factors other than discriminative capacity may contribute to accuracy levels in temporal discrimination tasks.

Because many methodological nuances may influence estimates of temporal control, we advocate that caution be exercised when arriving at conclusions pertaining to animals' temporal discriminative capabilities. Failure to scrutinize procedural details when attempting to consolidate findings into a cohesive theory of temporal discrimination may result in misconceptions about animal timing processes, while preoccupation with a single procedure will most probably result in conclusions that do not generalize across other experimental paradigms.

As a case in point, consider some of the recent research concerned with animals' time perception. Renewed interest in this general area has been accompanied by a variety of efforts to determine the relation between subjective time and real time. However, perusal of this literature leaves one uncertain about even the most basic properties of the psychophysical time function for animals. Some researchers maintain that subjective time grows linearly with physical time, and thus that the arithmetic mean of time values provides the best estimate of the point of subjective equality (e.g., Church & Gibbon, 1982; Gibbon & Church, 1981; Roberts, 1981; Spetch & Wilkie, 1981). Other researchers argue that the relationship is actually logarithmic, with the geometric mean representing the subjective midpoint of two durations (e.g., Church & Deluty, 1977; Meck, 1983; Stubbs, 1968, 1976). Still others claim that, similar to human time scales (Eisler, 1976), animal time scales are a power function of physical time, with an exponent less than 1.0 (e.g., Catania, 1970; Lowe, Har-

zem, & Spencer, 1979; Platt, 1979; Raslear, 1983). As one might suspect, these and other investigations of time perception differ with respect to several potentially important features, including the species of subject (e.g., rats, pigeons), the nature of the stimuli used to designate durations (e.g., houselight on or off, keylight illumination, white noise, blackout time, food-access time, the animal's own IRTs), and the range of particular time values to be discriminated. Moreover, the procedures used exhibit great diversity (e.g., peak procedures, generalization tests, position- and stimulus-discrimination tasks, response-differentiation procedures, staircase discrimination tasks).

In light of our finding that even slight procedural variations can seriously influence assessments of temporal control, the fact that discrepant conclusions have been reached about animals' perception of time should not be surprising. Decidedly, the success of any proposed theory of time perception will depend largely upon the degree of flexibility it offers for accommodating the between-task differences reported here and elsewhere. This approach toward the development of a general model of timing, capable of subsuming seemingly conflicting data, is exemplified by Gibbon and Church's (1984) information-processing theory. By incorporating several free parameters, this rather elaborate theory admits possible sources of variation at each of numerous stages in the discrimination process. Specifically, Gibbon and Church suggest that the nature of a given timing task may dictate the type of comparison rule used to make a decision regarding a temporal event. Although this hypothesis may account for some of the behavioral differences that have been reported with the various experimental procedures, additional research is needed before accurate prediction of behavior can be realized. Only further systematic investigation of temporal control, with strict heed paid to methodological details and to their particular behavioral effects, will enable a resolution of the existing ambiguities concerning the mechanisms governing temporally controlled behavior.

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Received March 11, 1986

Final acceptance January 6, 1987