Interresponse time analysis of behavioral interaction

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Five pigeons keypecked for food on a two-component multiple schedule. One stimulus was associated with a variable-interval 2-min unchanged component. A second stimulus was associated with an equal variable-interval schedule, then changed to differential reinforcement of low rate. During discrimination training, the overall rate of responding in the first, unchanged, component declined, but later was slightly higher than during prior nondifferential training. A more detailed analysis of responding during the unchanged component showed that responses with both short and quite long interresponse times increased in probability by the final sessions of discrimination training.

The rate of responding in one component, associated with a discriminative stimulus (S_1), of a multiple schedule can be affected when the schedule of reinforcement in another component, associated with a second stimulus (S_2), is changed. These behavioral interactions (Reynolds & Catania, 1961) are of two general kinds: The rate of response in the presence of S_1 can change in the same or in the opposite direction as the change in responding in the presence of S_2. In current usage the latter interaction is termed contrast and the former induction.

Although changes in rates of responding in multiple schedules have been the subject of considerable research, corresponding changes in the distributions of interresponse time (IRT) have not. The IRT distributions of responses to S_1 have been reported only by Reynolds and Catania and by Spealman and Gollub (1974) for multiple schedules alternating, respectively, differential reinforcement (VI) with extinction. In both studies, the frequency of responses with IRTs shorter than 2 sec increased with the overall rate of responding to S_1. Distributions of IRTs might make sources of behavioral interaction explicit when schedules with easily discernible effects on the IRT distribution are used as components in a multiple schedule. Accordingly, the present experiment examined the IRT distributions of responding to discriminative

stimuli associated, respectively, with VI and DRL in multiple-schedule discrimination training.

METHOD

Subjects
Five experimentally naive male Silver King pigeons, 6-8 years old, were maintained at about 75% of free-feeding weight throughout the experiment.

Apparatus
A Lehigh-Valley Model 1519 pigeon chamber was used. An Industrial Electronics Engineers in-line display cell transilluminated the key. Vertical and horizontal white lines, 3 mm wide by 22 mm long, on a green surround were presented by the display cell. The reinforcer was 3-sec access to mixed grain, illuminated during food presentation by a white lamp above the hopper. No houselight was used. White noise served to mask most extraneous sounds. Scheduling and recording equipment, including a PDP-8/I computer, were located in a separate room.

Procedure
Keypeck training was followed by sessions in which the requirement for reinforcement was gradually increased to 25 responses. The stimuli on the key during this preliminary training were those presented during all later sessions. Throughout the experiment, a horizontal line (S_1) and a vertical line (S_2) presented on a green surround appeared behind the key during alternate 4-min trials. The key was darkened during a 10-sec timeout between trials. Each session terminated after 16 trials. An IRT analysis was conducted for Trials 3-16.

During the nondifferential reinforcement phase of the experiment, S_1 and S_2 were correlated with identical but independent variable-interval (VI) component schedules. After four sessions with mult VI 1 min VI 1 min, the birds had 18 sessions with mult VI 2 min VI 2 min.

Discrimination training sessions were identical to prior nondifferential reinforcement sessions, except that the schedule of reinforcement associated with S_2 was shifted from VI to DRL. In a DRL t-sec schedule, responses with IRTs longer than t sec are reinforced and responses with IRTs shorter than t sec postpone the reinforcer for t sec. After three sessions with mult VI 2 min DRL 6 sec, the birds had 12 sessions with mult VI 2 min DRL 12 sec.
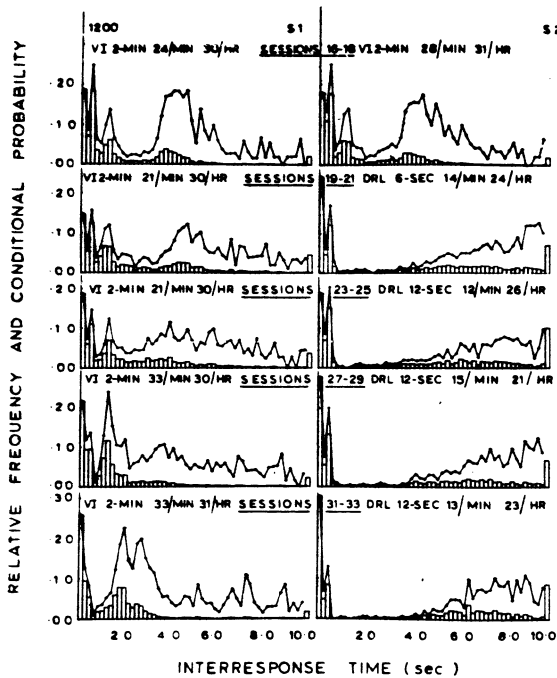
Figure 1. Relative frequency and conditional probability distributions of responding in .2-sec IRT categories to S_1 and S_2 for Bird 1200. Also given are responses/min and reinforcements/h for three session blocks.

