*DISCRIMINATED INTERRESPONSE TIMES:
ROLE OF AUTOSHAPED RESPONSES*

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When discriminated interresponse-time (IRT) procedures have been used to assess preference relations among temporally extended operants, deviations from matching have been obtained. Using a yoked-control procedure, the present study found that key pecking in a discriminated IRT procedure has two sources of strength—that arising from the response-reinforcer contingency that is explicitly arranged, and that arising from a stimulus-reinforcer contingency that is a by-product of the explicitly arranged contingency. The key pecking of all lead birds, and that of 3 of the 4 birds exposed to a yoked autoshaping procedure, was controlled by the keylight that signaled the lead birds' criterion IRTs. Because stimulus control of key pecking by the keylight, whether autoshaped or discriminative, fosters deviations from matching, the discriminated IRT procedure does not provide an appropriate basis for conclusions about preference relations among IRTs.

Key words: autoshaping, discriminated interresponse times, response classes, key peck, pigeons

This experiment investigated the possible inadvertent intrusion of autoshaped key pecks into responding maintained by discriminated interresponse-time (IRT) procedures, and the implications of that intrusion for the validity of IRTs as exemplars of temporally extended response classes (operants).

In a discriminated IRT procedure, reinforcement is contingent upon responses that occur within a limited-hold "window" that follows the immediately preceding response by one or more specified intervals (the reinforced IRTs), where the limited-hold intervals are signaled by a coextensive stimulus. For example, 5 s after a key peck, the key is illuminated for 1 s; a peck on the key when it is lit is scheduled for reinforcement. In studies of preference relations among temporally defined response classes, two or more IRTs would be scheduled for reinforcement. If IRTs emitted under such procedures are to be considered operants, then such IRTs must dis-

play the same dynamic properties as response classes defined in other ways. That is, IRTs emitted under the discriminated IRT procedure must be similarly affected by variables that are known to affect other operants (see Anger, 1956, 1973; Ferster & Skinner, 1957; Morse, 1966).

In keeping with such expectations, the relative rate of emission of two criterion IRTs has been found to be sensitive to the relative magnitude and frequency of reinforcement contingent upon those IRTs (Shimp, 1968). Moreover, when responding was measured by the relative time allocated to the two criterion IRTs (taking into account the fact that longer IRTs take longer to emit), measures of preference corresponded to relative reinforcement frequency (Shimp, 1969). That is, given equal reinforcement rates for the criterion IRTs, the relative frequency of an IRT was approximately equal to its relative length. This relationship conforms to the matching principle (Herrnstein, 1970), a principle that has been determined to hold for a variety of responses and species (de Villiers, 1977). Matching in the discriminated IRT procedure occurred whether the criterion IRTs were scheduled on a single key or on separate keys (Moffitt & Shimp, 1971).

When the experimental parameters were varied more widely, however, the discriminated IRT procedure failed to yield results

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that conformed to matching. If the rate of reinforcement for the criterion IRTs fell below approximately 0.3 per min (Shimp, 1970) or if the shorter IRT criterion was below 0.4 to 0.7 s or above 5.0 to 6.0 s (Hawkes & Shimp, 1974), matching did not occur. With low rates of reinforcement or short IRT criteria, the shorter IRT was emitted less frequently than predicted by the matching principle. With long IRT criteria, the shorter IRT occurred more frequently than predicted.

The failure of emitted IRTs to be well described by the matching principle throughout the full range of criterion IRTs may be interpreted in either of two ways. First, the deviations from matching may indicate that temporally extended operants require additional principles for their analysis and that matching is a special case of a more general theoretical formulation (Hawkes & Shimp, 1974; Shimp, 1975). Alternatively, the validity of the discriminated IRT procedure may be questioned as a technique for the study of temporally extended operants (Donahoe, Crowley, Millard, & Stickney, 1982). To be specific, because the discriminated IRT procedure introduces a localized stimulus (the keylight) during the criterion IRTs and because this stimulus therefore always precedes the occurrence of the reinforcer, the stimulus-reinforcer relationship that suffices for autoshaping (Brown & Jenkins, 1968) may be inherent within the procedure. Likewise, because responses are reinforced only in the presence of a keylight, the keylight may acquire discriminative control over responding. Indeed, the keylight was first introduced into this procedure on the assumption that it would exert some control over responding (Hawkes & Shimp, 1974). Thus the introduction of the keylight prior to the response-contingent delivery of food may permit the development of both autoshaped key pecks and key pecks under the discriminative control of the keylight (cf. Schwartz & Gamzu, 1977). In the discriminated IRT procedure, these two sources of key pecking are confounded with the putative control exerted by temporal variables (cf. Herrnstein & Loveland, 1975).

Moreover, the control of responding by the keylight, whether it be discriminative control or the result of autoshaping, may vary from one IRT condition to another. Specifically, we might expect control by the keylight to be

greater under long IRT conditions, when the interval between keylight presentations is relatively long, than under short IRT conditions, when the interval is relatively short. From autoshaping research, it is known that key pecking increases as the duration of the keylight decreases relative to the length of the interval between keylight presentations (the intertrial interval; see Gibbon, Baldock, Locurto, Gold, & Terrace, 1977; Perkins, Beavers, Hancock, Hemmendinger, Hemmendinger, & Ricci, 1975; Terrace, Gibbon, Farrell, & Baldock, 1975). Similarly, from work with discriminated operant procedures, it is known that stimulus control is facilitated by longer intervals between presentations of the stimulus correlated with reinforcement (Taus & Hearst, 1970). Any control by the keylight complicates the interpretation of observed preference relations among IRTs; but if the degree and origin of control vary from one IRT criterion to another, these relations may be wholly uninterpretable.

The present study used a yoking technique (Ferster & Skinner, 1957) to investigate the possible intrusion of autoshaped responding into the discriminated IRT procedure. The "lead birds" were exposed to discriminated IRT procedures of the type used by Hawkes and Shimp (1974). The "yoked birds" received the same stimulus-reinforcer contingencies as the lead birds, but with no contingency imposed between the response and the reinforcer. Any key pecking by the yoked birds was therefore maintained through autoshaping. To assess the possible contribution of the discriminative control of pecking by the keylight, we examined the distribution of responses relative to keylight onset and the ease of transfer of responding at keylight onset when the birds were shifted to a different IRT criterion. If responding in the lead birds were under discriminative control of the keylight, we would expect responses to follow the onset of the keylight; if responding were at least partly under control of temporal properties of behavior, we would expect at least some responses to occur prior to the onset of the keylight. For example, studies using differential-reinforcement-of-low-rate (DRL) schedules (Kramer's 1968 master's thesis, cited in Kramer & Rilling, 1970) and unsignaled IRTs (Shimp, 1981, 1983) typically find many responses occurring just prior to the IRT cri-

terion. An absence of pecks just before the keylight onset with most pecks occurring at the lighted key would suggest that the behavior was mostly, if not entirely, under discriminative control of the keylight.

To the extent that pecking is under temporal control, each change of conditions to a new pair of criterion IRTs is an extinction procedure for the earlier condition, and we would expect to see responding persevere at the formerly reinforced rates. Rapid adjustment to new conditions would suggest that responding is, at least in part, under control of the keylight.

METHOD

Subjects

Eight naive White Carneaux pigeons were maintained at approximately 80% of their free-feeding weights by supplementing the food gained during the experimental session with a measured ration given 1 hr after the end of each session.

Apparatus

Four two-key experimental chambers (Lehigh Valley Electronics) were interfaced with a laboratory minicomputer (Modcomp II®). Only the left key, which could be transilluminated with white light, was used during the study. Each chamber contained a centrally located food magazine that delivered Purina pigeon chow; a houselight was located at the top of the intelligence panel. Extraneous noises were masked by 80-dB white noise; ventilation was provided by an exhaust fan for each chamber enclosure.

Procedure

The 8 birds were randomly assigned to one of two squads of 4 birds each, the A squad and the B squad. In any given session, a squad consisted of 1 "leader" and 3 birds on a procedure yoked to that of the leader. Sessions were conducted 7 days per week, always with the A squad first. Prior to the beginning of the experiment, pecking a continuously available white key was shaped by successive approximations for the lead birds only. All birds were feeder trained.

Within each experimental condition, responses that met either of two IRT criteria produced food on concurrent variable-interval

120-s (VI 120) schedules. One IRT criterion (including both a lower and an upper bound) defined that class of reinforced key pecks terminating the shorter IRT; the other criterion (also including lower and upper bounds) defined that class terminating longer IRT. When a reinforcer became available with respect to one IRT criterion, the VI schedule for the other IRT criterion stopped timing until the reinforcer had been produced by a response within the selected range of IRTs. The reinforcer consisted of 3-s access to Purina pigeon chow. To ensure that the yoked birds received all food presentations, the reinforcer duration was longer than the 2-s value used by Hawkes and Shimp (1974), because, unlike the lead birds, the yoked birds were not necessarily facing the intelligence panel at the beginning of each food presentation.