RESULTS

Figure 1 shows the relative frequency and conditional probability of responses in each .2-sec interresponse time category, and the overall rates of responses/min and of reinforcements/h for the last three sessions of nondifferential training and three session blocks of discrimination training for Bird 1200. Interresponse times/opportunities, or IRTs/OP (Anger, 1956), estimate the conditional probability of a response in any given IRT category independently of the relative frequency of responses with shorter IRTs. Specifically, the IRTs/OP measure divides the number of responses in an IRT category by the number of responses in that and all remaining categories. However, when few or no responses occur in the remaining IRT categories, the

conditional probability statistic becomes highly variable and unreliable (Blough, 1969). In the present work, the conditional probability of responding in any given IRT category was calculated and plotted only if the remaining opportunities to respond included at least 1% of the total number of responses in the distribution.

The shift to DRL in S_2 (see Figure 1) engendered a reduced rate of responding to S_2. Also, in the S_2 component the relative frequency and conditioned probability of responses with long IRTs increased with further mult VI DRL sessions, but the relative frequency of responses with IRTs shorter than .6 sec was not reduced. The overall rate of responding to S_1, shown in Figure 1, at first declined during discrimination training, but by Sessions 27-29 was slightly higher than during nondifferential training. Also, in the S_1 component, the conditional probability of long IRTs increased noticeably during discrimination training. By Sessions 27-29, the conditional probability of responses with IRTs shorter than 3.0 sec had also increased. Performance across discrimination training seen in Bird 1200 was fairly typical of the other four birds as well.

Figure 2 shows conditional probability distributions in 1.0-sec IRT categories, and overall rates of responding and reinforcement to S_1 in the last three sessions of nondifferential training (Sessions 16-18) and to S_1 and S_2 in the last three sessions of discrimination training (Sessions 31-33) for Birds 2035, 2213, 6920, and 2633. Overall rates of responding to S_1 increased slightly, 2-14 responses/min, from nondifferential to discrimination training. Also, in the S_1 component, the modal IRT was shorter, but responses with long IRTs were more probable during discrimination training (the middle panels) than before (the upper panels). During S_2 the overall response rate was 18-26 responses lower than in S_1. The conditional probability of responding in the S_2 component (the lower panels) was high at 1 sec, low at 2-3 sec, then increased gradually at longer IRTs.

A summary of actual response frequencies of selected summary IRT classes for S_1 during the last three sessions of nondifferential reinforcement, and for S_1 and S_2 during the last three sessions of
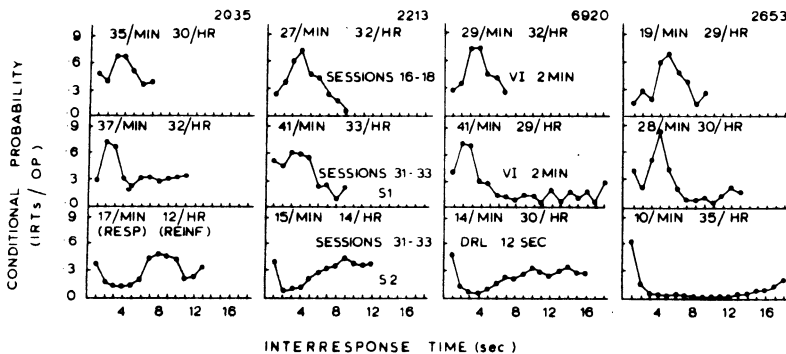

Figure 2. Conditional probability distributions for responding in 1.0-sec IRT categories. Also given are responses/min and reinforcements/h. The last three sessions of nondifferential reinforcement for S_1 and discrimination training for S_1 and S_2.