Stimuli. A white keylight indicated the intervals corresponding to the two IRT criteria for the experimental conditions. Each pigeon was initially placed in a dark chamber and then the houselight came on to begin the session. After a key peck, the houselight remained on until time had elapsed corresponding to the lower bound of the shorter IRT criterion. At that point, the keylight came on and the houselight went off until the upper bound of the shorter IRT criterion was reached. The keylight then went off and the houselight came on until the lower bound of the longer IRT criterion was reached. At that time, the keylight once again came on and the houselight went off until the upper bound of the longer IRT criterion was attained. Thereupon, the keylight went off and the houselight was reilluminated. Every key peck had the effect of resetting the IRT timer to zero and starting the sequence anew. Thus, a peck that occurred when the keylight was dark reset the timer but had no visual consequences. A peck when the key was white had one of two effects: If the VI schedule had not yet assigned a reinforcer for that IRT or if the next reinforcer had already been assigned to the other IRT criterion, a key peck turned off the keylight, turned on the houselight, and reset the interval. If the VI schedule had assigned a reinforcer for that IRT, a key peck turned off the keylight and operated the feeder with its feeder light for 3 s. At the end of 3 s, the feeder was withdrawn, the feeder light went off, and the houselight came on. At this point, a key

Table 1
Parameters of reinforced IRT criteria.

IRT condition	Shorter IRT criterion (s)	Longer IRT criterion (s)
0.4-s	0.4-0.7	1.1-1.6
2.0-s	2.0-3.0	5.2-6.2
8.0-s	8.0-9.5	19.0-20.5

peck had to occur to begin the sequence again. (The first key peck after a reinforcer was not counted as terminating an IRT and hence did not contribute to the data analysis.) The foregoing stimulus conditions were identical to those employed by Hawkes and Shimp (1974).

IRT conditions. Both squads were exposed to the same three pairs of IRT criteria, which corresponded to three of the ten pairs previously used by Hawkes and Shimp (1974). The parameters of one pair of criteria (the 0.4-s condition) were those at which responses within the shorter criterion range had been less frequent than predicted from the matching principle. The parameters of the second pair of criteria (the 2-s condition) were those at which matching had been found. Finally, the parameters of the third pair of criteria (the 8-s condition) were those at which responses within the shorter criterion had been relatively more frequent than predicted from the matching principle.

The specific upper and lower bounds of the criterion IRTs are shown in Table 1 for each of the three experimental conditions. Note that each IRT condition is identified by the lower bound of the shorter criterion IRT. The relative duration of the shorter IRT criterion was held constant at a value of approximately 0.7 for all three conditions. The relative duration was measured by the relative reciprocal of the shorter IRT criterion given by the following expression (Hawkes & Shimp, 1974):

$$\frac{\frac{1}{X_L} + \frac{1}{X_U}}{\frac{1}{X_L} + \frac{1}{X_U} + \frac{1}{Y_L} + \frac{1}{Y_U}},$$

where X and Y refer to the shorter and longer IRT criteria, respectively, and L and U refer to the lower and upper bounds of these criteria.

Yoking procedure. In each of the experimental conditions, only 1 of the 4 birds in each

Table 2
Summary of experimental procedures.

Order of condition	No. of sessions	Squad A		Squad B	
		Lead bird	IRT condition	Lead bird	IRT condition
1	36	A1	2.0-s	B1	2.0-s
2	20	A1	8.0-s	B1	0.4-s
3	29	A2	0.4-s	B2	8.0-s
4	45	A1	2.0-s	B1	2.0-s
5	37	A2	8.0-s	B2	0.4-s
6	30	A1	0.4-s	B1	8.0-s

squad was exposed to the contingencies described in the preceding section. The remaining 3 birds were yoked to the lead bird for that condition so that the stimulus and reinforcer events occurring in the lead chamber occurred simultaneously in the yoked chambers. Thus the response-reinforcer contingency of the lead chamber was absent in the yoked chambers, but all stimulus events were otherwise identical.

Two birds from each squad of 4 were yoked throughout the experiment. The other 2 birds in the squad alternated between being lead or yoked, according to the protocol outlined in Table 2. As an example of the general procedure, consider the third order of IRT conditions described in Table 2. For 29 sessions, Pigeon A2 was exposed to the 0.4-s IRT criterion. During those same sessions, Pigeons A1, A3, and A4 were yoked to the stimulus-reinforcer events presented to A2. In Squad B, Pigeon B2 received 29 sessions of exposure to the 8-s IRT criterion to which Pigeons B1, B3, and B4 were yoked.

Each experimental session was terminated after the delivery of 30 reinforcers, upon which the chambers were darkened. Each condition was in effect until the behavior of the lead birds, indexed by the proportion of responding that met the shorter IRT criterion, was stable by visual inspection for at least five sessions.

The numbers of key pecks during the keylight and during the entire session were recorded as well as the number of reinforcers and the duration of the keylight during the two IRT criteria. In addition, the time of occurrence of all stimuli, responses, and reinforcers was temporarily recorded for the lead birds on the computer disk for subsequent analysis of the distributions of time allocated

to IRTs of various durations. The durations of the IRT bins were 0.1 s wide for the 0.4-s condition and 0.5 s wide for the 2-s and 8-s conditions. These measures were supplemented by direct observations of the birds' behavior during the last 2 days of exposure to a condition.

Observational measures. The birds were observed directly for a period at the end of each session on the last 2 days of each condition. A single observer monitored the behavior of each bird for two to five interreinforcement intervals by looking through the observation port and one-way mirror in the door of the chamber. The lead birds were observed for evidence of stereotypic behavior between key pecks. The yoked birds were observed to assess the possibility that the stimulus-reinforcer contingency controlled behavior other than pecks contacting the key. Two behavior patterns were monitored: pecking movements toward the key and orientations toward the key (defined as a brief pause in ongoing behavior during which the pigeon faced the key; cf. Wessells, 1974). Quantitative measures of these types of behavior were not consistently obtained; rather, their presence or absence in the interval was simply noted, as it was the purpose of these observations merely to assess the validity of the dependent variables and to suggest explanations for variability in the birds' behavior. For example, during Conditions 4 and 5, a tally was kept of keylight presentations during which a pecking movement or orientation occurred. Interobserver reliability was not measured, but two experimenters alternated daily in making the observations.

RESULTS

The findings from the lead procedure—in which the three-term contingency between stimulus, response, and reinforcer was in effect—are presented first. The findings from the yoked procedure—in which only a stimulus-reinforcer contingency was instituted—are presented next. All reported results are based upon measures taken during the last 5 days of each condition.

Lead Procedure

The first goal in evaluating the results from the lead procedure was to determine whether the present experiment replicated earlier find-

Fig. 1. The relative preference for the shorter of the two ranges of reinforced IRTs for each of the three experimental conditions, designated by the lower bound of the shorter IRT criterion (number of responses with IRTs within the lower criterion range, divided by the total number of responses within the two criterion ranges). Each point shows a mean based upon the last five sessions of each condition for each bird in the lead procedure. The preference ratio consistent with matching is indicated by the broken line.

ings regarding the effects of the duration of the criterion IRTs on relative frequency with which the shorter IRTs occurred (Hawkes & Shimp, 1974). Following that determination, the data were evaluated for evidence of discriminative stimulus control by the keylight, particularly whether that control varied with the duration of the criterion IRT.

Effects of the duration of the criterion IRT on preference. As in the Hawkes and Shimp (1974) study, preference was measured by the ratio of the number of key pecks meeting the shorter IRT criterion to the total number of key pecks meeting both IRT criteria. This ratio is plotted as a function of the durations of the IRT conditions in Figure 1. Preference for the shorter IRT criterion fell below the matching value of 0.7 in the 0.4-s condition, was in the near vicinity of the matching value in the 2-s condition, and exceeded the matching value in the 8-s condition. In these respects, the present findings replicated the earlier study, although the departures from matching in the 0.4-s and 8-s conditions were somewhat less extreme. In the prior study, the mean preference ratios were .46, .67, and .91 for the 0.4-, 2-, and 8-s conditions, whereas the corresponding values here were .62, .67, and .88 (see Hawkes & Shimp, 1974).

Discriminative stimulus control. Having replicated the major feature of earlier findings

obtained with the discriminated IRT procedure, we sought evidence for changes in the control of key pecking by the stimulus that accompanied postresponse times within the IRT criteria. Performance was measured in terms of the proportions of the total session time allocated to IRTs of various durations. Thus, in a 1-hr session nine 20-s IRTs and one hundred eighty 1-s IRTs would account for the sample proportion of the total session time (5%) and be graphed accordingly. Relative time allocation was used as a measure because the responses of interest were of unequal duration. Frequency distributions and rate may be appropriate measures when responses are of uniform duration, but they may be inappropriate otherwise, because a few long responses may account for more of the total activity of the organism than many brief ones (Baum & Rachlin, 1969; Crowley, 1979; Gray, 1976). In the present experiment, if key pecking were affected by the IRT criteria (temporal control irrespective of the added stimulus), then most time should be allocated to IRTs in the vicinity of these criteria. However, if the key pecks were controlled mainly by the onset of the keylight stimulus, then increased time allocation should occur only *after* stimulus onset.

The proportion of session time allocated to IRTs of various durations (i.e., the relative allocation) is shown in Figure 2 for all birds for each of the IRT conditions in which they functioned as lead birds. Clearly the different IRT criteria led to different time-allocation distributions, with each bird showing an increase in both of the appropriate regions for all IRT conditions.

It is equally clear that the relation between the increased time allocation and the onset of the keylight varied as a function of the IRT criteria. At the 0.4-s criterion of the 0.4-s condition (see panels in the left column of Figure 2), responding occurred prior to or within 0.1 s of stimulus onset. A similar result was obtained at the 1.1-s criterion for the same condition for all birds except B1, which failed to show a substantial increase in time allocation until 0.3 to 0.4 s after stimulus onset. At the 2.0-s criterion of the 2-s condition (see panels in the middle column of Figure 2), pecking also increased prior to the lower bound of the criterion or almost immediately after stimulus onset. At the 5.2-s criterion of this condition,