discrimination training, is shown in Table 1. The first class, containing only responses with short IRTs (less than .6 sec) was not consistently affected by mult VI DRL training. A substantial number of these bursts of responses were emitted in S1 and S2. The number of responses with short- to intermediate-length IRTs (.6 to 3.0 sec) increased in S1 but decreased in S2 markedly. The number of responses with intermediate-length IRTs (3.0 to 6.0 sec) declined in both S1 and S2. Responses with much longer IRTs (over 6.0 sec) increased, of course, in S2 associated with DRL, but also tended to increase in S1 as well. Moreover, the number of responses with long IRTs in S1 was correlated with the number of responses with long IRTs in S2. These results are in good agreement with those based on relative frequencies and conditional probability analyses in Figures 1 and 2, respectively.

DISCUSSION

The IRT distributions and rates of responding emitted during the VI and DRL components of the multiple schedule examined in the present work have much in common with those obtained with individual VI and DRL schedules of reinforcement in published research. Multimodal and somewhat idiosyncratic IRT distributions of VI responding similar to those seen by Blough and Blough (1968) and Spealman and Gollub (1974) were obtained in the present work. Responding in bursts did not change systematically under DRL or VI in the present work, but under DRL fewer intermediate-length IRTs and many more long IRTs were seen, as in work reported by Kramer and Rilling (1969) and Reynolds (1964). Also, IRT distributions of conditional probability of responding under DRL shown by these authors have the same form as ours, shown in Figure 2.

In common with Spealman and Gollub (1974), who studied mult VI EXT discrimination training, we obtained an increase in the probability of responses with short- to intermediate-length IRTs in the VI component of the multiple schedule, in our case, mult VI DRL discrimination training. In the present study, every bird showed a shift toward a shorter modal IRT, but the resulting change in the overall rate of response was small (from 6% to 52%) compared to the change in overall response rate (approximately 35% to 130%) generated by mult VI 3 min EXT in the Spealman and Gollub study.

Opposing overall behavioral contrast were other, and heretofore unobserved, changes in responding to S1. The probabilities of responses with intermediate length decreased, while those of responses with long IRTs increased systematically during S1 following the shift to mult VI DRL. During early discrimination training sessions, the overall rate responding recovered and even increased, but responses with long IRTs remained generally more probable than prior to discrimination training. Since the most likely source of change in the frequency of intermediate and long IRTs seen in S1 would appear to be similar IRTs seen in S2, it seems reasonable to term these changes instances of IRT induction. Indeed the opposite tendency for responses with short- to intermediate-length IRTs to increase might be termed IRT contrast.

Mackintosh (1974) and Boakes, Halliday, and Mole (in press) recommend caution in describing slight changes in responding as behavioral interactions without a return to nondifferential reinforcement or the inclusion of a control group. Thus, slight, but reliable from bird to bird, increases in the probability of responses with short IRTs and in overall response rate in the present work might only reflect the tendency for the rate of responding to increase over even extended VI training. Of course,

Table 1
Responses Per Hour in Summary IRT Classes in S₁ During Nondifferential Reinforcement and S₁ and S₂ During Discrimination Training

Bird	Stimulus	.6	3.0	6.0	> 6.0
1200	S₁	636	378	357	68
	S₁	805	914	163	90
	S₂	314	15	71	319
2035	S₁	880	988	246	67
	S₁	488	1581	87	85
	S₂	263	251	170	275
2213	S₁	259	990	264	42
	S₁	816	1410	183	62
	S₂	248	125	230	234
6920	S₁	299	1264	206	32
	S₁	505	1758	53	64
	S₂	301	118	86	275
2653	S₁	153	402	446	73
	S₁	365	1118	220	34
	S₂	285	104	104	167

(IRT Classes (sec) spans the .6, 3.0, 6.0, >6.0 columns)

decreased response rates at the beginning of discrimination training and a continuing increased probability of long IRTs can hardly be attributed to gradual increases in response rate.

The present results, although only preliminary, appear to encourage the further study of IRT distributions of responding in multiple schedules. It is not clear that opposing changes in the IRT distribution during S1 do not often cancel each other out, leaving the overall rate of responding only slightly changed. Moreover, IRT analyses might prove a useful adjunct to rate analysis even when the change in the overall rate of responding is large.

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