however, the relationship between the increase in the time-allocation distribution and the onset of the keylight began to change. For the 2 lead birds in this condition, both the initial and subsequent exposures yielded the same result: Essentially no key pecking occurred immediately prior to the lower bound of the criterion, a small increase occurred within 0.5 s of stimulus onset, and the major increase was delayed until the 0.5-s to 1-s interval following stimulus onset. The restriction of an increase in pecking to some time after keylight onset was also found in the 8-s condition (see panels in the right column of Figure 2). For the 8-s and 19-s criteria, no pecking occurred immediately prior to the lower bound of the criterion and most responding was delayed until the 0.5 to 1-s interval after the keylight came on. The time-allocation distributions are therefore consistent with the proposition that the control of pecking changed as the IRT criteria lengthened. In the discriminated IRT procedure, the onset of the keylight became a discriminative stimulus at longer IRT criteria, with the boundary for this change in control falling in the region between IRT criteria of 2.0 and 5.2 s.

Further evidence of the control of pecking by the keylight at longer IRT criteria comes from the first session of exposure to changed IRT conditions. If responding were controlled exclusively by temporal properties of behavior, we would expect perseverance at long IRTs when conditions changed to shorter IRT criteria. If responding were controlled at least in part by the keylight, we would expect relatively rapid adjustment to the new conditions. The latter case does not argue for exclusive or even predominant control by the keylight, because any pecks at the lighted key would eliminate opportunities for longer IRTs under temporal control. On the other hand, considerable control by the keylight would be indicated for short IRTs if the birds rapidly adjusted to longer IRT conditions, whereas at least partial control by temporal properties would be demonstrated if the birds persevered at their former rate, thus postponing the appearance of the keylight and, hence, opportunities for responses under discriminative control of the keylight.

Transfer of stimulus control was measured by the ratio of the number of pecks during the

Fig. 2. The relative time allocation (percentage of total session time allocated to different IRT classes) as a function of IRT length for each bird in the lead procedure. Horizontal lines within the fields of each panel indicate the criterion IRTs during which reinforcers were scheduled. Numbers in parentheses indicate the relative time allocated to IRTs that exceeded the monitored IRT classes (i.e., longer than 1.8, 9.0, or 23.0 s for the 0.4-s, 2-s, or 8-s conditions, respectively). Note that the 2-s condition was replicated for the A_1 and B_1 birds, the second exposure being designated by a prime symbol. The mean time-allocation distributions are displayed in the bottom row of panels.

Table 3

Proportion of total responding during the keylight in the first session of transfer to a new IRT condition.

Prior condition	New condition	Bird	Proportion during keylight
Transfer to shorter IRT condition			
8.0-s	2.0-s	B1	.67
		B2	.30
8.0-s	0.4-s	A1	.35
		A2	.37
2.0-s	0.4-s	B1	.37
		B1'	.31
Transfer to longer IRT condition			
2.0-s	8.0-s	A1	.07
		A1'	.17
0.4-s	2.0-s	A1	.10
		A2	.39
0.4-s	8.0-s	B1	.14
		B2	.05

keylight to the total number of pecks occurring within the first session of exposure to the new IRT condition. These proportions are shown in Table 3 for all changes in which the birds served as lead animals in the prior condition. As expected from the supposition that longer IRT conditions fostered control by the keylight, changing from a longer to a shorter IRT condition resulted in a generally higher proportion of key pecks during the lighted key than when changing from a shorter to a longer IRT condition. The one exception to this finding was the shift of Bird A2 from the 0.4-s to the 2-s IRT condition. This bird, as shown in Figure 1, also emitted the highest proportion of responses during the keylight of any of the birds in the 0.4-s condition. Thus, the anomalously high proportion of responding during the keylight when Bird A2 was shifted to the 2-s condition may have been the result of stimulus control by the keylight already present in the prior 0.4-s condition.

A consideration of individual data gives a clearer sense of this differential transfer. Bird A1 pecked the darkened key 2,983 times during the first session after a shift from the shorter 0.4-s condition to the 2-s condition. Most of these pecks were emitted at the high rate characteristic of the prior 0.4-s condition. After 36 sessions of the new 2-s condition, only 185 pecks occurred on the darkened key.

Thus, responding changed substantially as training progressed under the 2-s IRT condition. Now consider the performance of Bird B2 when shifted from the longer 8-s condition to the 2-s condition. On the very first session of exposure to the 2-s condition, performance was very nearly optimal with only 227 pecks on the darkened key and no perseveration of IRTs at the longer IRT criteria. After 36 sessions of the new 2-s condition, the number of pecks on the darkened key was 180—a value that differed little from the first session of exposure to that IRT condition.

Yoked Procedure

Turning from discriminative control by the keylight in the lead procedure, we now examine the possibility of stimulus control as a result of autoshaping in the yoked procedure. To begin, all yoked birds pecked the key at some time during the experiment, with substantial rates of key contact maintained in 2 of the 4 birds. A cumulative record of key pecking by B3 in the 8-s IRT condition is shown in the upper portion of Figure 3. During this condition, B3 was yoked to B2 as the lead bird, and the highest rates of autoshaped pecking were observed. For the yoked bird, the cumulative record indicated little pecking when the key was dark, except very early in the session. Thereafter, key pecking was confined to those times when the keylight was illuminated. (Periods when the keylight was on are indicated by downward slashes that customarily denote the occurrence of reinforcers in conventional cumulative records.) The performance of the lead bird is shown in the lower portion of Figure 3. Note that, like the yoked bird, key pecking by B2 was probable during the periods that the keylight was illuminated. Note also that, unlike the yoked bird, bouts of pecking sometimes occurred when the key was dark. These interstimulus-interval pecks were necessary to begin an IRT but were followed by pecks at subcriterion IRTs that prevented the keylight from coming on.

Performances of all birds that were exposed only to the yoked procedure are summarized in Table 4 for each of the three IRT conditions. Two indices were used to estimate the strength of autoshaped key pecking. First, the rate of pecking during the keylight was determined. This measure underestimated the strength of autoshaping, however, because

Fig. 3. Cumulative key-pecking records of one complete session during which Bird B2 (lower record) was in the lead procedure with an 8-s IRT condition and Bird B3 (upper record) was in the yoked procedure. Downward marks on the cumulative records indicate the times during which the keylights were on. Downward marks on the horizontal line at the bottom of the figure indicate deliveries of food. The performance of the lead bird is typical of that of all lead birds in the 8-s condition; the performance of the yoked bird is typical of that of all yoked birds except A4 and B4, birds that seldom pecked the key.

many pecks that were initiated by yoked birds when the keylight was illuminated contacted the key after the light had been terminated by a peck from the lead bird. Accordingly, a second measure of autoshaping was obtained by dividing the total number of pecks by the duration of the keylight. By both indices, measurable autoshaping occurred with 3 of the yoked birds, and substantial rates were observed for Birds A3 and B3. For all birds whose pecking was autoshaped, by these indices the strength of autoshaping increased as the IRT criteria for the lead birds grew longer. Thus, the 8-s condition, in which the lead birds showed the most preference for the shorter IRT, produced the most autoshaping in the yoked birds.

Restriction of the indices of autoshaping to key pecks that contacted the key provided a conservative measure. Direct observations of the yoked birds revealed pecks directed toward the key that did not make contact ("airpecks") or orientations of the head toward the region of the key. The following excerpts of the observations of A4 and B4, the yoked birds that least often pecked the key, are representative. For Bird A4 during the 2-s IRT condition, airpecks or orientations occurred on 57% of the 123 monitored keylight presentations. The accompanying descriptive comments by the observer were: "pecking movements around the key, head movements toward the house-light as well." For Bird B4 during the 8-s IRT condition, airpecks or orientations occurred on 69% of the 58 monitored keylight presentations. The behavioral description indicated: "When the keylight comes on, the pi-

geon cranes his neck back and looks at it. Several times, he made very strong pecks toward the key, but did not make contact with it."

To facilitate comparison of the stimulus-reinforcer parameters occurring in the yoking procedure with those that produce autoshaping in more customary paradigms, several statistics were computed. The durations of the keylight stimulus varied from a maximum of 0.3 to 1.5 s, while the proportions of keylight presentations paired with food were .02, .05, and .26 for the 0.4-, 2-, and 8-s IRT conditions, respectively. These values fell below those typically studied (Brown & Jenkins, 1968; Gibbon et al., 1977; Perkins et al., 1975; Terrace et al., 1975; Williams & Williams, 1969; cf. Schwartz & Gamzu, 1977). Earlier research has determined that the ratio between the duration of the intertrial interval (I) and the duration of the keylight (T) provides a sensitive predictor of the rate of acquisition of autoshaping. The I/T ratios in the present study ranged from 0.8 (0.4-s condition) to 6.3 (8-s condition). These values are to be compared with those ranging from 1.5 to 24 in which autoshaping has been found to be an increasing function of the I/T ratio (Gibbon et al., 1977). As shown in Table 4, the rate of autoshaped pecking tended to increase as the duration of the criterion IRT increased—and, therefore, as the I/T ratio increased as well. Thus, although the present experiment was not designed to manipulate directly the parameters of stimulus duration and I/T ratio, the trend of the observations was supportive of earlier work.

In general, the contribution of autoshaping

Table 4
Rates of key pecking (responses/min) in yoked birds.

Bird		IRT condition (s)		
		0.4	2.0	8.0
A3	Pecks during keylight	0.3	5.1	5.6
	Total pecks	1.0	8.6	9.4
A4 ^a	Pecks during keylight	—	—	—
	Total pecks	—	—	—
B3	Pecks during keylight	2.2	6.7	17.8
	Total pecks	6.5	15.1	52.1
B4	Pecks during keylight	0.02	0.05	0.11
	Total pecks	0.05	0.05	0.28

^a Pecks contacting the key were too infrequent to calculate meaningful rates for Bird A4.

to the discriminated IRT procedure is probably even more pervasive than is indicated by the findings obtained from those birds exposed only to the yoking procedure. In the discriminated IRT procedure, pecking results in contact with the key inasmuch as reinforcers are contingent upon such contact. Airpecks would therefore become rare. The rates of key pecking obtained when the lead birds in the present study were shifted to the yoked procedure did indeed reveal a high rate of sustained responding. The rates generally exceeded those produced by birds exposed to only the yoked procedure. For former lead birds shifted to the yoked procedure, the rate (responses/min) of key pecking in the various IRT conditions varied between 127 and 171 for Bird A1, 1 and 48 for Bird A2, 10 and 78 for Bird B1, and 1 and 26 for Bird B2 during the final five sessions of the yoked procedure.

DISCUSSION

The discussion focuses on two issues. First, there is the narrower question of whether the discriminated IRT procedure is suitable for the study of preference among IRTs. Second, there is the more fundamental issue of the conditions under which IRTs provide appropriate measures of temporally extended behavior patterns—that is, the circumstances in which an IRT defines a functional response class or operant.

Discriminated IRTs and Preference

The discriminated IRT procedure has been used regularly to study variables that affect

preference among temporally extended behavior patterns as measured by IRTs (e.g., Hawkes & Shimp, 1974; Menlove, Moffitt, & Shimp, 1973; Shimp, 1968, 1969, 1970, 1971; Shimp & Hawkes, 1974). What the present study indicates is that the discriminated IRT procedure fosters the development of stimulus control by the keylight stimulus that signals the criterion IRTs. More particularly, as the duration of the criterion IRT increases, stimulus control by the keylight increases.

Stimulus control of responding has two origins in the discriminated IRT procedure. In the lead procedure, in which a response-reinforcer contingency was operative, discriminative stimulus control of key pecking was acquired as the duration of the criterion IRT lengthened, as indicated by the relationship of pecking to keylight onset. With the shorter IRT criteria, considerable pecking preceded the onset of the keylight and the modal response tended to occur within 0.1 s of keylight onset. With the longer IRT criteria, however, almost no pecking occurred prior to keylight onset, and the modal IRT followed keylight onset by over 0.5 s (see Figure 2). If temporal properties of behavior were controlling the emission of longer IRTs, some pecks would be expected to occur prior to the appearance of the keylight. It is unlikely that key pecking would be precisely timed at longer IRT criteria but inaccurate at shorter IRT criteria.

Consistent with this conclusion was the finding of differential transfer effects when the IRT criteria were shifted. Optimal performance (most responses occurring within the IRT criterion) was virtually immediate when lead pigeons were shifted from longer to shorter IRT criteria. In contrast, there was considerable perseveration of previously reinforced IRTs when birds were shifted from shorter to longer IRT criteria (see Table 3). As noted earlier, these findings alone do not rule out the possibility that the keylight and temporal variables jointly control responding at all IRTs; only in conjunction with the distribution of responses relative to the stimulus onset are we justified in concluding that the variables controlling the emission of pecking changed qualitatively as the IRT criteria lengthened. Unspecified temporal properties of behavior provided the main controlling stimuli for the shorter IRTs; the keylight, functioning as a discriminative stimulus, con-

trolled the emission of those pecks scored as longer IRTs.

The findings obtained with the yoked procedure provide additional evidence for a change in the control of pecking as the IRT criteria lengthened. Although the response-reinforcer contingency of the lead procedure fostered stimulus control by the keylight at longer IRT criteria, this contingency was not necessary. The stimulus-reinforcer contingency of the yoked procedure was sufficient, by itself, to produce autoshaped key pecks. Essentially no autoshaping occurred in the 0.4-s condition, somewhat more in the 2-s condition, and most in the 8-s condition (see Table 4). Thus, as with discriminative stimulus control in the lead procedure, the variables affecting the emission of pecking changed such that the keylight acquired increasing control over responding as the IRT criteria grew longer.

The implication of the present experiment for the utility of the discriminated IRT procedure as a technique for studying preferences among IRTs is clear: Although the earlier result was replicated—that relatively more short IRTs were emitted as the IRT criteria lengthened (Hawkes & Shimp, 1974)—this finding has little bearing on the preference relation among the behavior patterns corresponding to different IRTs. The increase in the frequency of shorter IRTs with longer IRT criteria may be more parsimoniously explained as follows: In order for the longer of two IRTs to be emitted, the opportunity to terminate the shorter IRT must be passed by. As the IRT criteria lengthen, causing pecking to come increasingly under the discriminative and autoshaped control of the keylight, the pigeon is more likely to peck the lighted key, thereby preventing the occurrence of the longer criterion IRT. In this way, the increasing control of pecking by the keylight leads to the illusion of an increasing preference for the shorter IRT.

Beyond the question of preference relations among IRTs, these findings and their interpretation cast doubt upon the validity of the discriminated IRT procedure for any purpose related to the study of temporally extended behavior patterns. That a pigeon restricts responding to a particular IRT is meaningless with respect to the issue of temporally extended patterns if the response that terminates the IRT is controlled by a discriminative stim-

ulus whose occurrence is independent of the temporal extent of that behavior. If the keylight controls pecking independently of the temporal extent of the preceding behavior—as it does with longer IRT criteria—then such pecks are members of a different operant than those pecks appropriately described as terminating an IRT. As Skinner (1935) pointed out, the orderliness of the correlation between a response and its controlling variables differs over a wide range depending on how the response is defined. Thus, it does not follow that an arbitrary IRT will always constitute a defining attribute of a response class, even when that attribute has been scheduled to produce a reinforcer.

IRTs as Operants

The complexities that may be encountered when IRTs are used to define temporally extended operants are not confined to the discriminated IRT procedure. Shimp (1981, 1983) employed an IRT procedure similar to that of the present study but without using a keylight as a discriminative stimulus. Although his procedure addressed a different experimental question, his results are relevant to the present experiment. His pigeons emitted predominantly more shorter than longer IRTs under conditions similar to our 8-s condition, suggesting that the keylight may not qualitatively affect the measurement of preference relations among IRTs. We caution against such an interpretation, however. The clear bimodality of responses in the present experiment (Figure 2) was missing in Shimp's data except at relatively short IRTs—parameters at which we would expect good discrimination even without a keylight. That an organism exposed to such a procedure collects all of the scheduled reinforcers is not sufficient evidence that two operants defined by the two IRT criteria have been conditioned. An alternative account that does not refer to temporally extended behavior patterns is also consistent with these same facts. After collecting food for a key peck terminating the shorter IRT, the pigeon pecks at a relatively high rate—that is, food has functioned as a reinforcer for the momentary (relatively unextended) response of key pecking. If the next food presentation were scheduled for the longer IRT, further pecking would not be reinforced and the behavior would undergo ex-

tion. At some point the decreasing probability of response would lead to a peck whose time of occurrence corresponded to the longer IRT criterion. Key pecking would then again increase in strength and lead, relatively promptly, to a reinforcer if the shorter IRT criterion were scheduled next or, with a delay corresponding to the time required for extinction, to a reinforcer at the longer IRT criterion. This periodic conditioning and extinction of the momentary response of key pecking would be sufficient to collect reinforcers with two IRT criteria and, if conditioning and extinction occurred more rapidly over successive cycles (cf. Clark, 1972), the behavior would become more efficient in producing the reinforcers. No special appeal to temporally extended operants is required by such an analysis (cf. Eisler, 1984).

At a minimum, the inference that different operants are produced by different IRT criteria requires an increase in the frequency of, or time allocated to, the different behavior patterns corresponding to those IRTs. This increase in criterion IRTs must occur relative to a condition in which the distribution of reinforcers is otherwise identical, as would be approximated by a yoked VI schedule of reinforcement (Richardson, 1973; see also Anger, 1956, 1973; Reynolds & McLeod, 1970).

Ideally, the distribution of time allocated to IRTs of various durations denotes the time allocated to behavior patterns that are relatively homogeneous within a given class of IRTs. As an illustration, the 0.5- to 1.0-s class might consist of brief head movements away from the key interspersed between successive pecks, whereas the 3.5- to 4.0-s class might consist of complete turns of the entire body. When the IRT classes are homogeneous, the IRT distribution is closely related to the animal behaviorist's concept of an ethogram (e.g., Immelman, 1980, p. 2). An ethogram is an exhaustive compilation of the behavior patterns characteristic of a species. Inasmuch as all behavior patterns take time for their occurrence and inasmuch as similar behavior patterns occupy similar times, an IRT distribution may be viewed as an approximation to the time allocated to the various activities in which the organism engages while in the experimental chamber. From this perspective, the measured response—key pecking in this experiment—serves to demark the boundary

between the end of one behavior pattern and the beginning of an instance of the same or a different pattern. Distinctive and relatively homogeneous behavior patterns have been noted in other studies in which reinforcers were contingent upon meeting an IRT criterion (e.g., Laties, Weiss, Clark, & Reynolds, 1965; Wilson & Keller, 1953; cf. Richardson & Loughhead, 1974). Observation of the lead birds in the present experiment indicated that such patterns were present during the shorter IRT criteria, but not during the longer criteria.

Finally, although the analysis of temporally extended operants may encounter complications of the sort found with the discriminated IRT procedure, their study—and the use of IRT criteria and measures to carry out that study—is to be encouraged. As has been argued persuasively by Shimp (1969, 1975), the fact that operants have temporal extension has potentially important conceptual implications.

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